INST 262 (Digital Control Systems), section 1

Lab

Automatically-controlled process: *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, currents, powers and/or resistances in a DC series-parallel circuit
- Identify proper controller action (direct or reverse) for a given process
- Predict the response of a single-loop control system to a component fault or process change
- Identify specific instrument calibration errors (zero, span, linearity, hysteresis) from data in an "As-Found" table
- Solve for a specified variable in an algebraic formula
- Determine the possibility of suggested faults in a 4-20 mA loop circuit given measured values (voltage, current), a schematic diagram, and reported symptoms
- Motor/relay/3phase/PLC Review: Sketch proper wire connections for sourcing or sinking PLC I/O points
- INST240 Review: Determine suitability of different level-measuring technologies for a given process fluid type
- INST251 Review: Identify the graphed response of a controller as being either P, I, or D

Recommended daily schedule

Day 1

Theory session topic: Feedback control

Questions 1 through 20; answer questions 1-8 in preparation for discussion (remainder for practice)

Day 2

Theory session topic: PID control

Questions 21 through 40; answer questions 21-28 in preparation for discussion (remainder for practice)

Day 3

Theory session topic: DCS configuration

Questions 41 through 60; answer questions 41-48 in preparation for discussion (remainder for practice)

Day 4

Theory session topic: DDC, DCS, and SCADA system configuration

Questions 61 through 80; answer questions 61-68 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. Download and save these documents to your computer.

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

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

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

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

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

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

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

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

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

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

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

file `howto`

General Values, Expectations, and Standards

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

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

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

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

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

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

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

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

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

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

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

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

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

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 262 Course Outcomes

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

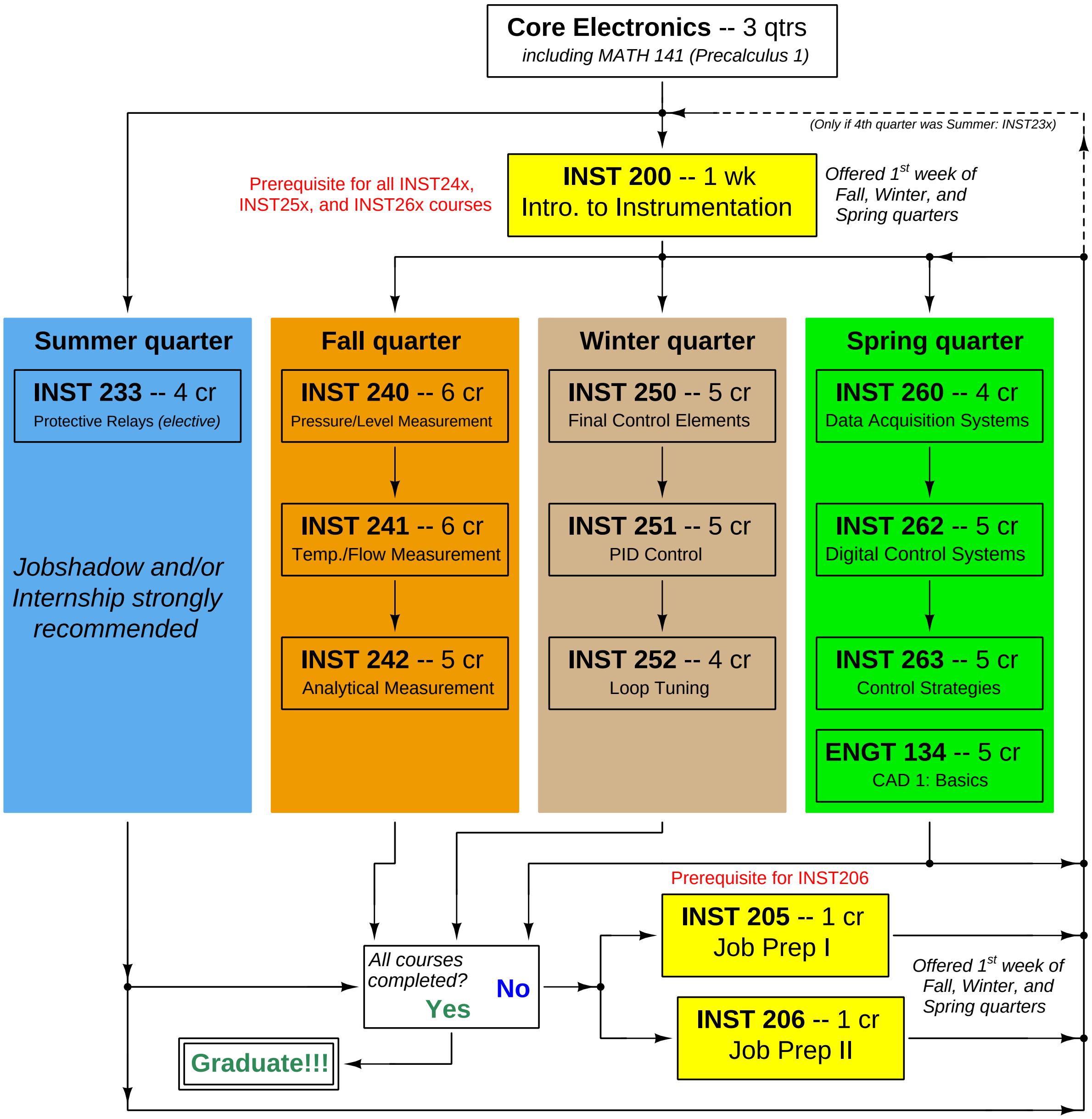
- Calculate voltages, currents, powers, and/or resistances in a DC series-parallel circuit. [Ref: Program Learning Outcome #4]
- Calculate voltages and currents in an ideal AC transformer circuit. [Ref: Program Learning Outcome #4]
- Identify proper controller action for a given process. [Ref: Program Learning Outcome #5]
- Predict the response of a single-loop control system to a component fault or process condition change, given a pictorial and/or schematic illustration. [Ref: Program Learning Outcome #4]
- Determine proper AI block parameters to range a Fieldbus transmitter for a given application. [Ref: Program Learning Outcome #5]
- Use decibels to calculate power gains and losses. [Ref: Program Learning Outcome #4]
- Identify specific instrument calibration errors (zero, span, linearity, hysteresis) from data in an "As-Found" table. [Ref: Program Learning Outcome #7]
- Calculate instrument input and output values given calibrated ranges. [Ref: Program Learning Outcome #7]
- Solve for specified variables in algebraic formulae. [Ref: Program Learning Outcome #4]
- Determine the possibility of suggested faults in a simple circuit given measured values (voltage, current), a schematic diagram, 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 labwork. [Ref: Program Learning Outcomes #1 and #2]
- 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 an accurate loop diagram compliant with ISA standards documenting your team's control system. [Ref: Program Learning Outcome #8]
- Commission and decommission a WirelessHART instrument. [Ref: Program Learning Outcome #5]
- Configure a digital indicator to poll instrument data via the Modbus/TCP protocol. [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]
- Build a circuit to sense either pressure or vacuum using a differential pressure transmitter with HART

communication capability, reporting the sensed variable on an analog meter chosen by the instructor, setting the range values according to instructor specifications, capturing peak signal value using a digital multimeter, and capturing binary 0 and 1 bits using a digital oscilloscope. [Ref: Program Learning Outcome #5]

- 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]

- Diagnose a random fault placed in another team's control system by the instructor within a limited time using no test equipment except a multimeter, logically justifying your steps in the instructor's direct presence. [Ref: Program Learning Outcome #4]

file `outcomes_INST262`


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
INST 205 -- 1 cr
Job Prep I
INST 206 -- 1 cr
Job Prep II
Offered 1st week of Fall, Winter, and Spring quarters
All courses completed?
No
Yes
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.

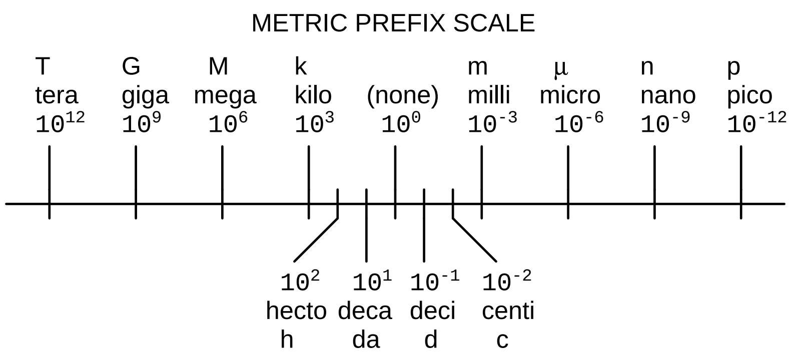
Labwork is perhaps the most difficult portion of the curriculum for a "distance" student to complete, since the equipment used in Instrumentation is typically too large and expensive to leave the school lab facility. "Distance" students must find a way to complete the required lab activities, either 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 ($W/m^2{\cdot}K^4$)

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

Properties of Water

Freezing point at sea level = 32^oF = 0^oC

Boiling point at sea level = 212^oF = 100^oC

Density of water at 4^oC = 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^oC = 1.00002 calories/g$\cdot^o$C = 1 BTU/lb$\cdot^o$F = 4.1869 Joules/g$\cdot^o$C

Specific heat of ice $\approx$ 0.5 calories/g$\cdot^o$C

Specific heat of steam $\approx$ 0.48 calories/g$\cdot^o$C

Absolute viscosity of water at 20^oC = 1.0019 centipoise (cp) = 0.0010019 Pascal-seconds (Pa$\cdot$s)

Surface tension of water (in contact with air) at 18^oC = 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^oC 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^oC and 760 torr = 0.018 centipoise (cp) = 1.8×10^{-5} Pascal-seconds (Pa$\cdot$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, especially before applying any mathematical techniques.
- Devise a thought experiment to explore the characteristics of the problem scenario, applying known laws and principles to mentally model its behavior.
- 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. Annotate any diagrams or illustrations with these calculated values.
- For quantitative problems, try approaching it qualitatively instead, thinking in terms of "increase" and "decrease" rather than definite values.
- For qualitative problems, try approaching it quantitatively instead, proposing simple numerical values for the variables.
- Were there any assumptions you made while solving this problem? Would your solution change if one of those assumptions were altered?
- Identify where it would be easy for someone to go astray in attempting to solve this problem.
- Formulate your own problem based on what you learned solving this one.

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Question 1

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 2

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 3

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 4

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.

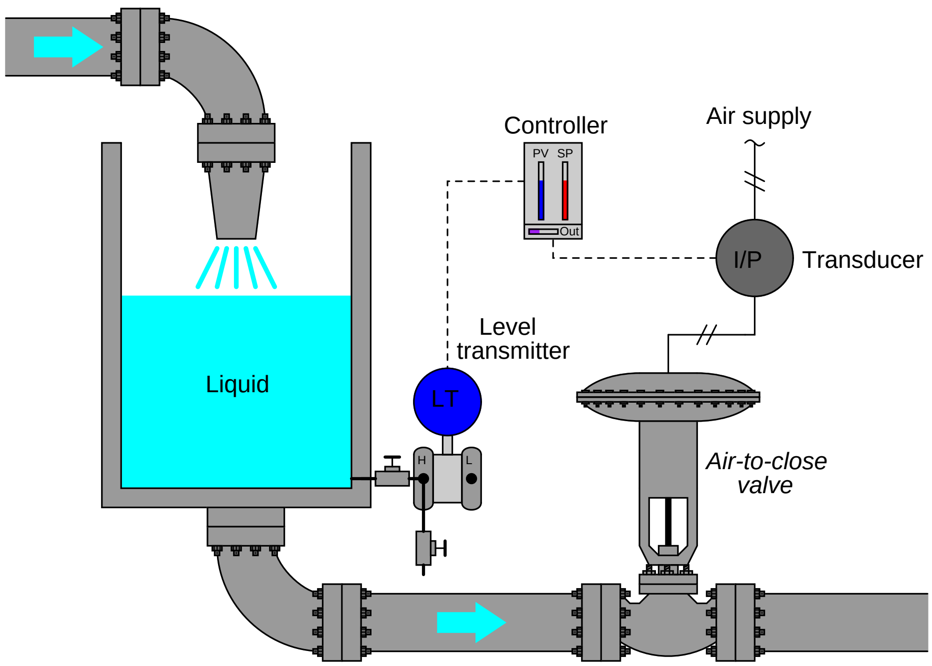
file i04254

Question 5

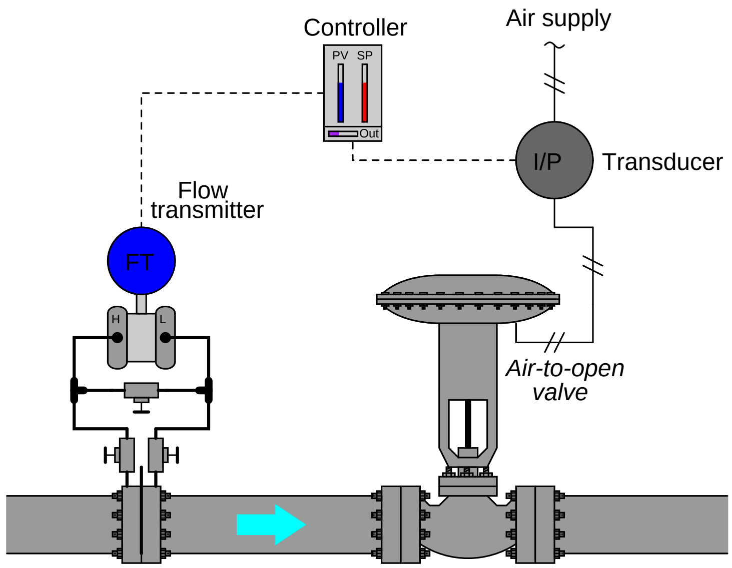
In each of these process control examples, the transmitter produces an increasing signal for an increase in process measurement (level, pressure, temperature, etc.), and the I/P transducer produces an increasing air pressure signal out for an increasing current signal in.

Your task is to determine the proper action for the process controller, either *direct-acting* or *reverse-acting*. Remember, a direct-acting controller produces an increasing output signal with an increasing process variable input. A reverse-acting controller produces a decreasing output signal for an increasing process variable input. It is essential for stability that the controller have the correct direction of action!

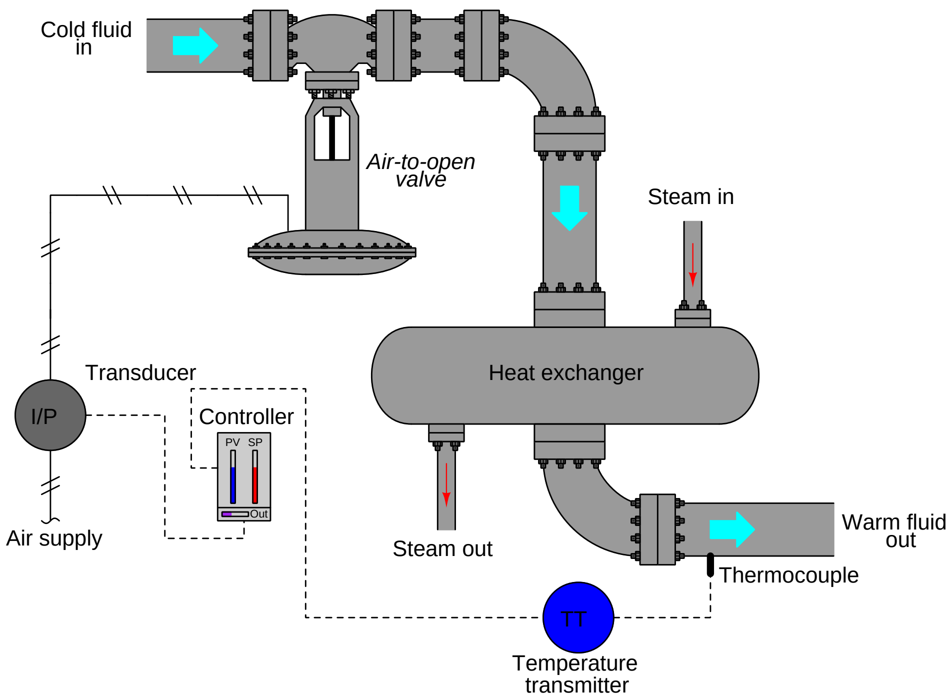
Example 1:



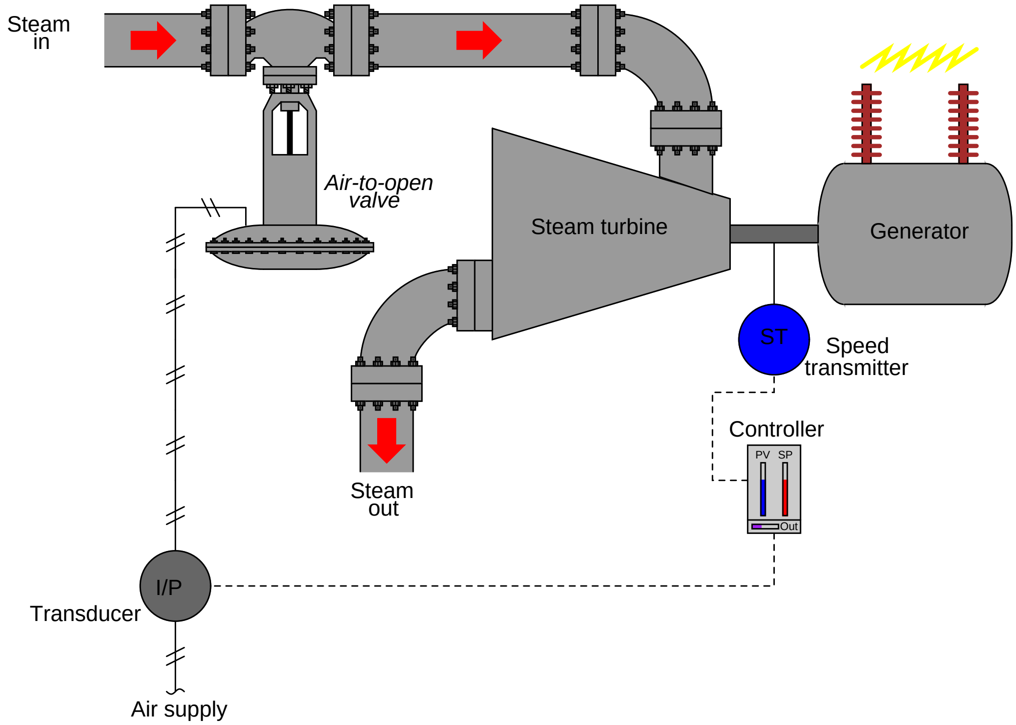
Example 2:



Example 3:

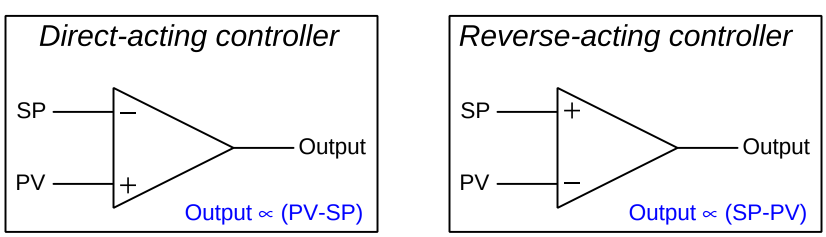


Example 4:

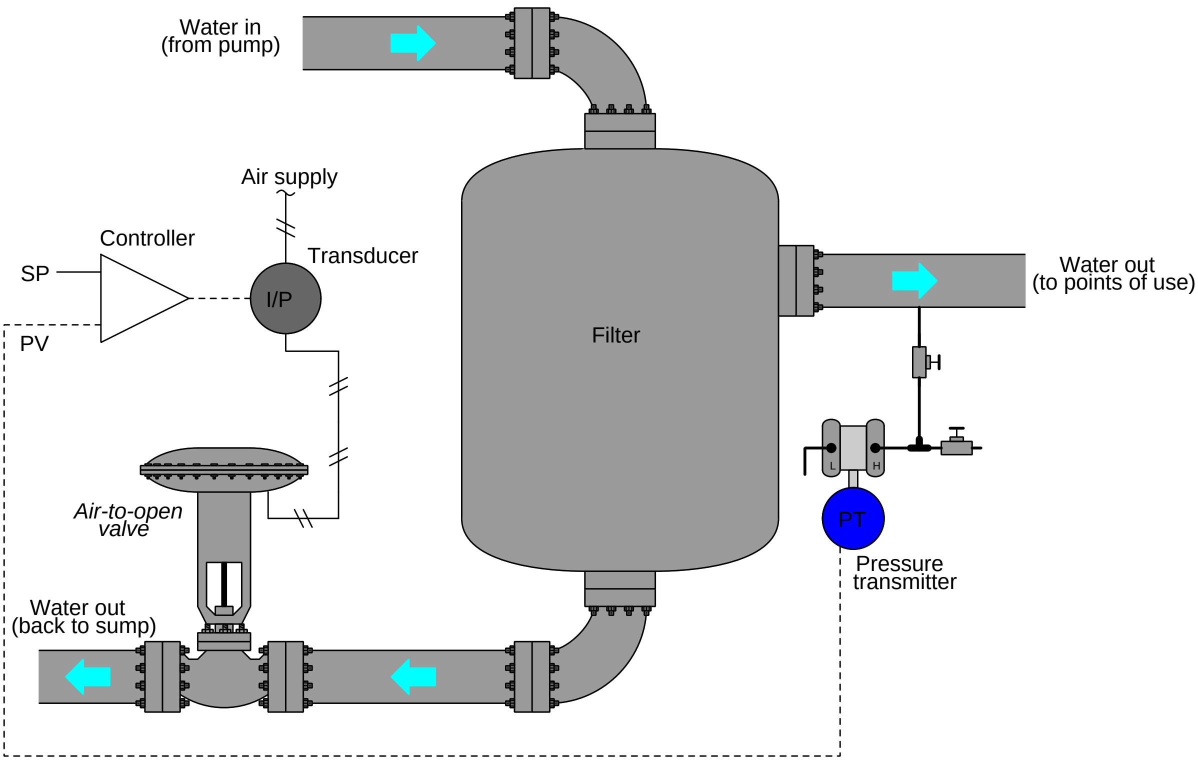


A concept familiar to students of electronics is the *differential amplifier*, a device built to compare two input signals and generate an output signal proportional to that comparison. The most common form of differential amplifier is the so-called *operational amplifier* or "opamp", drawn as a triangle with two inputs labeled "+" and "−" to show the relative influence of each input signal on the output. A process controller may be thought of as a kind of differential amplifier, sensing the difference between two input signals (the process variable and the setpoint) and generating an output signal proportional to the difference between PV and SP to drive a final control element.

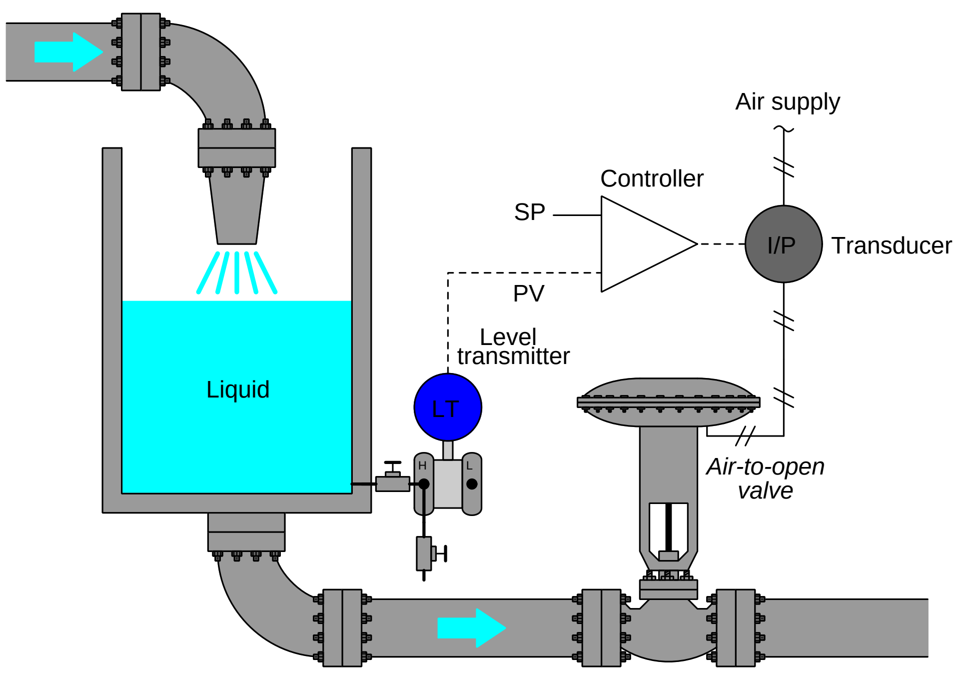
The following process control examples replace the controller symbol with an amplifier symbol. Your task is to figure out appropriate labels for the amplifier's input terminals (e.g. "+" and "−"). Remember that a controller is defined as being "direct-acting" if an increase in PV causes an increase in output and "reverse-acting" if an increase in PV causes a decrease in output. Following opamp labeling, this means the PV input of a direct-acting controller should bear a "+" mark while the PV input of a reverse-acting controller should bear a "−" mark.



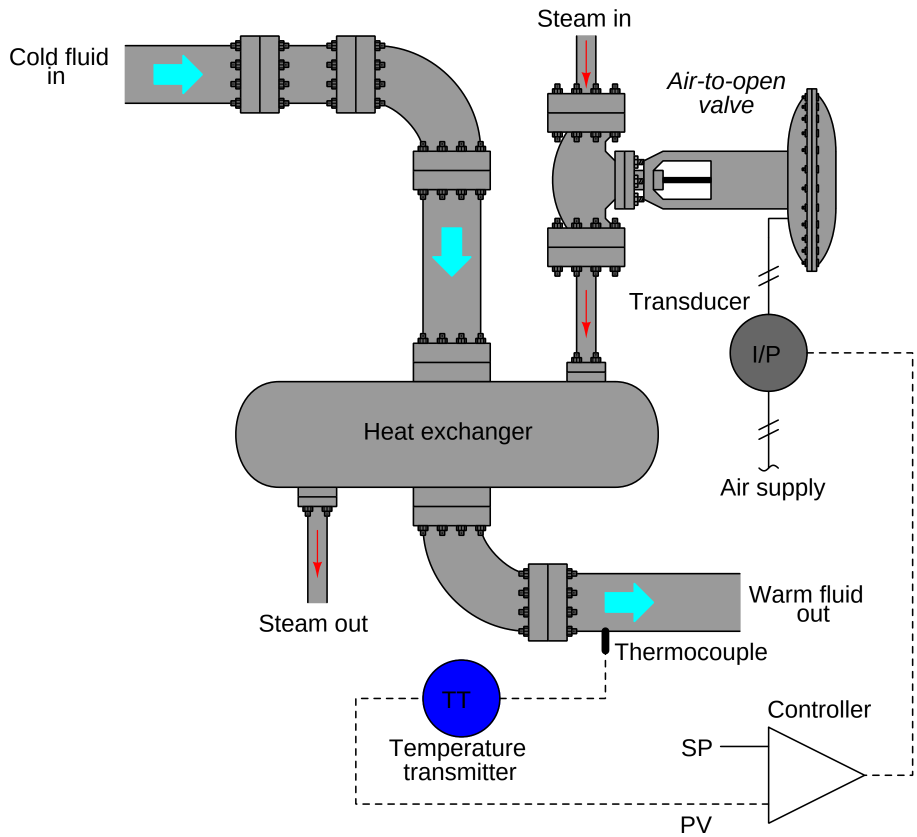
Example 5: *Label the PV & SP amplifier inputs for the correct controller action*



Example 6: *Label the PV & SP amplifier inputs for the correct controller action*



Example 7: *Label the PV & SP amplifier inputs for the correct controller action*



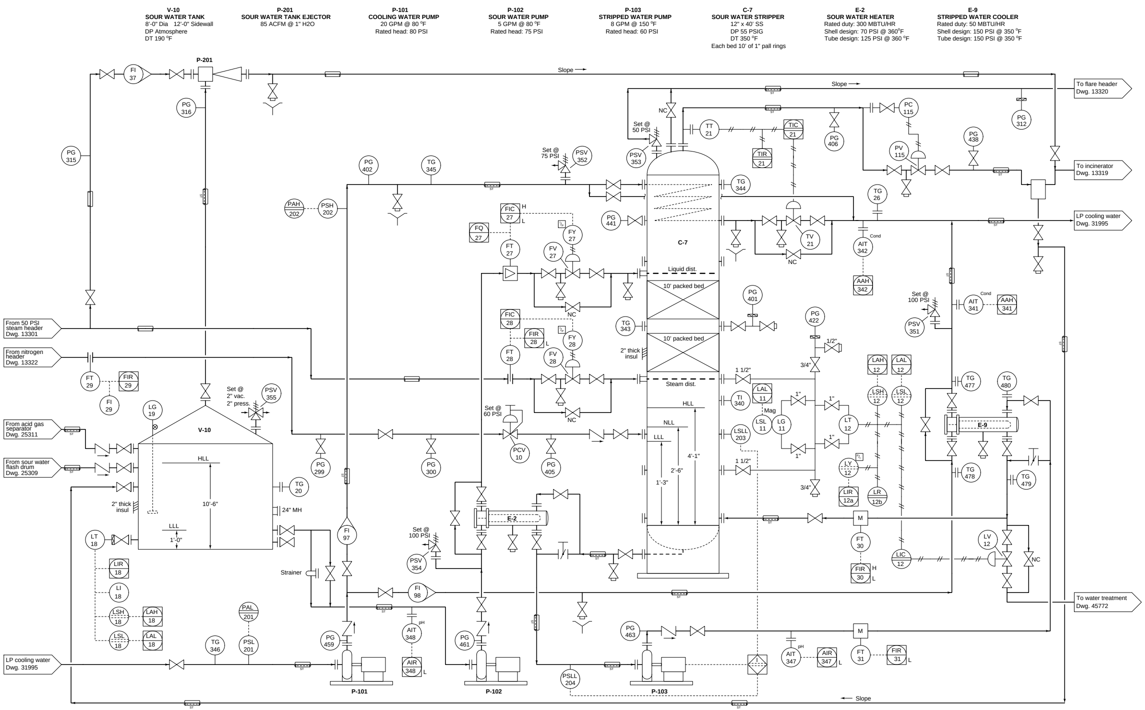
Suggestions for Socratic discussion

- As always, what is more important than arriving at the correct answer(s) is to develop a clear and logical *reason* for your correct answers. Explain the problem-solving technique(s) you used to determine correct controller action in each of these process control examples.
- A powerful problem-solving technique is performing a *thought experiment* where you mentally simulate the response of a system to some imagined set of conditions. Describe a useful "thought experiment" for any of these process control loops, and how the results of that thought experiment are helpful to answering the question.
- Explain how to reliably identify the process variable (PV) in any controlled process presented to you.
- Explain how to reliably identify the manipulated variable (MV) in any controlled process presented to you.
- Identify and explain the deleterious effect(s) caused by a process controller configured with the wrong action.
- Identify an instrument mis-calibration or mis-configuration that could cause the process variable to settle at a greater value than it should be, assuming all other components in the system are functioning properly.
- Once you have identified the proper controller action for any given process example, identify something that could be altered about the process to require the *other* control action.

file i00788

Question 6

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.

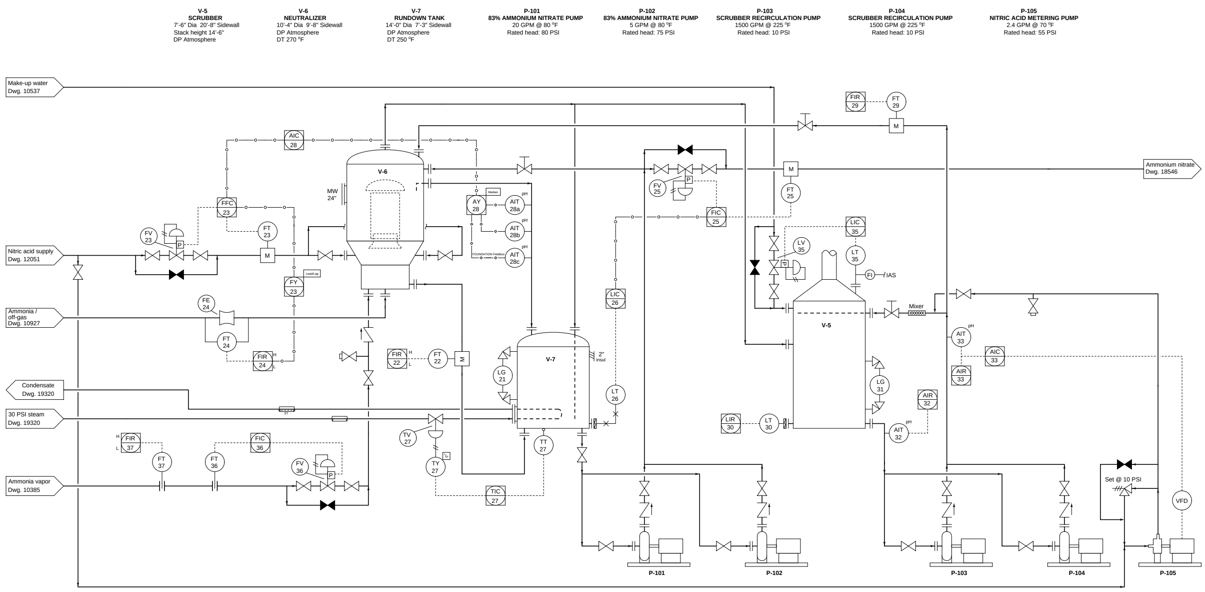
Suggestions for Socratic discussion

- 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 7

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.

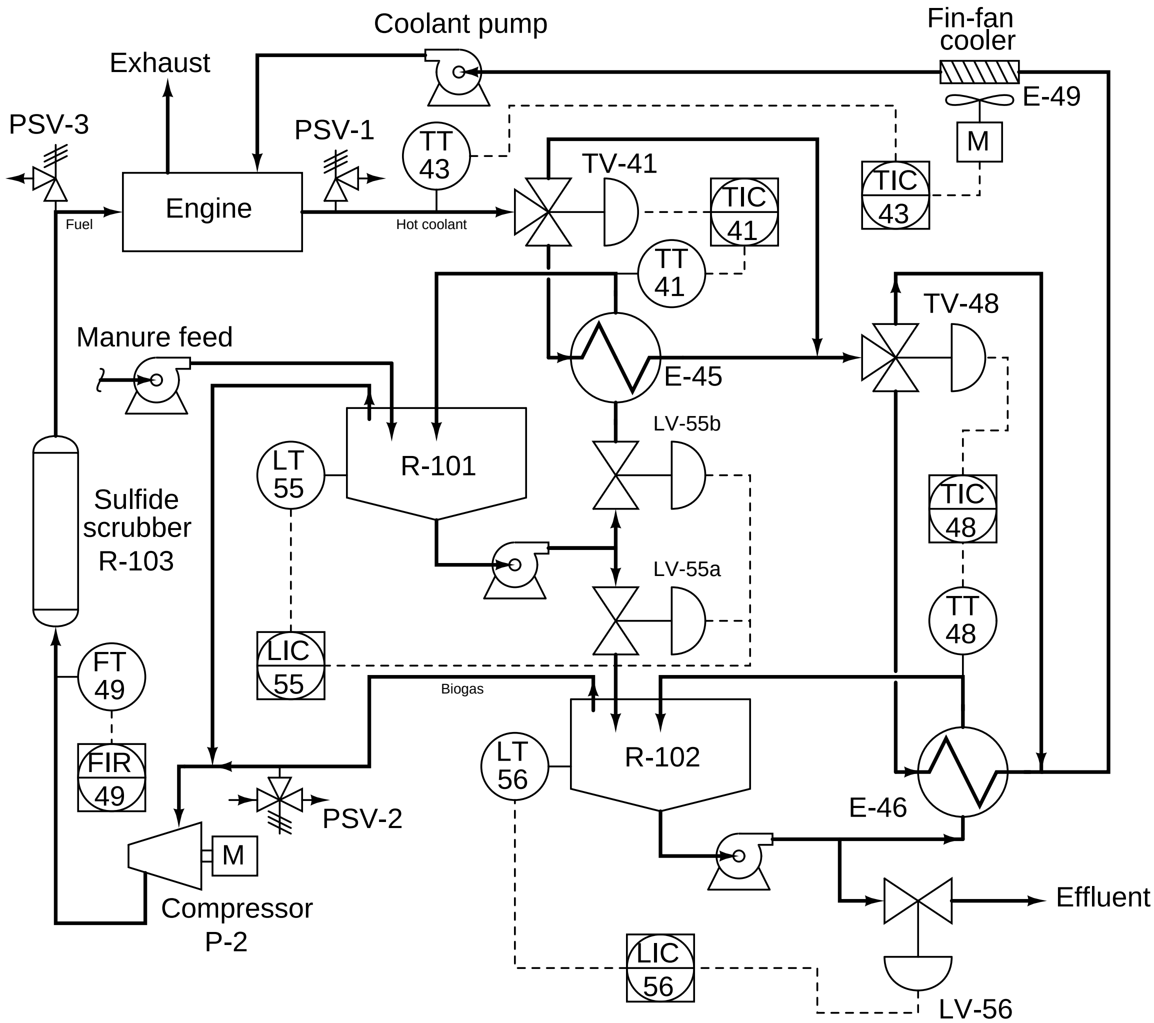
Suggestions for Socratic discussion

- 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 8

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 $\pm$ 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?

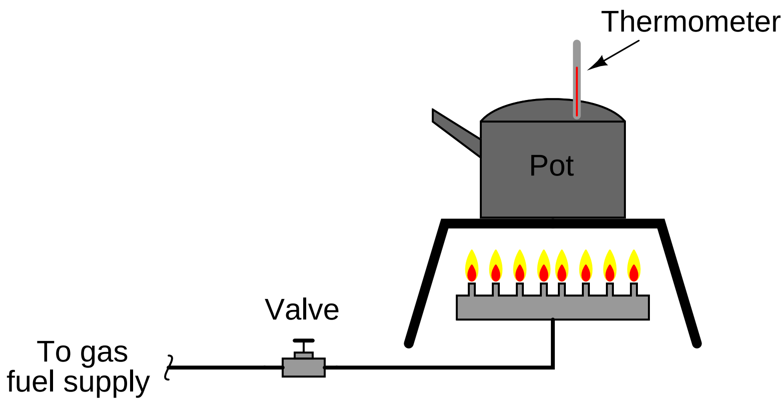
- Suppose an engineer suggested the reactor vessels be heated by electric heating elements, powered by an electric generator turned by the engine. Do you think this is a better or worse idea than using heat from the engine's coolant loop? Explain why or why not.
- For those who have studied control valve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

file i01432

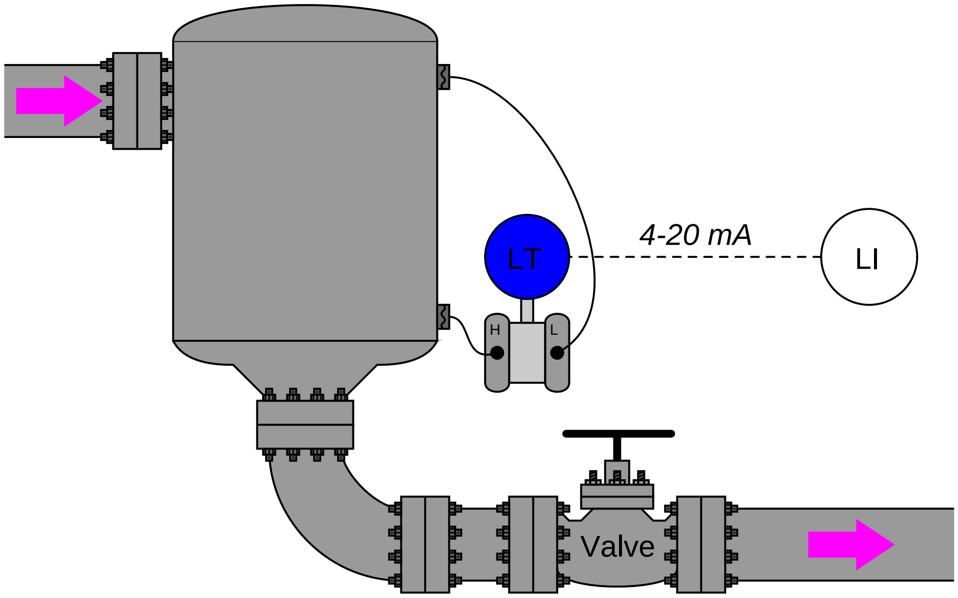
Question 9

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:

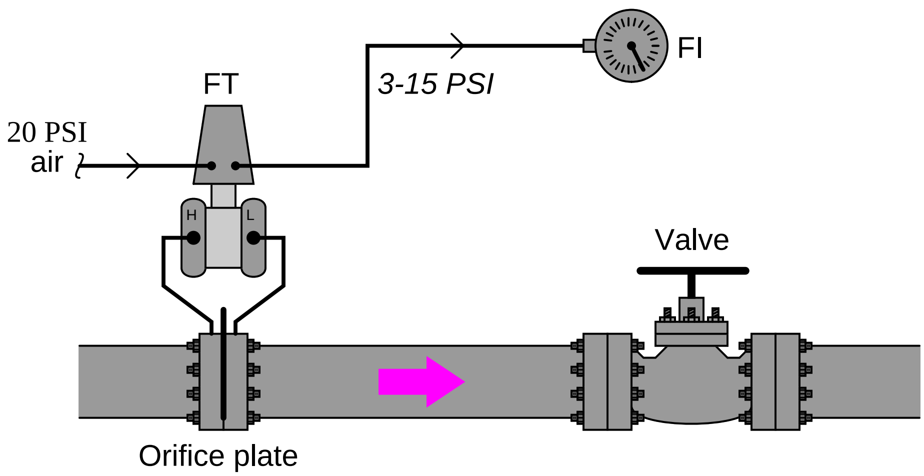
Example 1: Temperature control application



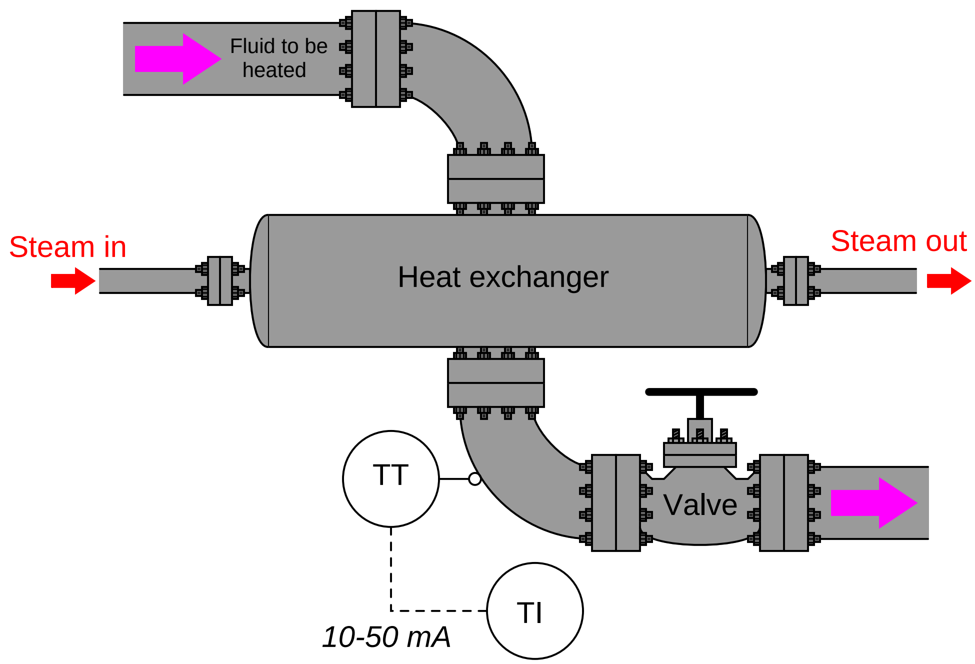
Example 2: Level control application



Example 3: Flow control application



Example 4: Temperature control application



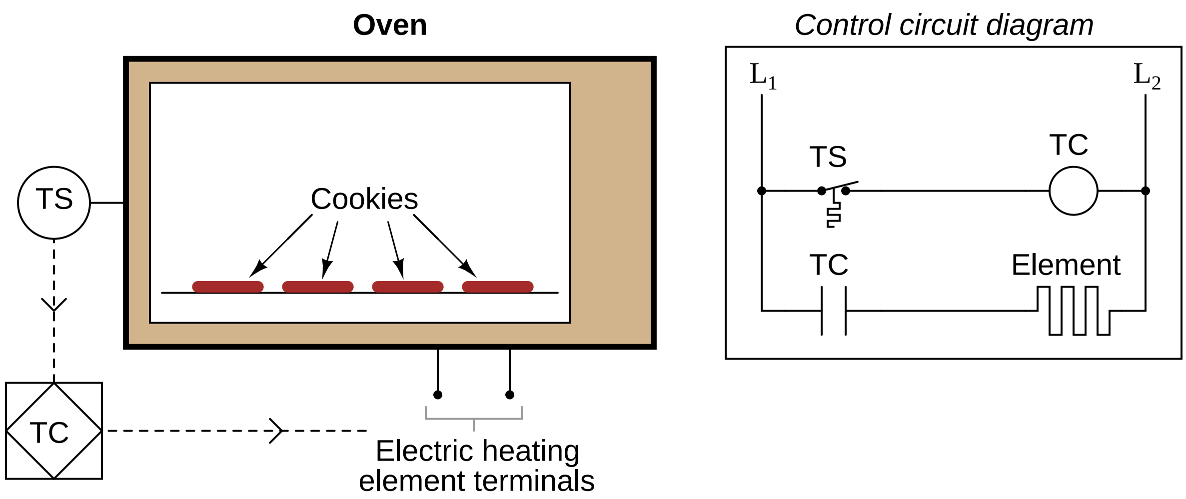
Suggestions for Socratic discussion

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

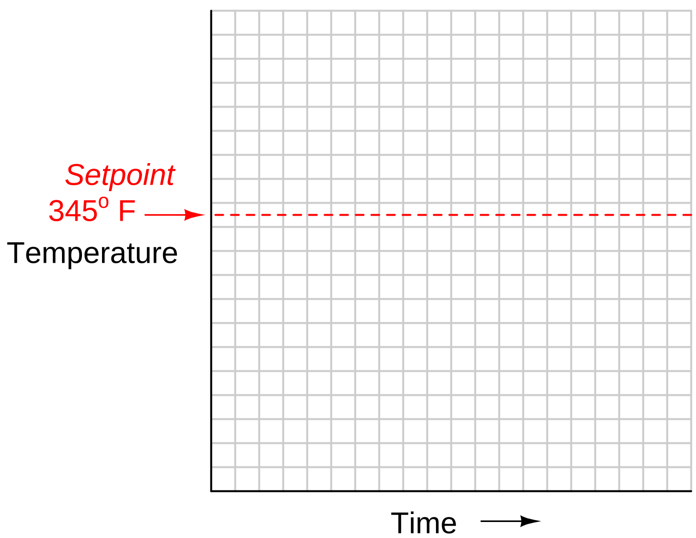
  file i01453

Question 10

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:

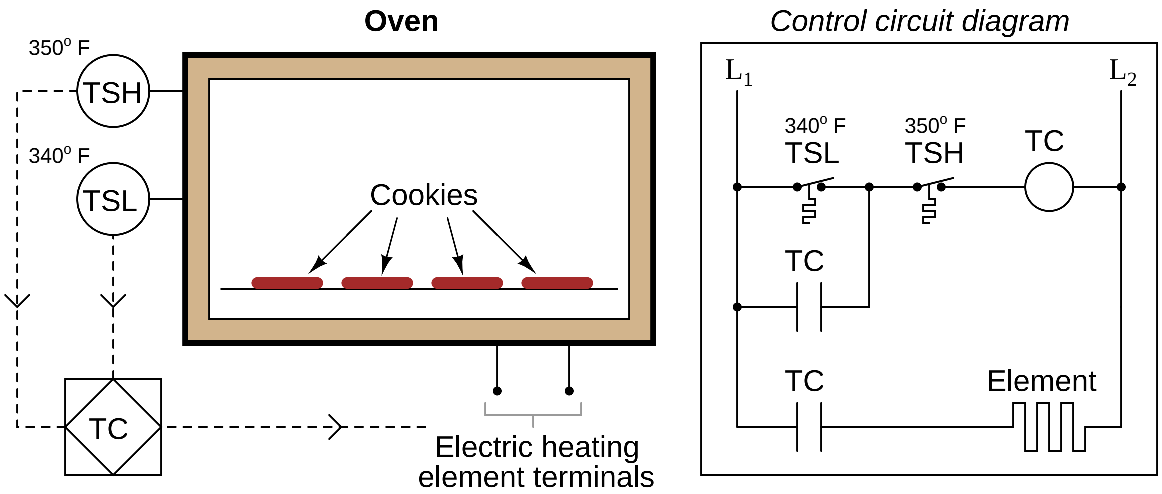


file i01449

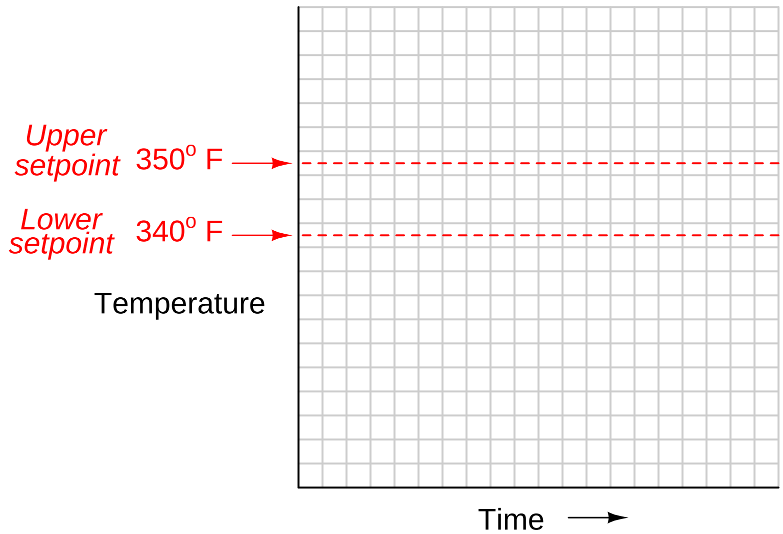
Question 11

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:

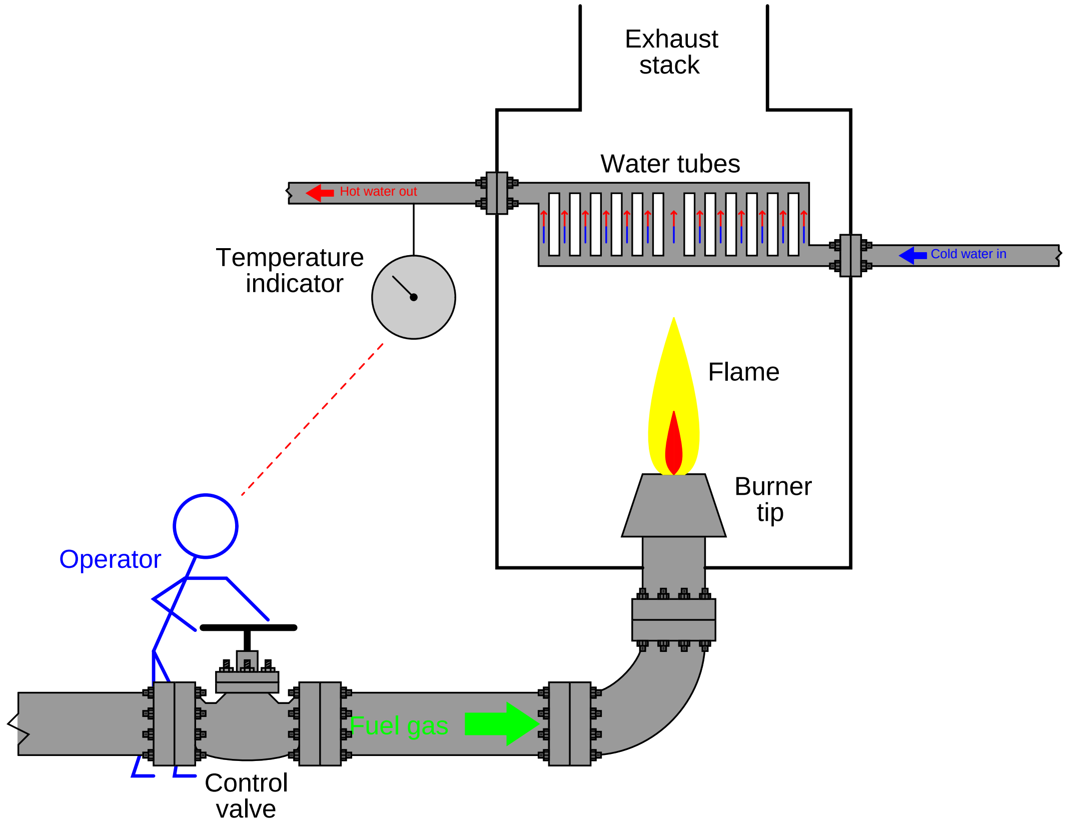


Graph this oven's temperature over time as the control system operates, and contrast its behavior against that of a single-point on-off control system.

file i01450

Question 12

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:



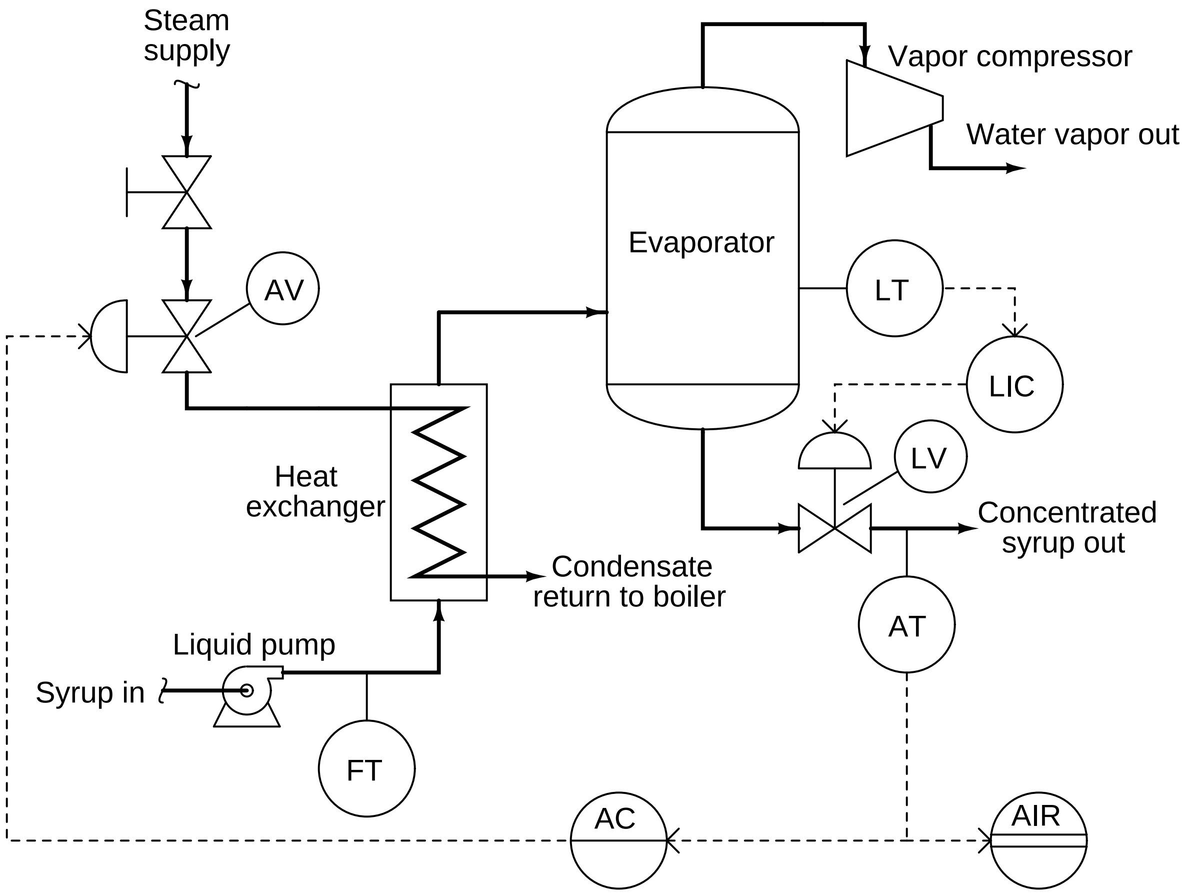
Does the operator play the part of a *direct-acting* controller, or a *reverse-acting* controller, in this process control scenario?

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

file i01452

Question 13

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.

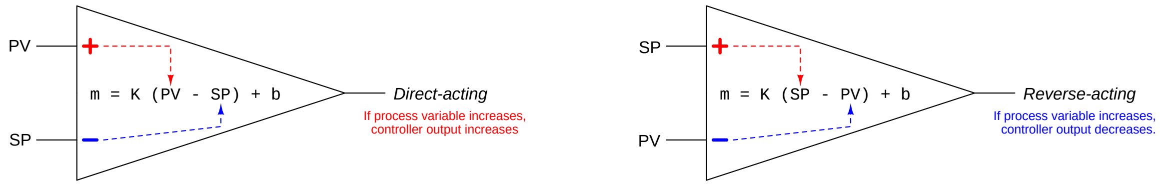
Suggestions for Socratic discussion

- 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?

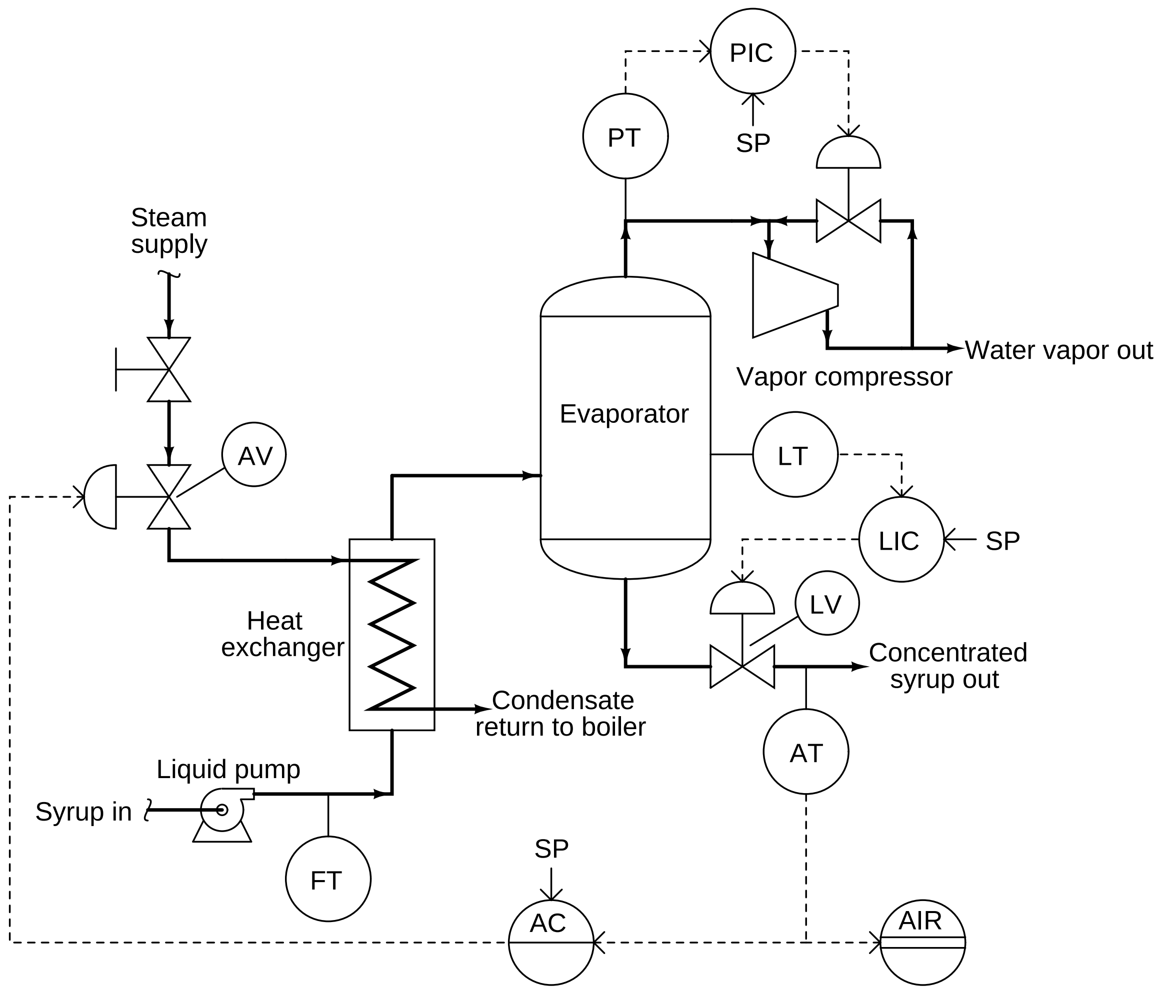
file i02936

Question 14

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:



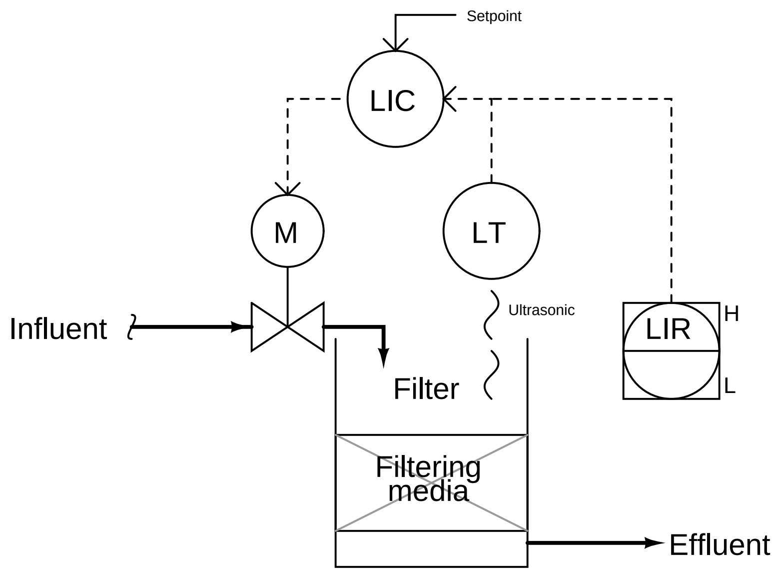
One way to get yourself into this mind-set of marking loop controller inputs with "+" and "−" symbols is to completely replace the ISA-standard "bubble" symbols with triangular opamp symbols. Try doing this in the following PFD, showing the proper direction of action for each controller for the maple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



file i04555

Question 15

This water filter level control system uses an ultrasonic level transmitter to sense the level of water in the filter, and a controller to drive a motor-actuated valve introducing raw water to be filtered:



Assuming a direct-acting level transmitter (increasing filter level = increasing signal), and a signal-to-open control valve (increasing controller output signal = wider open valve), determine whether the level controller needs to be configured for *direct-action* or *reverse-action*, and explain your reasoning. Annotate the diagram with "+" and "−" symbols next to the PV and SP controller inputs to show more explicitly the relationships between the controller inputs and output.

Next, determine the response of the controller to the following situations. In other words, determine what the controller's output signal will do when this water level control system is affected in the following ways:

- A sudden increase in effluent flow rate (clean water demand)
- Level transmitter fails high (indicating 100% full water level)
- Control valve actuator fails, driving valve fully open (ignoring controller signal)

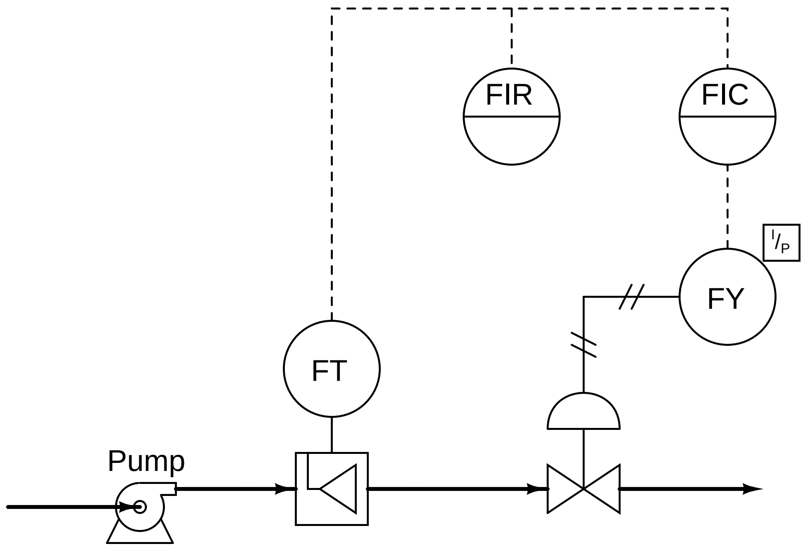
Suggestions for Socratic discussion

- Re-draw the diagram for this water filter level control system, replacing the controller (circle) with an op-amp symbol (triangle), determining the "+" and "−" input assignments on the opamp for PV and SP.
- Explain why level control is important in a water filter such as this.
- What do the "H" and "L" symbols near the LIR represent?

file i02370

Question 16

There is a problem somewhere in this liquid flow control system. The controller is in automatic mode, with a setpoint of 65%, yet the flow indicator and the flow controller both register 0.3%: (nearly) zero flow. A P&ID of the loop appears here:



Explain how you would begin troubleshooting this system, and what possible faults could account for the controller not being able to maintain liquid flow at setpoint.

Suggestions for Socratic discussion

- Explain how you could divide this control system into distinct areas or zones which you may then begin to refer to when "dividing and conquering" the problem.

file i02518

Question 17

Question 18

Question 19

Question 20

Question 21

Read and outline the "Integral (Reset) 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.

Further exploration . . . (optional)

The now-famous paper on PID controller tuning written by Ziegler and Nichols in 1942 contains many useful insights into behavior of the basic PID control algrithm. Here is one of them:

> In most controllers using automatic reset, some adjustment of the reset rate is provided, though continuous adjustment appears in only a few. In one, the reset rate is adjustable from zero to 20 per min. In order to determine reset rates on an instrument without a calibrated dial, it is only necessary to move the pen away from the set pointer far enough to cause a 1 psi output change and note the additional output-pressure change per minute. The same value can be put on the reset adjustment in controllers other than those of the air-operated type, by making a sustained pen change from the set point, noting the altered valve position which results from proportional response and the additional travel at the end of 1 min from automatic reset. The reset rate is the travel from reset divided by the travel from proportional.

Expressing the meaning of this passage in your own words. What are Ziegler and Nichols trying to say here? What does this suggest about the pneumatic PID controllers of their era? Do you suspect this same procedure might work on a modern electronic controller?

file i04284

Question 22

Read and outline the "Derivative (Rate) 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.

Further exploration . . . (optional)

The now-famous paper on PID controller tuning written by Ziegler and Nichols in 1942 contains many useful insights into behavior of the basic PID control algrithm. Here is one of them:

> Pre-act response does not replace automatic reset response since it ceases to act when the pen becomes stationary. However, while reset increases period of oscillation and decreases stability, the effect of pre-act is just the opposite. On the debit side for pre-act lies only the increased difficulty of adjusting three responses instead of two, but the use of the basic unit, pre-act time, allows the setting to be determined from the period of oscillation.

Describe what this passage is saying, in your own words. Do you see any unfamiliar terms, which you may determine the meaning of from context? What insight(s) can you gather about the use of the integral control mode, as well as the derivative control mode?

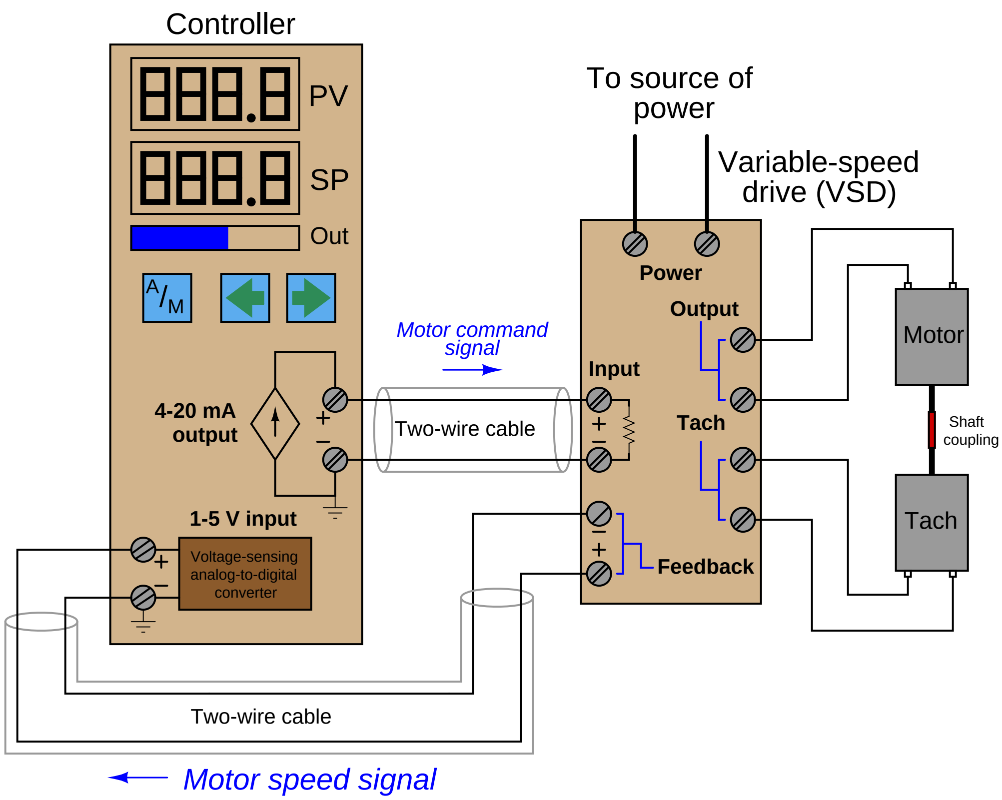
file i04301

Question 23

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 24

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 25

Desktop Process exercise

Configure the controller as follows. 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 = *one-tenth the value yielding optimal control = ten times the proportional band value yielding optimal control*
- Reset (Integral) = *1 minute/repeat = 1 repeat/minute*
- Rate (Derivative) = *minimum effect = 0 minutes*

Use the controller's manual mode to establish the process variable at approximately 50%, then switch to automatic mode. Make a sudden setpoint adjustment (at least 10%, in either direction) and observe the controller's *slow* integral-action response to this change.

Try increasing the "aggressiveness" of the integral action (i.e. more repeats per minute, or fewer minutes per repeat) until a more satisfactory control response is seen from the controller. Without adjusting the controller's gain (proportional action), experiment with different integral settings until good control response is seen with large setpoint changes. Your goal is to achieve a quality of control that eliminates offset quickly while minimizing "overshoot" and oscillation of the process variable.

Suggestions for Socratic discussion

- Explain in your own words why more "repeats per minute" yields a more aggressive integral response, and why more "minutes per repeat" yields a tamer integral response.

file i04290

Question 26

Desktop Process exercise

Tune the controller in your Desktop Process first using proportional action only (reset and rate settings at minimum effect), testing the control quality by observing the graph produced by the data acquisition software. Your goal is quick response to setpoint changes with minimal oscillation of the PV. 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.

After determining a reasonable value for the controller's gain setting, incorporate some reset (integral) action in order to eliminate offset following a setpoint or load change. Once again, your goal is quick response with minimal oscillation and overshoot of the PV.

Record these gain and reset settings for future use.

file i04292

Question 27

Desktop Process exercise

Configure your Desktop Process for full proportional-plus-integral-plus-derivative (PID) control. Experiment with different "gain," "reset," and "rate" tuning parameter values until reasonably good control is obtained from the process (i.e. fast response to setpoint changes with minimal "overshoot," good recovery from load changes). Record the "optimum" P, I, and D settings you find for your process, for future reference. 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.

Compare the optimum PID tuning parameter values you arrived at compared to those of your classmates.

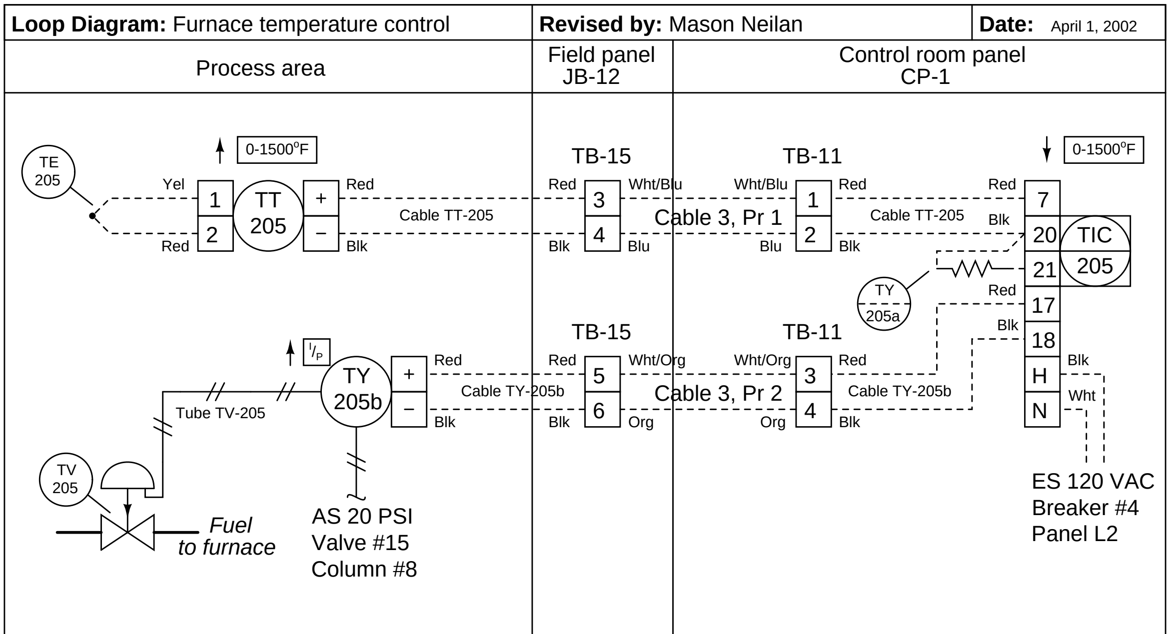
Suggestions for Socratic discussion

- How do the P, I, and D settings (when all used together to achieve optimum control) compare to the P setting by itself found to yield optimum proportional-only control, or the P and I settings found to yield optimum PI control, or the P and D settings found to yield optimum PD control?

file i04309

Question 28

This temperature control system has a problem. The process temperature is running above setpoint significantly – the setpoint is 850 ^{o}F and the temperature (as indicated by TIC-205) is 934 ^{o}F 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 ^{o}F. 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?

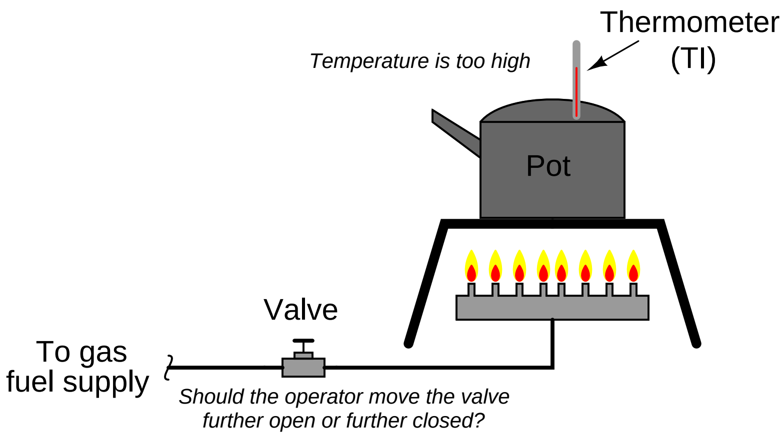
Suggestions for Socratic discussion

- 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.

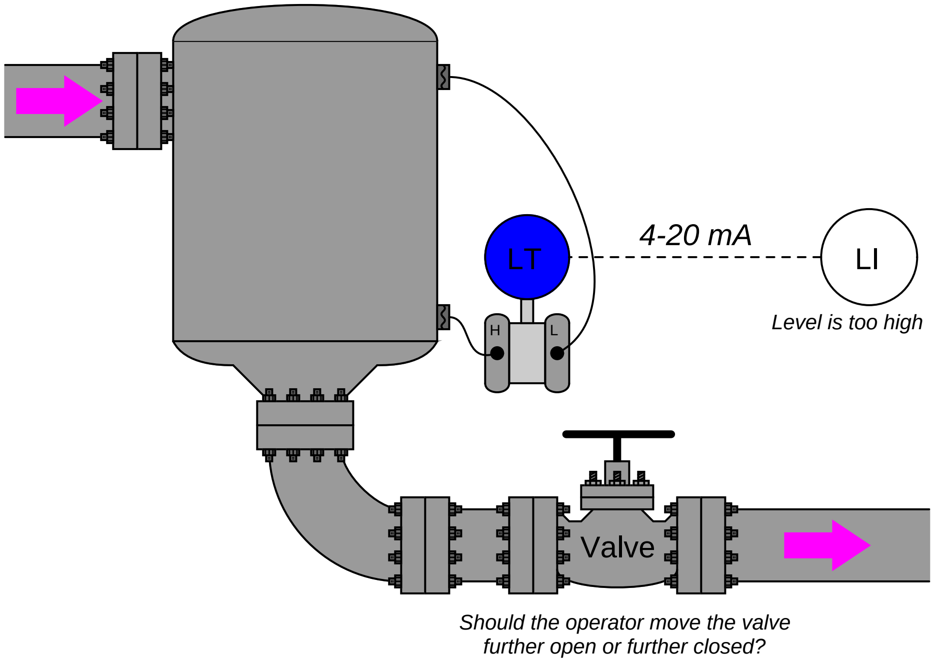
Question 29

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:

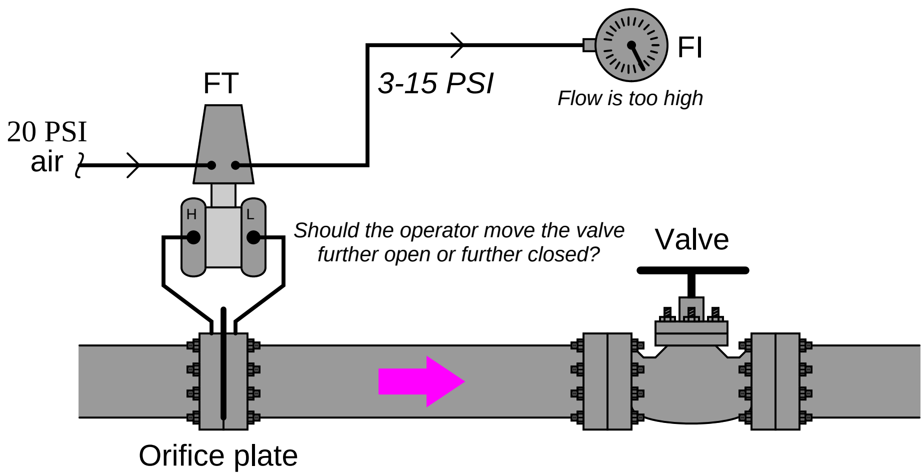
Example 1: Temperature control application



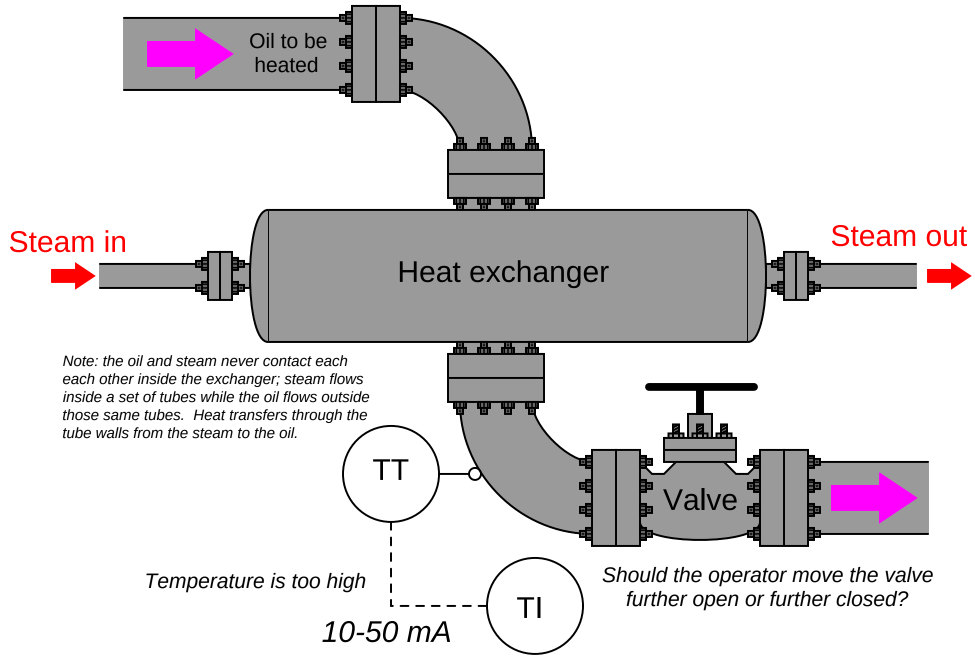
Example 2: Level control application



Example 3: Flow control application



Example 4: Temperature control application



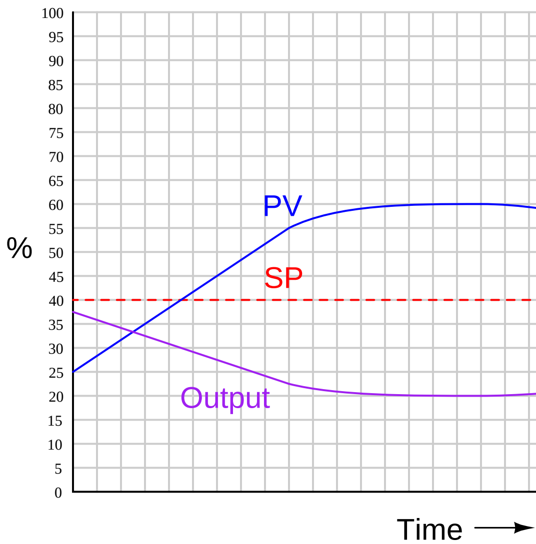
Suggestions for Socratic discussion

- 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 30

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.

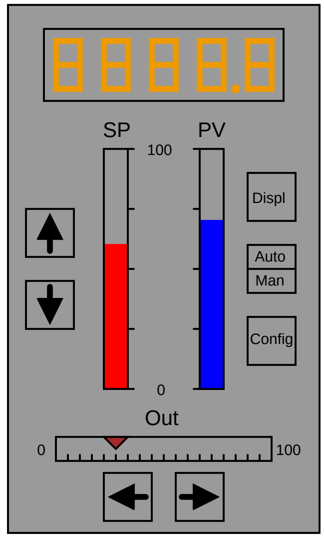
Suggestions for Socratic discussion

- 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 31

Shown here is the faceplate of a digital electronic single-loop process controller:



State your best guesses as to the functions of all buttons on this controller. In particular, elaborate on the difference between *Auto* and *Manual* modes, and which parameters the "arrow" buttons affect.

Also, describe what steps an operator would have to take to switch this controller from automatic to manual modes, and manually change the output signal going to the control valve, and describe a practical situation where the operator might be inclined to do such a thing.

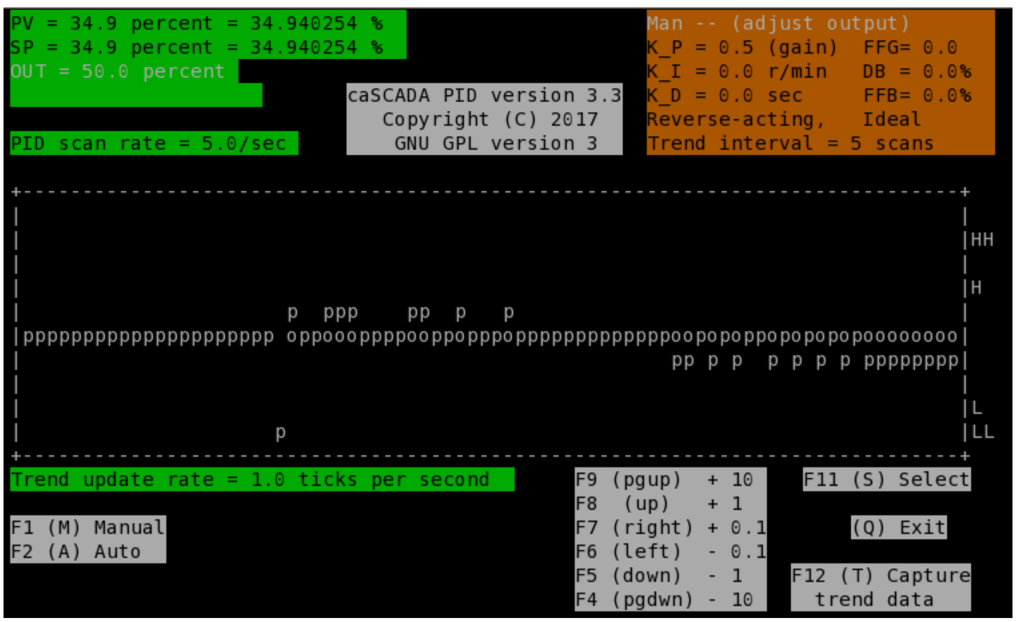
file i02373

Question 32

In order to explore different process characteristics, it is useful to have access to loop simulation software you can run on your own personal computer. A "loop simulation" program mimics the behavior of a real process, allowing you to make tuning changes to a PID controller and see the results in a trend graph.

The caSCADA control system available in the BTC Instrumentation lab room offers loop simulation capability, in an application named `looptune`. In order to use this software, you must remotely log in to one of the caSCADA computers with the following instructions:

- 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 listed below. The user name is `btc` and the password is `btc`.
  → `169.254.8.103` is the RTU-DCS02 node located in cabinet DCS-02
  → `169.254.8.133` is the RTU-JB15 node located in cabinet JB-15
  → `169.254.8.113` is the RTU-JB17 node located in cabinet JB-17
- Type `./looptune` at the terminal command prompt and press Enter.
- Follow the instructions as the program launches.
- After following the set-up instructions, you should see a trend graph and control screen that looks something like this:



Control parameters are selected by pressing the "S" key as many times as necessary. The selected parameter is shown in white text, as opposed to the default text color black. Manual mode is selected by pressing "M" and automatic mode is selected by pressing "A". In manual mode the default parameter selection is Output (OUT), while in automatic the default parameter becomes Setpoint (SP). Parameter values are adjusted by tenths using the left and right arrow keys, by ones using the up and down arrow keys, and by tens using the Page Up and Page Down keys.

The rather crude trend graph shows process variable with letter "p" characters, Output with letter "o" characters, and Setpoint with letter "s" characters. If you wish to capture a trend display, you may do so at any time by pressing the "T" key – a comma-separated variable file will be written (`0_pid_trend.csv`) which may be opened in any spreadsheet program (e.g. Microsoft Excel) and used to draw a nice trend graph with colored traces.

file i04320

Question 33

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 34

Question 35

Question 36

Question 37

Question 38

Question 39

Question 40

Question 41

Read and outline the "Distributed Control Systems (DCS)" subsection of the "Digital 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 i00813

Question 42

Search through Chapter 1 ("DeltaV System Overview") of the "Getting Started with your DeltaV Digital Automation System" manual (document D800002X122, March 2006) to answer the following questions:

Based on the simple network diagram shown on page 1-1, what type of digital network connects the PC workstation(s) to the DCS controller?

What is the *System Identifier* in a DeltaV system, and what purpose does it serve?

Several software applications find frequent use in the maintenance and operation of a DeltaV control system: *DeltaV Explorer*, *DeltaV Operate Run*, *DeltaV Operate Configure*, *Control Studio*, and *DeltaV Books Online*. Identify what each of these software tools does.

Suggestions for Socratic discussion

- A hallmark of Distributed Control Systems (DCSs) is *hardware redundancy*. Identify specific redundant features of the Emerson DeltaV DCS.
- Access a DeltaV workstation PC and try opening each of the software applications listed, exploring the features of each. *Do not "download" or "save" anything, which will alter the configuration of the DCS – just explore and observe!*

file i00811

Question 43

Read Exercise 5 ("Creating a New Module (LI-101) from Scratch") in Chapter 4 ("Creating and Downloading the Control Strategy") of the "Getting Started with your DeltaV Digital Automation System" manual (document D800002X122, March 2006) and answer the following questions:

Which function block type is used in the LI-101 module, and what does it do?

The output of the main function block in this module is "wired" to another object called an *Output Connector*. What does an "output connector" do in the DeltaV system?

One of the configuration steps described has you add "History Collection" to the function block. What exactly does this feature do?

After this module's function block has been "wired" to the Output Connector, there are a few final steps required to finish the module. Identify these steps and explain their purpose.

Suggestions for Socratic discussion

- Access a DeltaV workstation PC and try opening a module using Control Studio. Find some of the `AI` block parameters and options discussed in this exercise. *Do not "download" or "save" anything, which will alter the configuration of the DCS – just explore and observe!*
- Compare the setting of the process variable's "engineering units" to the MINSCALE and MAXSCALE parameters of the `AI` function block in a Siemens 353 loop controller. How are these tasks similar, and how are they different?
- Why do you suppose it is necessary to *add* a History Recorder feature to each desired data point in the control system, rather than have history recording be a default feature for all data points?

file i00812

Question 44

Read Exercise 6 ("Creating a PID Control Loop (FIC-101)") in Chapter 4 ("Creating and Downloading the Control Strategy") of the "Getting Started with your DeltaV Digital Automation System" manual (document D800002X122, March 2006) and answer the following questions:

In this exercise the user is shown how to begin configuring a control module without starting from scratch as in Exercise 5. How is this done?

Although you will often find `PID` function blocks "wired" to analog input (`AI`) function blocks and analog output (`AO`) function blocks to make a complete working loop module, here in this exercise the `PID` function block stands alone. In lieu of `AI` and `AO` function blocks to route the signals to and from real-world I/O channels, how does this `PID` function block "know" where to get its PV input and where to send its MV output signals?

Suggestions for Socratic discussion

- Access a DeltaV workstation PC and try opening a module using Control Studio. Find some of the `PID` block parameters and options discussed in this exercise. *Do not "download" or "save" anything, which will alter the configuration of the DCS – just explore and observe!*
- Note where the controller's direction of action (i.e. "direct" or "reverse" action) is selected in the `PID` function block. How does one determine the correct direction of control action for any specific process?
- Immediately following the instruction on how to set controller's direction of action (i.e. "direct" or "reverse" action), this exercise specifies how to set a similar parameter in the IO_OPTS collection of parameters called *Increase to Close*. This is used when the control valve happens to be air-to-close (fail-open), to make the controller faceplate's output bargraph match the valve stem position (so that a displayed output of 0% represents a shut valve and a displayed output of 100% represents a wide-open valve). Explain why this parameter is an important one to set in processes where the control valve is air-to-close. One way of explaining the importance of this parameter is to describe what would happen if it were *not* set correctly for a particular control loop.
- Compare the setting of the process variable's "engineering units" to the MINSCALE and MAXSCALE parameters of the `AI` function block in a Siemens 353 panel-mounted loop controller. How are these tasks similar, and how are they different?

file i00814

Question 45

Read Exercise 9 ("Downloading the Modules") in Chapter 4 ("Creating and Downloading the Control Strategy") of the "Getting Started with your DeltaV Digital Automation System" manual (document D800002X122, March 2006) and answer the following questions:

The final step in implementing control modules in the DeltaV system is to do a "download." Explain what this procedure accomplishes, and what would happen if we forgot to do it.

An "Important" warning note is given on page 4-53 of this tutorial. Explain in your own words what you need to be cautious about.

Suggestions for Socratic discussion

- For those students who have programmed PLCs (Programmable Logic Controllers), identify aspects of this exercise that are similar to what you have done with PLCs and PLC programs.
- Suppose you absolutely needed to download some changes to an operating DCS, and knew that there was the possibility of this update upsetting a few control loops. What could you do as a precaution to minimize the probability of disturbing these control loops?

file i00816

Question 46

Search through Chapter 5 ("Creating Operator Pictures") of the "Getting Started with your DeltaV Digital Automation System" manual (document D800002X122, March 2006) to answer the following questions:

Identify a fast way to switch between the "Run" and "Configure" modes of *DeltaV Operate*.

This tutorial advises against creating a new "picture" file from scratch. Instead, what is the recommended method for creating a graphical screen for operators to use?

Describe the purpose of the *DeltaV_Toolbox* in *DeltaV Operate* (Configure mode), and how this "toolbox" may be used to create graphic objects on the screen for operator displays.

Explain what a "link" is in *DeltaV Operate*. Specifically, what is a "datalink" and what might one be used for?

Explain what a "parameter reference" is in *DeltaV Operate*.

Explain what a "dynamo" is in *DeltaV Operate*.

Page 5-30 begins a discussion on Trend Links, which is another form of link supported by *DeltaV_Run*. In this discussion the tutorial mentions that trend links are able to display any "floating point" data (i.e. any parameter reference ending in `.F_`. Explain what "floating point" data is and how it differs from integer or boolean data.

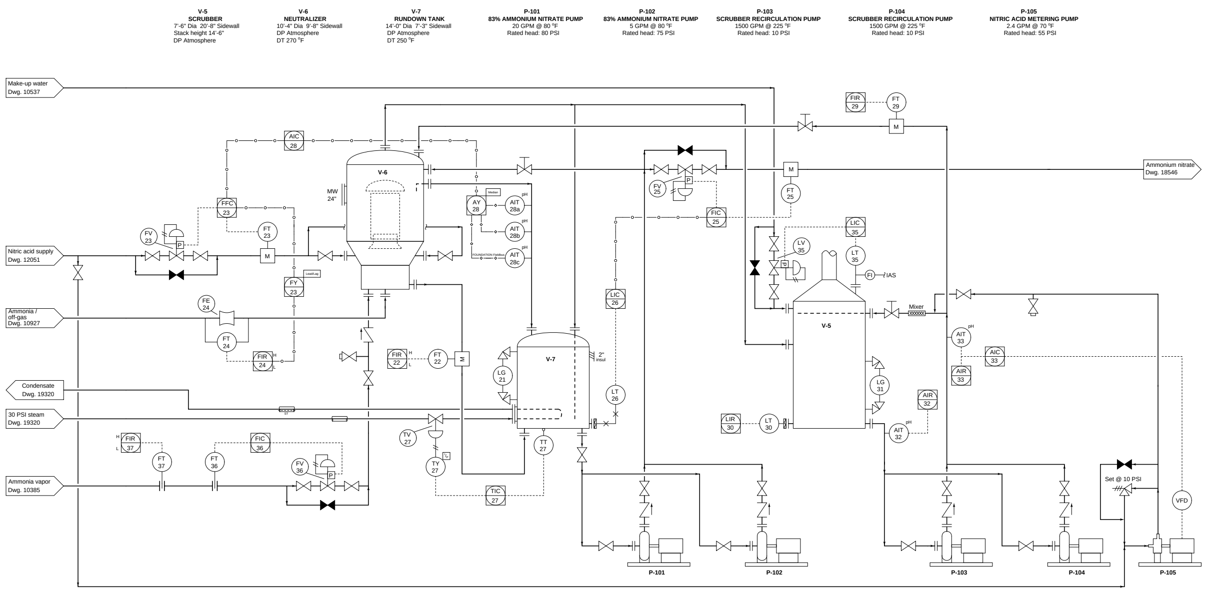
Suggestions for Socratic discussion

- Access a DeltaV workstation PC and try opening an operator picture using DeltaV Operate Configure. Explore the parameters associated with the datalinks and dynamos in this picture. *Do not "download" or "save" anything, which will alter the configuration of the DCS – just explore and observe!*
- For those students who have programmed HMIs (Human-Machine Interfaces), identify aspects of *DeltaV Operate* that are similar to other HMIs you have worked with.
- Identify practical applications where you might wish to show *integer* data on an operator display.
- Identify practical applications where you might wish to show *boolean* data on an operator display.

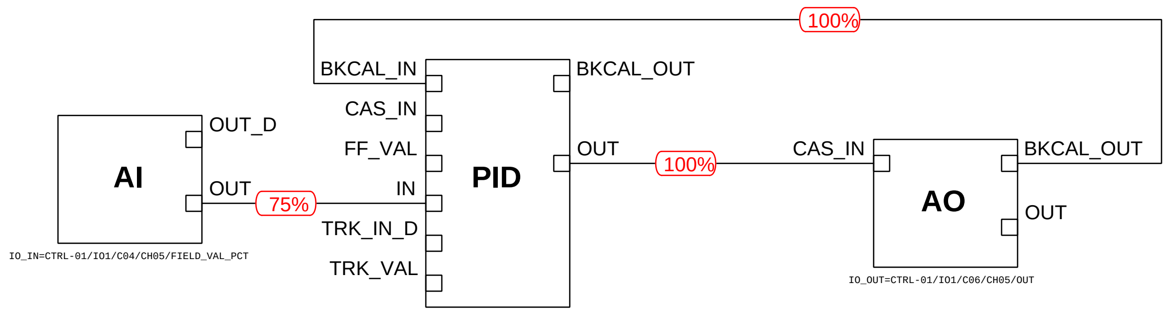
file i00817

Question 47

The scrubber (vessel V-5) liquid level is being controlled by an Emerson DeltaV DCS, but something is wrong. The operator reports seeing a liquid level of 90% in the LG-31 sightglass while claiming the setpoint entered into the DeltaV Operate controller faceplate is 75%:



A very useful feature of the *DeltaV Control Studio* application is being able to switch the view to "online" mode and watching real-time numerical data appear on the interconnecting lines between function blocks. When you use the *Control Studio* software to examine this loop's function block program module in online mode, this is what you see:



Identify the likelihood of each specified fault in this process, based on what you see in the online Control Studio view. 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 process.

Fault	Possible	Impossible
Poor tuning in the PID function block		
LT-35 miscalibrated, reading too low		
LT-35 miscalibrated, reading too high		
Make-up water source shut off		
Pump P-103 failed (not pumping)		
LG-31 sightglass block valve plugged		
Pump P-105 failed (not pumping)		
Human operator error		

Suggestions for Socratic discussion

- Choose any of the listed faults that are *impossible*, and then predict the effects on the process and on the control system if they were to occur.

file i00961

Question 48

Sketch a diagram showing all wire connections between any model of Rosemount differential pressure transmitter, an Emerson DeltaV DCS controller, and a Fisher DVC6020 valve positioner to form a simple PID control system. You may arbitrarily choose to use either "M-series" or "S-series" DeltaV I/O cards. Your task is to locate the appropriate datasheets or manuals in the Instrumentation Reference (or online) to identify the proper wire terminals to connect, then sketch a simple loop diagram showing how the appropriate terminals on each device connect to terminals on the other devices to make a functional instrument loop. You are free to choose which channel on the DeltaV I/O cards to use for your loop.

Suggestions for Socratic discussion

- A problem-solving technique useful for making proper connections in pictorial circuit diagrams is to first identify the directions of all DC currents entering and exiting component terminals, as well as the respective voltage polarity marks (+,−) for those terminals, based on your knowledge of each component acting either as an electrical *source* or an electrical *load*. Discuss and compare how these arrows and polarity marks simplify the task of properly connecting wires between components.
- Locate a wiring diagram for one of the *redundant* I/O card options available for the DeltaV system (either M-series or S-series) and reference that diagram to explain how redundant I/O cards connect to the same field instrument.

file i00818

Question 49

Read Section 10.0 of the Siemens model 353 Process Automation Controller user's manual (document UM353-1, Revision 11, March 2003). This section, entitled "Controller and System Test", describes how to test a model 353 controller by stepping through a set of exercises designed to explore its major features. It also doubles as an excellent exercise for students to use in understanding this controller's features and capabilities.

To do this exercise, you will need access to a Siemens model 353 controller. Feel free to use one of the panel-mounted 353 controllers in the lab, or one of the Desktop Process units, or even a 353 controller taken from storage. It is definitely a hands-on activity!

10.1.1 Connections and Power

This subsection describes how to connect AC power to the controller, and also how to connect the output to the PV input for the purposes of the subsequent tests. Feel free to skip this second part, especially if your controller is already connected to a real process. Proceed through each of the subsections, following the step-by-step instructions.

10.1.2 Configuration

This subsection refers you to another section of the manual, instructing you to load Factory Configured Option number 101 (FCO 101).

10.1.3 Input/Output

This subsection shows you how to verify the Setpoint, Output, and Process Variable I/O as configured in FCO 101, and points you to the diagram of FCO 101 to verify the "connections" of P, S, and V in the ODC function block.

10.1.4 Auto/Manual

This subsection shows you how to test the Automatic and Manual modes.

10.1.5 Modifying an FCO

This subsection shows you how to make changes to the function blocks within FCO 101. The changes include:

- Adding a new function block to FCO 101
- Perusing parameters inside a function block
- Changing MINSCALE and MAXSCALE parameters of the AIN1 function block

10.1.6 Alarms

This subsection shows you how to change the alarm values and priorities. The instructions imply a connection between output and PV input, such that you can simulate any PV signal desired simply by switching to manual mode and adjusting the output. If your controller is connected to a working process, I recommend running the controller in automatic mode and adjusting the setpoint to make the PV go to the desired value(s).

10.1.7 Tag

This subsection shows you how to change the "tag" name of the loop.

10.1.8 Quick

This subsection explores the "Quick" set feature to change certain parameters in any function block. In this particular case, the instructions guide you to configuring a ramping setpoint value.

10.1.9 Tune

This subsection explores the "Tune" feature to change P, I, and D tuning parameters, and also to activate autotune. If your controller is connected to a working process, feel free to engage the "autotune" feature and see how well it does. In my general experience a competent technician can always achieve more robust control through careful hand-selection of tuning parameter than by relying on an autotune feature, but go ahead and try it just for fun.

10.1.10 View

This subsection explores the "View" feature to monitor variables inside the controller. This can be a very useful diagnostic tool, especially when developing and "debugging" new function-block programs.

Suggestions for Socratic discussion

- Suppose you wished to change the "connection" path between two function blocks in a program. Demonstrate how to do this.
- Suppose you wished to take the factory configured option program #101 and add a discrete output block, then connect that block to the alarm block so that an external alarm light could be controlled by the alarm settings in the controller. Demonstrate how to do this.
- Identify some of the different Factory Configured Options (FCOs) available to you.
- In section 10.1.5 a clever way is shown to change the upper range value of the AIN function block from 100 to 500. Instead of simply turning the pulser knob to increment 100 to 500, some decimal-point shifting is used. Explain how this works.
- Section 3.2.12 describes the meaning of five different priority levels for alarms in the ALARM function block. Explain these priority levels in your own words.
- In section 10.1.8 describes one of the quick-set parameters as "POWER UP SETPOINT". Explain what this parameter is useful for, citing a practical application if possible.

file i00808

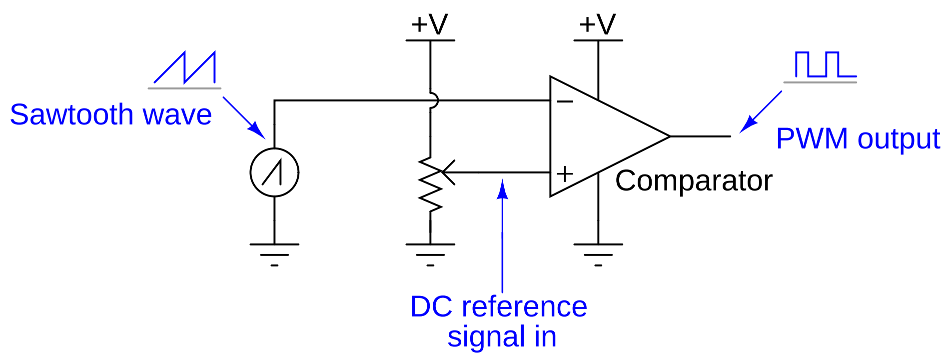
Question 50

Examine the "Siemens/Moore 353 program for pulse-width modulation" contained on your Instrumentation Reference, showing a function block program for equipping the 353 controller with a PWM output signal (modulated on/off) rather than an analog 4-20 mA output signal, then answer the following questions:

Identify those function blocks which are connected identically to the standard Factory Configured Option 101 program, then identify those function blocks which are different.

Explain why anyone would wish to have a loop controller equipped with a PWM output instead of a 4-20 mA analog output.

Explain how this analog circuit functions to produce a PWM output signal from a sawtooth waveform and a DC reference signal, and how this functionality is mimicked by the function block program of the Siemens 353 controller:



Suggestions for Socratic discussion

- Describe the steps necessary to edit the FCO 101 program so that it resembles this program, using the faceplate pushbutton controls and displays.
- Which way would you have to move the wiper on the potentiometer in the analog circuit in order to increase the duty cycle of the PWM output?
- What would be the effect of the +V power source connection to the potentiometer failing open?
- What would be the effect of the ground connection to the potentiometer failing open?
- What would be the effect of the sawtooth wave generator connection failing with a 0 volt output?
- What would be the effect of the +V power source connection to the comparator failing open?
- Sketch the diagram of an "interposing" circuit that can take the opamp's output signal and amplify it to drive PWM power to a large electric heating element (e.g. rated at a much greater voltage such as 240 VAC).

file i00356

Question 51

Read the Siemens model 353 controller application note on "Ethernet Peer-to-Peer Communication With Model 353 and Procidia i/pac Controllers" (document AD353-113, Revision 1, July 2002), then answer the following questions:

The communication protocol used by model 353 controllers is *Modbus TCP/IP*. Explain how this differs from implementations of Modbus you have seen in RS-485 networks.

Explain how the AIE and AOE function blocks are used in a pair of model 353 controllers to exchange analog signal data between the two. Does one controller *read* data from another controller, or does it *write* data to another controller, or can both events take place?

The "Ethernet Function Block" section does presents a good example of how the subnet mask is used to identify a range of IP addresses that controllers may communicate between. Read the example given and explain in your own words how the subnet mask works.

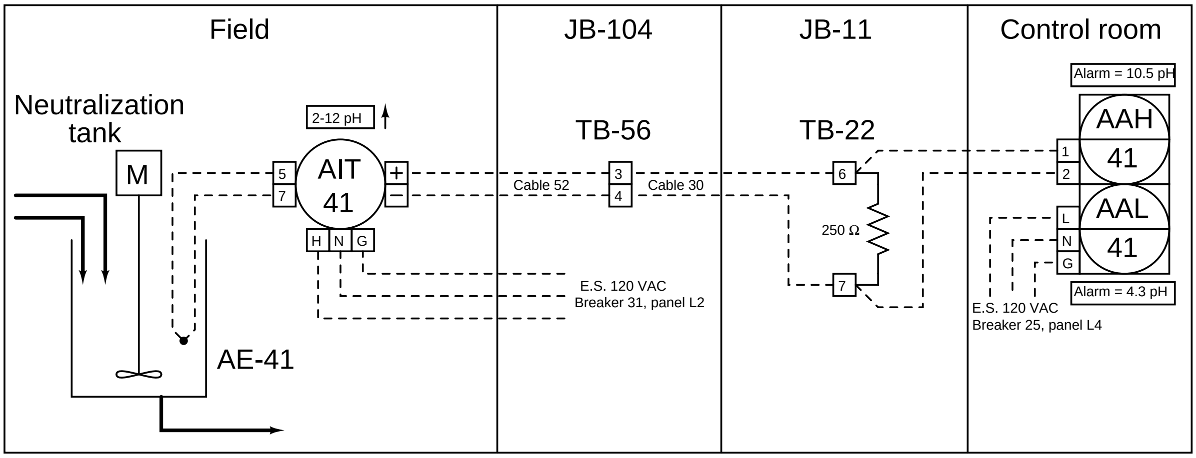
Suggestions for Socratic discussion

- Explain why communicating variables via Ethernet would be considered an advantage to a single-loop controller such as the Siemens model 353. Why not just communicate all process-related variables via 4-20 mA analog signals over twisted-pair instrument cables?
- Identify any disadvantages to communicating process data between controllers using Ethernet. Can you think of any faults that could really cause control problems in a system using Ethernet to exchange process data between controllers?
- If you had the choice of connecting multiple Ethernet-capable controllers together, would you opt for an Ethernet *switch* or an Ethernet *hub* as the connecting node between controllers? Explain your reasoning.
- Modbus is designed to employ master-slave arbitration. Ethernet is uses CSMA/CD arbitration. How is it possible for Modbus to work over an Ethernet connection if the two arbitration protocols are different?

file i00716

Question 52

This pH monitoring system triggers an alarm if the pH value of the process water in the neutralization tank drifts past either of two threshold (trip) values:



Answer the following questions about this pH alarm system:

- If a wire breaks loose at TB56-4, creating an "open" fault in the loop circuit, determine what will happen at the alarm unit (AAH, AAL-41) and also where you would expect to measure voltage in the loop circuit and where you would expect to measure *no* voltage in the loop circuit.

- If breaker #25 in panel L4 suddenly trips, what will happen in this system? Will an operator still be able to read the pH value of the water in the neutralization tank?

- If a fire breaks out near the conduit through which cable 52 runs, causing the plastic insulation around the conductors of cable 52 to melt and consequently causing those conductors to *short* together, what will happen in this system? Where would you expect to measure voltage in the loop circuit, and where would you expect to measure *no* voltage in the loop circuit? Where would you expect to measure current in the loop circuit, and where would you expect to measure *no* current in the loop circuit?

- Calculate the loop current value when the pH measures 6.8 inside the neutralization tank.

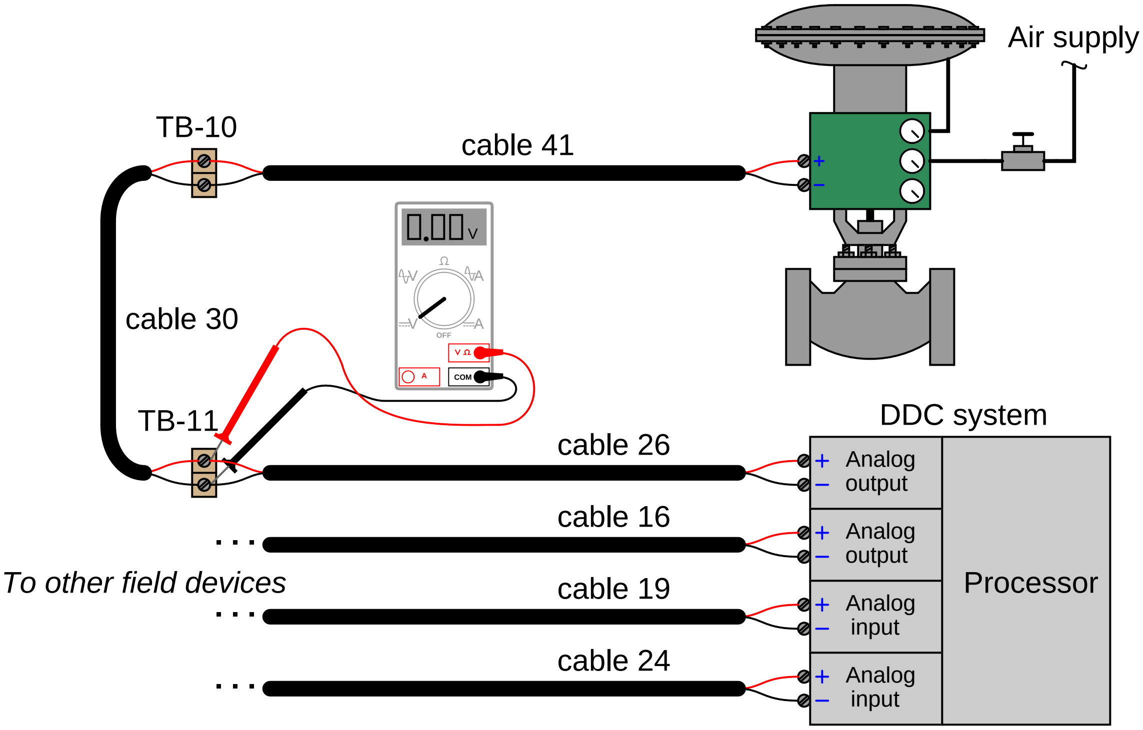
Suggestions for Socratic discussion

- For those who have studied pH measurement, explain why pH "neutralization" is an important control process in industry.
- How can we tell from this diagram whether the 4-20 mA output of transmitter AIT-41 is *active* or *passive* (i.e. *sourcing* or *sinking*)?

file i00239

Question 53

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



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

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

Suggestions for Socratic discussion

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

file i00792

Question 54

Question 55

Question 56

Question 57

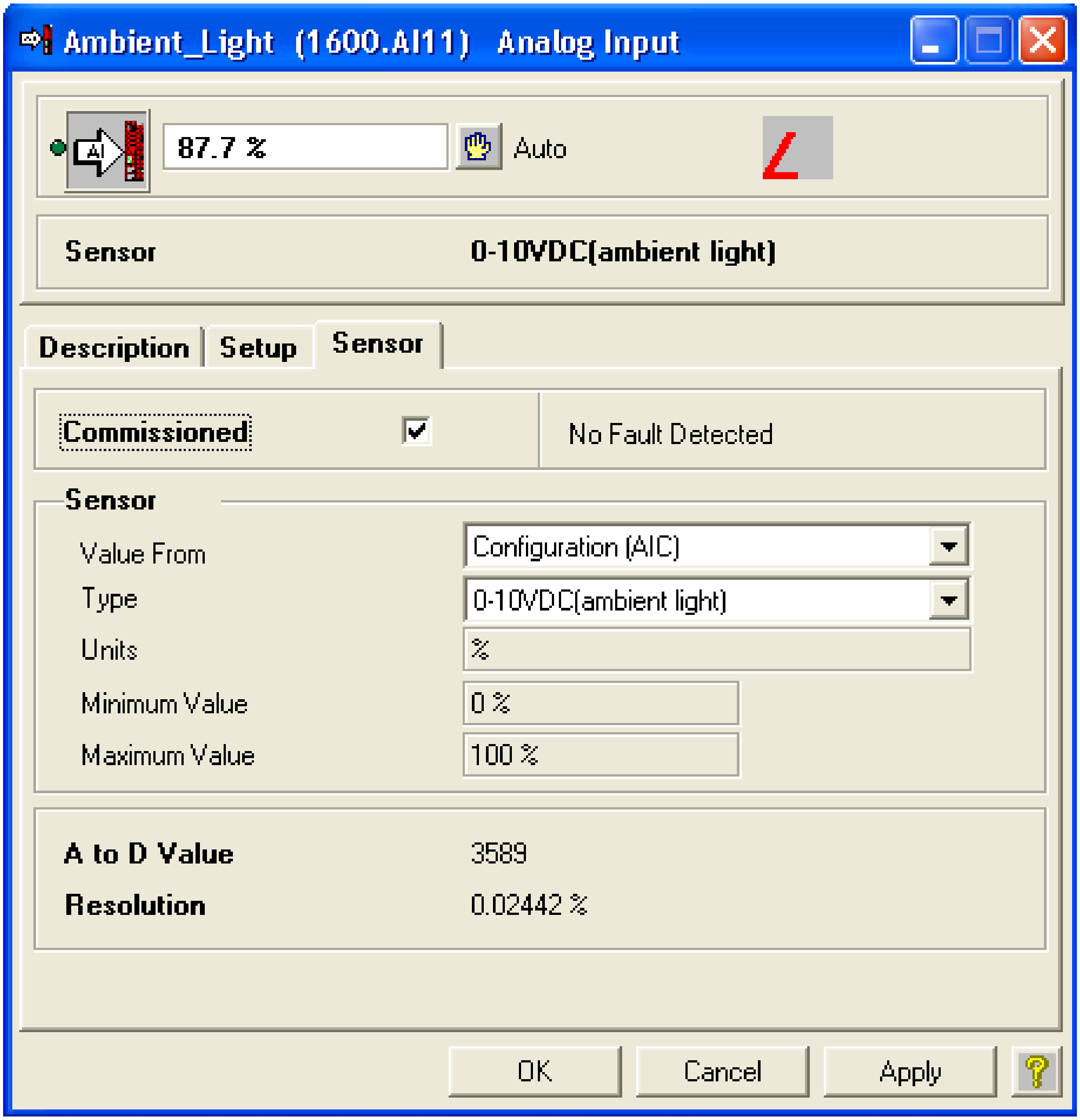
Question 58

Question 59

Question 60

Question 61

The following screenshot shows the configuration window for an analog input on a Delta DSC-1280 DDC building automation controller:

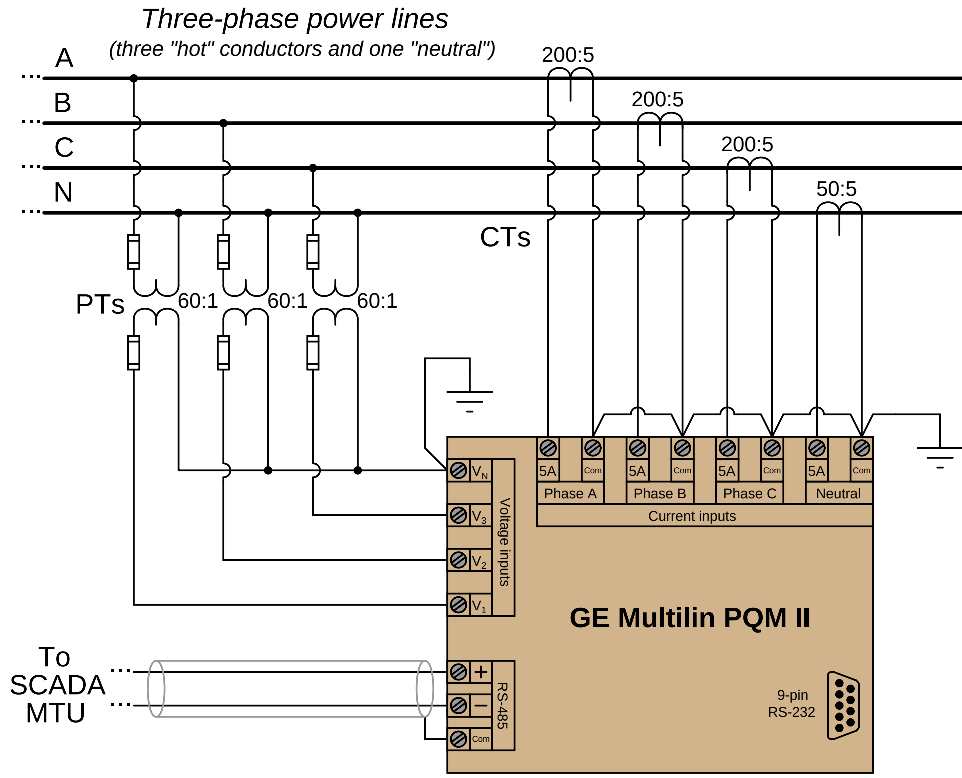


Based on the parameters you see in this configuration window, how many bits does the analog-digital converter inside the DDC controller use?

file i00484

Question 62

An example of a SCADA component in an electric power system is the General Electric model PQM II power quality monitor. This panel-mounted instrument inputs voltage and current signals from the power lines through instrument transformers (voltage and current step-down transformers), computing power factor, true power (P), reactive power (Q), apparent power (S), frequency, and imbalances of voltage or current between the different phases. This device also has the ability to record and trend power system values over time. A diagram showing the connections between a PQM II and the power lines is shown here:



Explain why *instrument transformers* (PTs and CTs with voltage step-down and current step-down ratios) are used to connect the PQM to the power system conductors.

Assuming a phase-to-neutral voltage on "B" phase of 7155 volts AC, calculate the voltage seen between the PQM instrument's V_2 and V_N terminals.

Assuming a current of 148 amps AC through the "C" phase conductor of the power lines, calculate the current seen at the PQM instrument's Phase C "5A" terminal.

Suppose you wished to connect a personal computer with a 9-pin serial port to the 9-pin serial port of the PQM. Which terminals of each 9-pin serial port would you need to connect together, at minimum, to enable communication between the PQM and the PC? Note: a personal computer is considered a DTE device, while the PQM is considered a DCE device!

Suggestions for Socratic discussion

- An important safety consideration when working with current transformers (CTs) is to *never* open-circuit the secondary winding of an energized CT. Explain why.

- An important safety consideration when working with current transformers (CTs) is to *never* short-circuit the secondary winding of an energized PT. Explain why.
- For those who have studied three-phase power circuits, calculate the line voltage of this system based on the 7155 VAC phase voltage presented above.
- Are the PT primary windings connected together in a Wye or a Delta configuration?
- Are the PT secondary windings connected together in a Wye or a Delta configuration?

file i02030

Question 63

Read selected portions of the National Transportation Safety Board's safety study, *Supervisory Control and Data Acquisition (SCADA) in Liquid Pipelines* (Document NTSB/SS-05/02 ; PB2005-917005), and answer the following questions:

Question #22 of the Safety Study in Appendix E lists the major features provided by pipeline SCADA systems. Identify the most common features of these SCADA systems. Question #38 lists the number of data points handled by each respondent's SCADA system. Just how data-rich are some of these systems?

Question #42 of the Safety Study in Appendix E lists the various communication media used by SCADA systems to relay data between RTU and MTU points. Explain what each of these terms refers to. How many SCADA systems do not use redundant (backup) communication channels between RTU and MTU locations (hint: see question #43)?

Questions #19 and #21 of the Safety Study in Appendix E list the rationale given by respondents as to why they are considering an upgrade (or are currently implementing an upgrade) for their SCADA system. What are some of the reasons given? Do any of them surprise you?

The "SCADA Screens and Graphics" section of chapter 4 showcases several examples of graphic displays in use in liquid pipeline control systems. How much blank space should there be on any one screen in order to avoid "clutter"? How should color schemes be chosen to maximize effectiveness?

The Safety Study results shown in Appendix E list a number of different manufacturers ("vendors") for SCADA systems used in pipeline control (see question #15). Based on the vendor names and number of installations, what is your impression of pipeline SCADA systems in the United States: is there much standardization, or is there a wide diversity of system types in use? Is there a clear leader among the manufacturers represented in the survey?

Suggestions for Socratic discussion

- An interesting section of this report to read is the one entitled "Alarm Philosophy". In this section, the report describes how alarm conditions are reported to human operators by the SCADA system, and some of the challenges associated with the management of this information. Read this section and discuss your findings with classmates!
- Another interesting section of this report to read is the one entitled "Training and Selection", in which the report describes how pipeline operators are trained for their jobs. It is interesting to compare the different methods and modalities of operator training. Read this section and discuss your findings with classmates!
- There is a typographical error in the caption of Figure 4.10 – can you identify it?

file i00277

Question 64

Read and outline the "Introduction to Pseudocode" subsection of the "Digital PID Algorithms" 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.

Feel free to skip past the portions of this subsection discussing *branching* and *functions*.
file i02920

Question 65

Examine this page of program code from a Siemens APOGEE system used for building controls within a scientific laboratory (written in Siemens' "PPCL" programming language), then answer the following questions:

```
02530 C
02540 C IF THE ROOM TEMP IS LESS THAN HEATING SETPOINT THAN TURN ON THE HEATING PUMP
02550 C ELSE SHUT OFF HEATING PUMP
02560 C
02570 IF ("LAB.2E:ROOM TEMP" .LT. "LAB.2E.HTG.STPT") THEN ON ("LAB.2E:DO 2")
02580 IF ("LAB.2E:ROOM TEMP" .GT. "LAB.2E.HTG.STPT"+1) THEN OFF ("LAB.2E:DO 2")
02590 C
02600 C *****ROOM 3E CONTROLS*****
02610 C
02620 C IF SOMEONE PUSHES THE OVERIDE BUTTON, THEN TURN ON THE EXHAUST FAN
02630 C OVERRIDE FOR 2 HOURS
02640 C
02650 IF ("LAB.3E:DI OVRD SW" .EQ. ON) THEN SET (0,"LAB.3E.OT")
02660 IF ("LAB.3E.OT" .GT. 1000) THEN SET (1000, "LAB.3E.OT")
02670 IF ("LAB.3E.OT" .LT. 120) THEN ON ("LAB.3E.OVRD") ELSE OFF ("LAB.3E.OVRD")
```

What is the significance of the letter `C` preceding many of the lines of code in this program?

Identify the meanings of the following "operators" in Siemens PPCL code: `.LT.`, `.GT.`, `.EQ.`.

Explain how the "heating pump" code functions (lines 2570 and 2580) to turn the pump on and off.

Explain how the "exhaust fan override" code functions (lines 2650 and 2670) to turn the fan on for two hours. Specifically, where does the code tell the Siemens controller to invoke a *two-hour* time delay?

Line 6000 of this program (not shown on this page) instructs the controller to `GOTO 00190`, with 00190 being a line near the beginning of the program (also not shown on this page). In fact, this is the only "GOTO" instruction in the entire program. Why do you think this "GOTO" instruction exists?

Suggestions for Socratic discussion

- Modify this PPCL code to increase the amount of differential gap between the LSP and USP values.
- Do you think it would be easier or more difficult to program custom control algorithms in a text-based language like PPCL or in a graphic-based language such as function blocks?
- Suppose operations personnel asked you to change the override timer from 2 hours to 3 hours. Explain how you could modify the PPCL code to do this.
- Suppose the pump's function were physically altered from heating to cooling (i.e. turning the pump on caused coolant to enter the heat exchanger, thus lowering the room's temperature). How would you modify the PPCL code to be compatible with this new pump functionality?
- Identify the benefit(s) of adequately *commenting* a program such as this.

file i00671

Question 66

Examine this page of program code from a Siemens APOGEE system used for building controls in a workshop (written in Siemens' "PPCL" programming language), then answer the following questions:

```
04600 C *****SWAMP COOLER CONTROL*****
04610 C
04620 C IF ANY WEST ROOM IS GREATER THAN 2 DEG ABOVE ITS SETPOINT, THEN TURN ON
04630 C THE SWAMP COOLER, ELSE SHUT OFF SWAMP COOLER
04640 C
04650 IF ("SHOP.1W:ROOM TEMP" .GT. "SHOP.1W.CLG.STPT" + 2) THEN ON ("SHOP.1W.CLG")
04652 IF ("SHOP.1W:ROOM TEMP" .LE. "SHOP.1W.CLG.STPT") THEN OFF ("SHOP.1W.CLG")
04660 IF ("SHOP.2W:ROOM TEMP" .GT. "SHOP.2W.CLG.STPT" + 2) THEN ON ("SHOP.2W.CLG")
04662 IF ("SHOP.2W:ROOM TEMP" .LE. "SHOP.2W.CLG.STPT") THEN OFF ("SHOP.2W.CLG")
04670 IF ("SHOP.3W:ROOM TEMP" .GT. "SHOP.3W.CLG.STPT" + 2) THEN ON ("SHOP.3W.CLG")
04672 IF ("SHOP.3W:ROOM TEMP" .LE. "SHOP.3W.CLG.STPT") THEN OFF ("SHOP.3W.CLG")
04680 C
04690 IF ("SHOP.1W.CLG".OR."SHOP.2W.CLG".OR."SHOP.3W.CLG") THEN ON ("SHOP.3W:DO 6")
      ELSE OFF ("SHOP.3W:DO 6")
```

What is the significance of the letter `C` preceding many of the lines of code in this program, particularly the signficance of lines 04610, 04640, and 04680?

Identify the meanings of the following "operators" in Siemens PPCL code: `.LE.` and `.GT.`

Explain how lines 04650 through 04690 control the "swamp cooler".

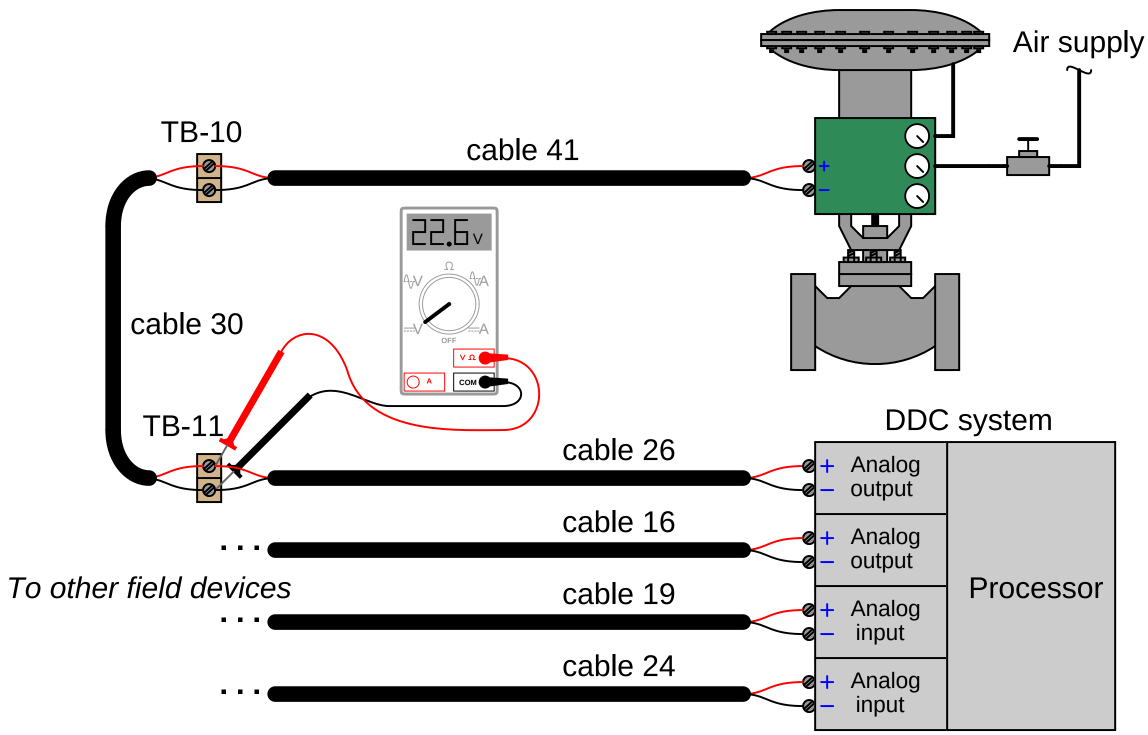
Suggestions for Socratic discussion

- Modify this PPCL code to completely ignore the temperature of room 2W.
- Modify this PPCL code to increase the amount of differential gap between the LSP and USP values.
- Do you think it would be easier or more difficult to program custom control algorithms in a text-based language like PPCL or in a graphic-based language such as function blocks?
- Is this program an example of *differential gap* ("on/off") control or *proportional* control?
- Identify any "adjustments" that may be made in the program to alter its quality of control (i.e. how tightly it regulates room temperature to setpoint).

file i00709

Question 67

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



The technician knows a reading of 22.6 volts indicates an "open" fault because the electronic positioner on the valve is known to have an input resistance of less than 200 ohms. Based on the location of the measured voltage, determine where in the wiring a single "open" fault could be located.

For the next diagnostic test, the technician momentarily connects a jumper wire between the screws of TB-10 while continuing to measure voltage at TB-11. The new voltage measurement at TB-11 (with the jumper installed) reads 0.0 volts. Determine what this result tells us about the nature and location of the fault.

Explain whether or not there is any danger of introducing a short-circuit into a system like this. Could a fuse be blown by doing this test?

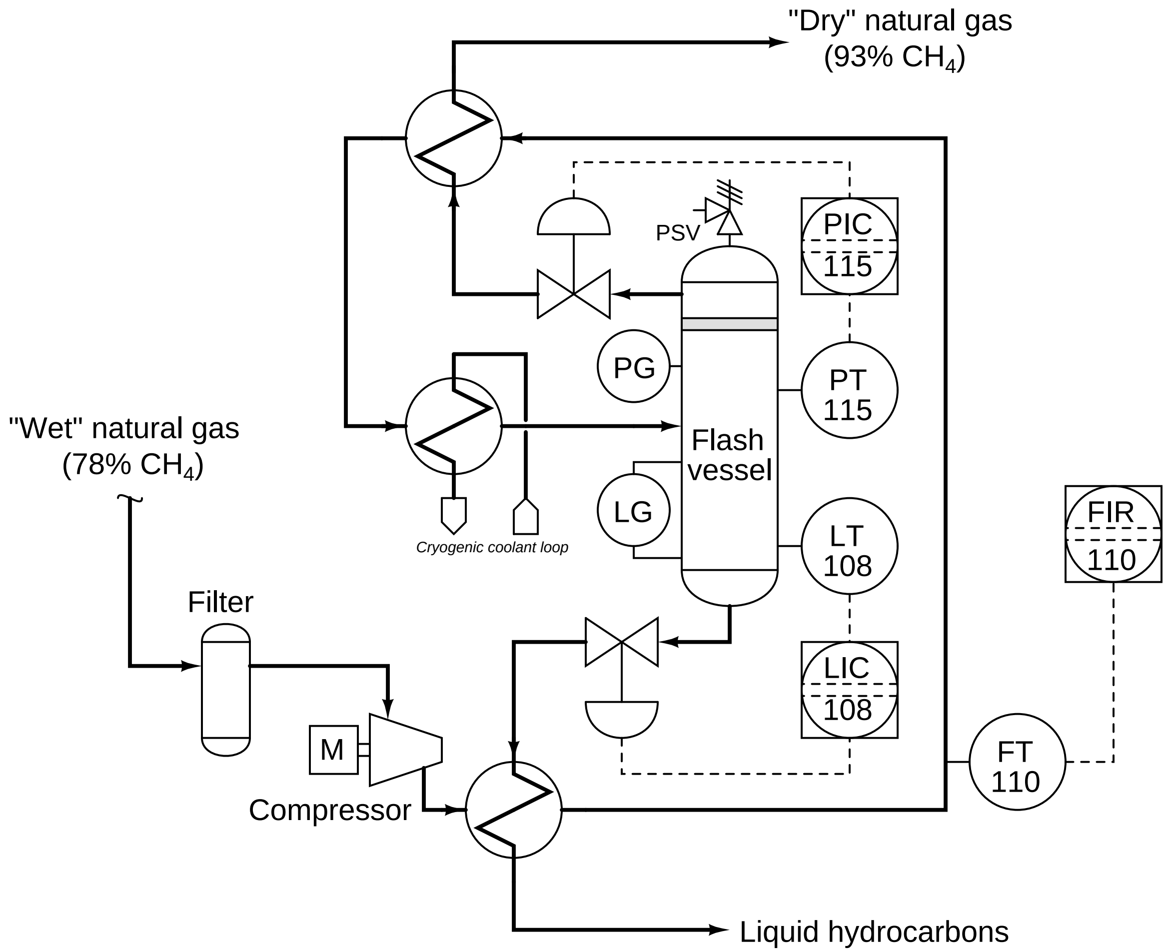
Suggestions for Socratic discussion

- Explain why it is critically important to determine the identities of the valve and DDC card as being either electrical *sources* or electrical *loads* when interpreting the diagnostic voltage measurements.
- Identify some of the pros and cons of this style of testing (measuring voltage at a set of points before and after a purposeful wiring short) compared to other forms of multimeter testing when looking for either an "open" wiring fault.
- Describe a good "next test" to perform on this system to further diagnose the location and nature of the fault.

file i00717

Question 68

"Wet" natural gas is mostly methane (CH_4) mixed with significant amounts of heavier hydrocarbon species such as ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), and pentane (C_5H_{12}). A process for separating these heavier hydrocarbons from the chief component (methane) using compression and cooling is shown here:



Chilled gases enter the flash vessel, where methane rises and escapes in gaseous form, while all the other (heavier) hydrocarbon molecules condense into liquid and exit out the bottom.

Suppose PT-115 is mis-calibrated, such that it falsely indicates a pressure lower than what is actually inside the flash vessel. How will this mis-calibration affect the control of flash vessel pressure? Will the operator be able to know anything is wrong by observing the DCS monitor screens for this process?

Suggestions for Socratic discussion

- Explain the purpose of the heat exchangers in this P&ID, especially the two exchanging heat between the incoming (compressed) gas and the products coming off the top and bottom of the flash vessel.
- Identify and explain the purpose of the "PSV" valve in this diagram.
- Assuming air-to-open control valves, identify the correct actions for each loop controller (direct or reverse).

- Identify the effect(s) of LV-108 failing shut.
- Identify the effect(s) of PV-115 failing shut.

file i03084

Question 69

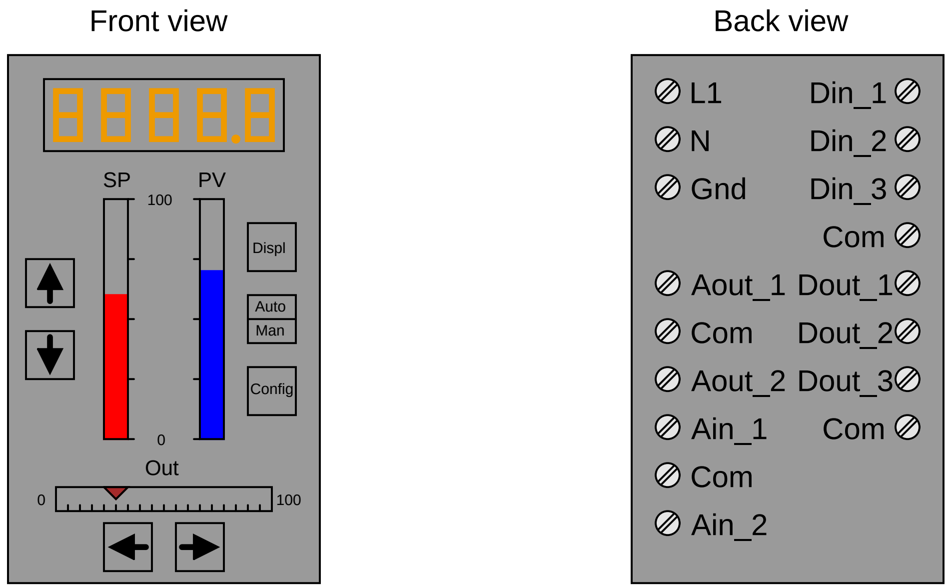
Read Exercise 8 ("Creating a Sequential Function Chart") in Chapter 4 ("Creating and Downloading the Control Strategy") of the "Getting Started with your DeltaV Digital Automation System" manual (document D800002X122, March 2006) and answer the following questions:

Describe what a SFC program does, explaining how an SFC could be used to help automate some real-life process.

file i00815

Question 70

Digital single-loop process controllers are stand-alone units: they require no auxiliary hardware to perform their function. As such, they are equipped with analog-to-digital converters (ADC) and digital-to-analog converters (DAC) to interface directly with instruments via the traditional 4-20 mA standard. Many single-loop controllers also have discrete (on/off) inputs and outputs for interfacing with process switches and alarm circuits. Shown here is a typical example of a single-loop controller, front and back:



Distributed control systems (DCS) are quite different. These systems are designed to control *hundreds* or even *thousands* of loops. As such, they are made in a modular fashion so the users can add whatever types of input and output (I/O) capability they need.

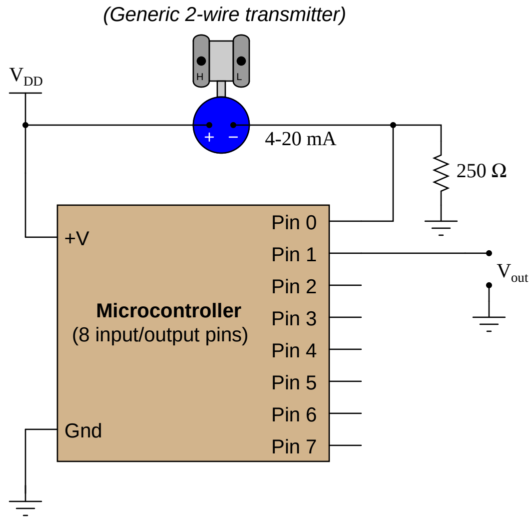
Identify the purpose of each type of I/O module listed here, as it might be applied in a DCS. What I'm looking for here is an educated guess from you, as it may be quite a challenge to actually research these specific I/O types for different distributed control systems:

- AI 1-5 VDC
- AI 4-20 mADC
- AI 4-20 mADC w/ HART
- AO 4-20 mA
- AO w/ HART
- DI 24VDC dry contact
- DI 24VDC isolated
- DI 120VAC isolated
- DO 24VDC high side

file i02426

Question 71

Examine this microcontroller circuit and program, designed to act as a general-purpose proportional controller:



Pseudocode listing

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

LOOP
  SET ERROR = Pin0 - SP
  SET Pin1 = (GAIN * ERROR) + BIAS
ENDLOOP
```

Is this controller *direct* or *reverse* acting? What edit(s) to the program listing would be required to change the direction of the controller's action?

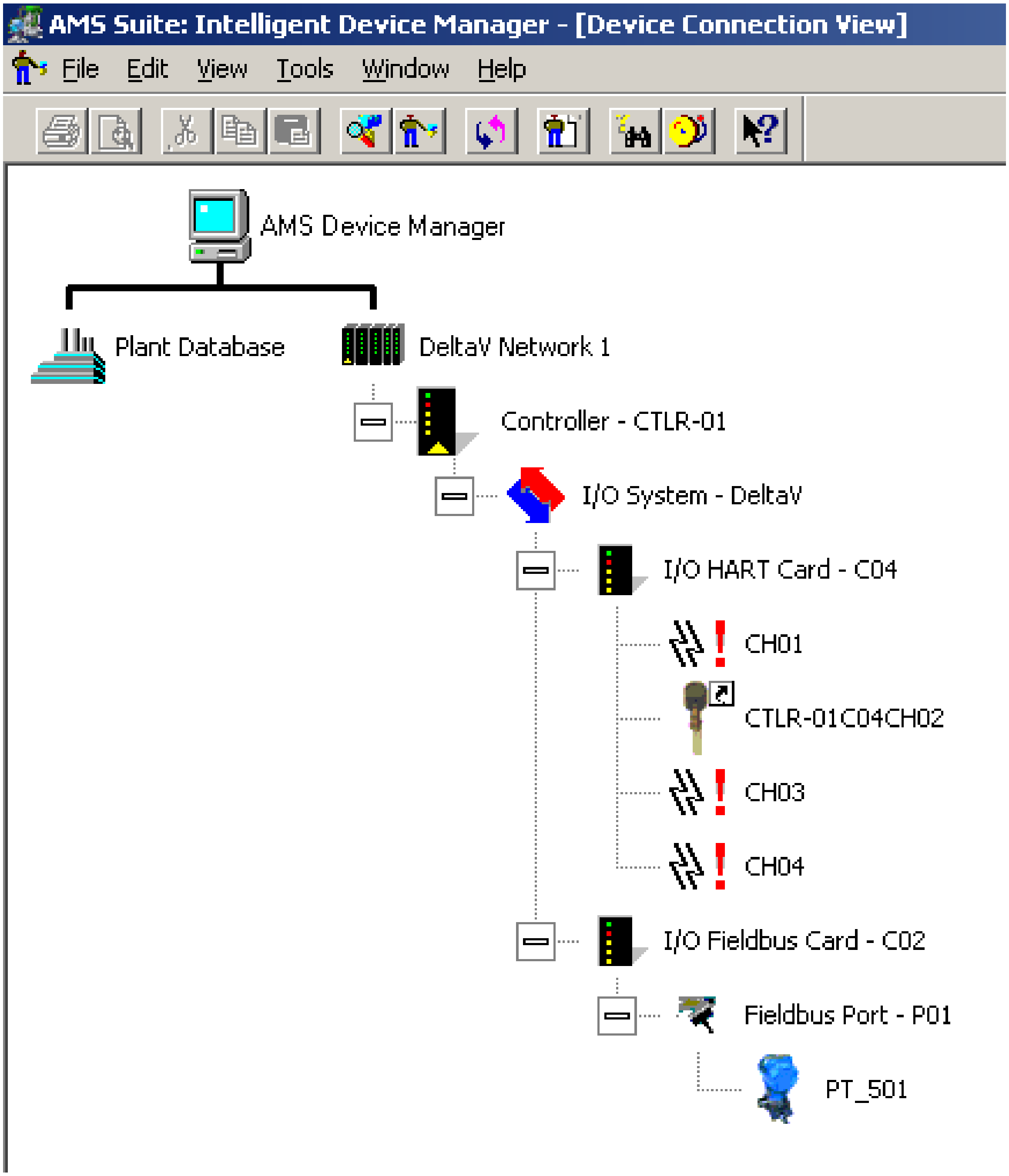
Suggestions for Socratic discussion

- Which sections of the pseudocode program listing are executed repeatedly, and which sections are executed only once?
- How many bits of resolution does this microcontroller have for the analog input on pin #1, assuming that 0 to 1023 is the full range of the converter?
- Does the speed of program execution (i.e. how fast the loop repeats itself) affect the controller's ability to control a process?
- Could all the "Declare" instructions be placed within the loop of this program? Why or why not?
- Explain what would happen if you deleted the `LOOP` and `ENDLOOP` statements in the microcontroller program.
- Modify this program to include a PV alarm, turning on an LED alarm lamp if the PV exceeds a certain value, and turning it back off when the PV drops below another value.

file i01486

Question 72

Many modern distributed control systems (DCS) also host software to allow communication with HART-enabled instruments. One example of such software is Emerson's *AMS*:



What does this particular screenshot reveal about the HART-enabled instruments connected to this Emerson DeltaV DCS? What advantages do you think might be realized by having the DCS be able to digitally communicate with field instruments? What disadvantages can you see to this method of HART interface, as opposed to a hand-held HART communicator?

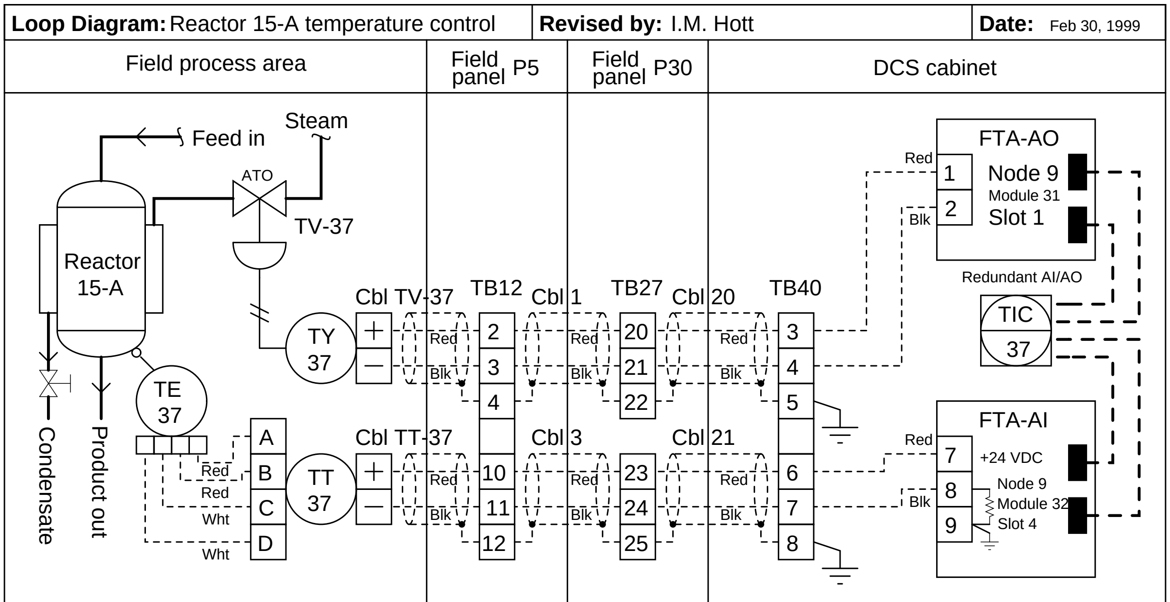
Suggestions for Socratic discussion

- With the DCS enabled to "talk" HART with field instruments, one cannot also use a handheld HART communicator to "talk" with the same field instruments. Explain why.

  file i00665

Question 73

Identify the effects of the faults listed (considered one at a time) in this temperature control system:



Tag number	Description	Manufacturer	Model	Calibration	Notes
TE-37	4-wire platinum RTD	Chromalox		100 Ω , α = 0.00392	
TT-37	Smart temp. transmitter	Rosemount		100-250^{o} F , 4-20 mA	Direct action
TIC-37	DCS controller	Honeywell	PM		Reverse action
TY-37	I/P transducer	Fisher	546	4-20 mA , 3-15 PSI	Direct action
TV-37	Steam control valve	Fisher	Easy-E	3-15 PSI	Air-to-open

- FTA-AI module resistor fails shorted
- FTA-AI module resistor fails open
- Ground wire falls off terminal TB40-8
- Condensate valve left closed
- Corroded wire connection at TB12-3
- Cable 1 fails open
- Cable 1 fails shorted
- Cable 21 fails open
- Cable 21 fails shorted

Suggestions for Socratic discussion

- A problem-solving technique useful for analyzing circuit faults is to first identify each component's function as either an electrical *source* or an electrical *load*. Discuss and compare how these determinations aid in your analysis of component faults.
- For those who have studied RTD temperature sensors, determine the effect of a short-circuit between terminals B and C on temperature transmitter

file i04019

Question 74

Question 75

Question 76

Question 77

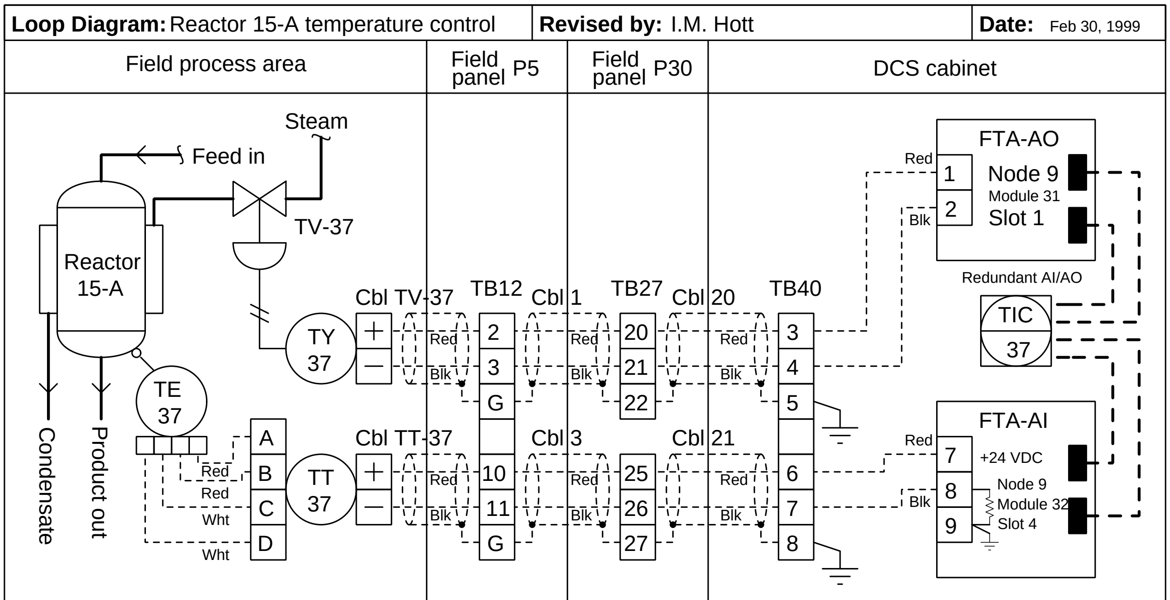
Question 78

Question 79

Question 80

Question 81

Examine this loop diagram for a chemical reactor heating control system, then determine how the system will respond to *any one* of the scenarios listed below (you choose). Your answer should describe four parameters of the control system over time: (1) What happens to the process temperature, (2) What the operator's indication does, (3) Which direction the controller's output changes, and (4) What happens to steam flow through the control valve.



Tag number	Description	Manufacturer	Model	Calibration	Notes
TE-37	4-wire platinum RTD	Chromalox		100 Ω , α = 0.00392	
TT-37	Smart temp. transmitter	Rosemount	3244	100-250^{o} F , 4-20 mA	Direct action
TIC-37	DCS controller	Honeywell	PM		Reverse action
TY-37	I/P transducer	Fisher	546	4-20 mA , 3-15 PSI	Direct action
TV-37	Steam control valve	Fisher	Easy-E	3-15 PSI	Air-to-open

Choose one!

- Broken wire connection at TB12-11
- Short in cable 20
- Resistor fails open in analog input field termination (FTA-AI)
- Sudden influx of *cold* fluid into reactor
- Sudden increase in steam supply pressure and temperature

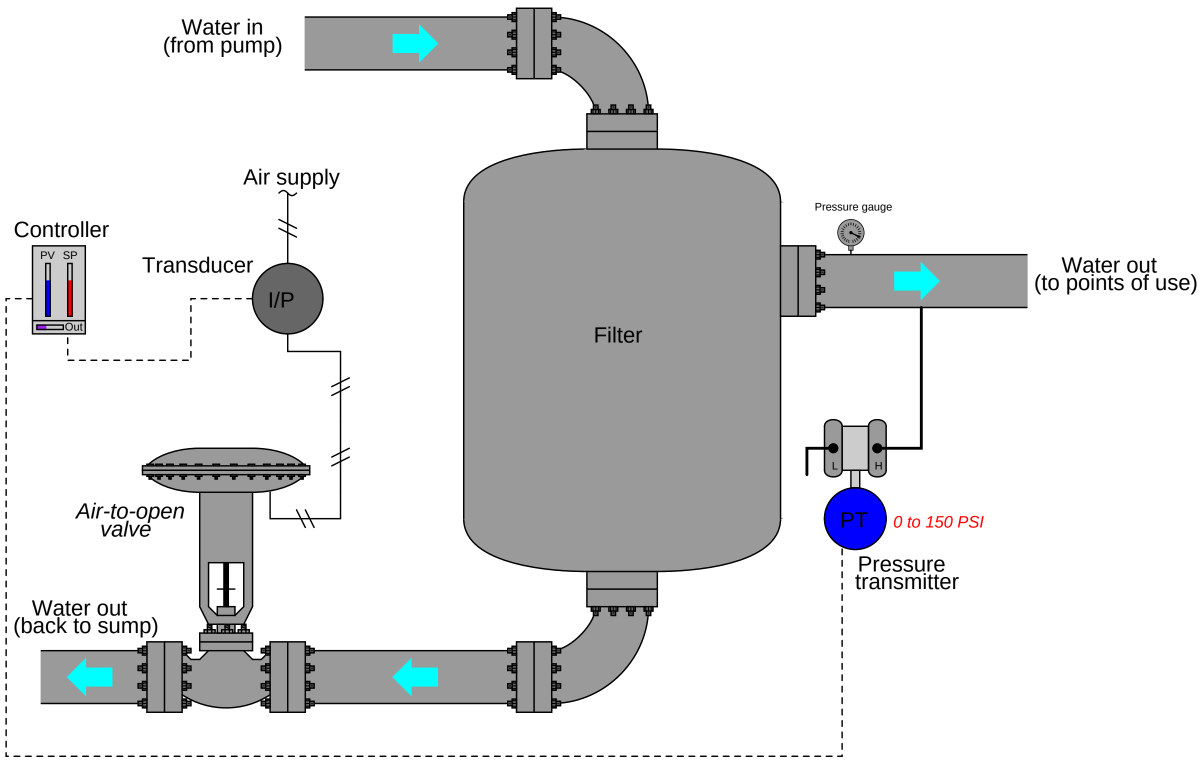
Determine these four system responses:

- Process temperature response over time:
- Operator indication of process temperature over time:
- Controller output over time:
- Steam flow through control valve over time:

  file i02450

Question 82

According to the operator, this pressure-control system is not regulating filter water pressure correctly. The controller faceplate indicates the pressure holding at setpoint (110 PSI), but pressure indicated by a pressure gauge on the outlet pipe of the filter shows substantially less pressure (85 PSI):



Your first test is to measure loop current in the circuit connecting the pressure transmitter to the pressure controller. There, your multimeter registers 15.7 milliamps.

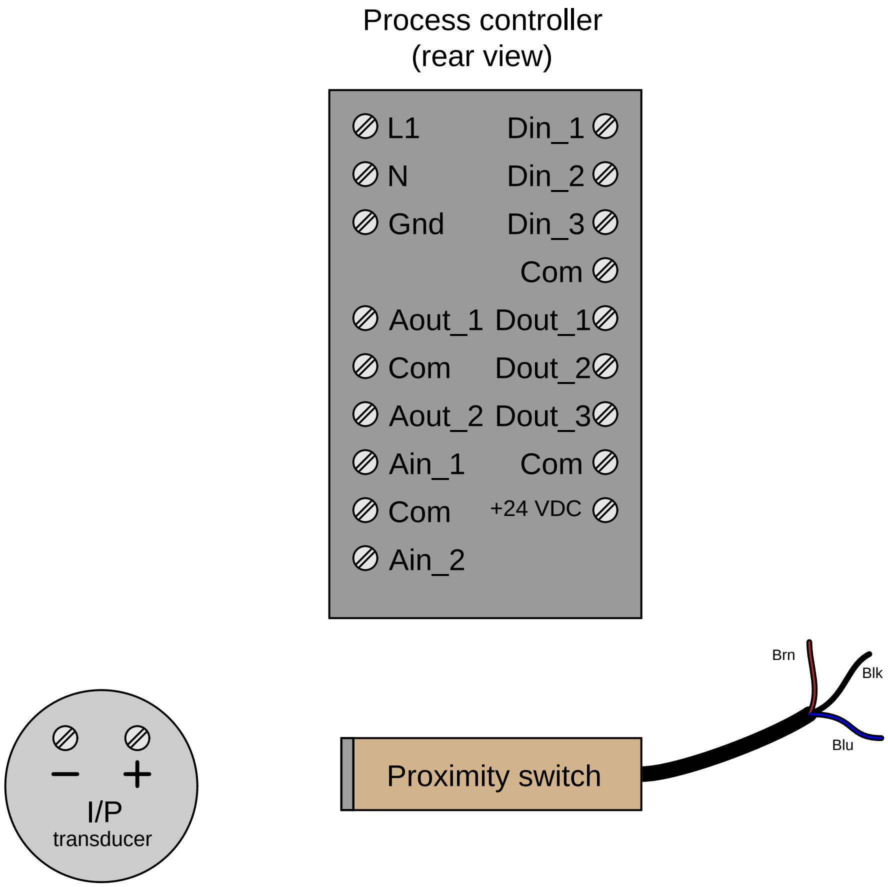
Identify the likelihood of each specified fault for this control system. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this circuit.

Fault	Possible	Impossible
PT out of calibration (outputting wrong current)		
PIC input out of calibration (not interpreting PV signal properly)		
PIC output out of calibration (not sending correct mA signal to I/P)		
Pressure gauge out of calibration (not displaying pressure properly)		
I/P out of calibration (not outputting correct pressure)		
Control valve is oversized		
Control valve is undersized		
PIC is poorly tuned (not making good control "decisions")		
Instrument air supply not at full pressure		

file i03284

Question 83

Sketch the wire connections necessary to interface an electronic (sourcing) proximity switch to (sinking) discrete input channel #2 on the process controller, and also the I/P transducer to analog output #1:



file i02453

Question 84

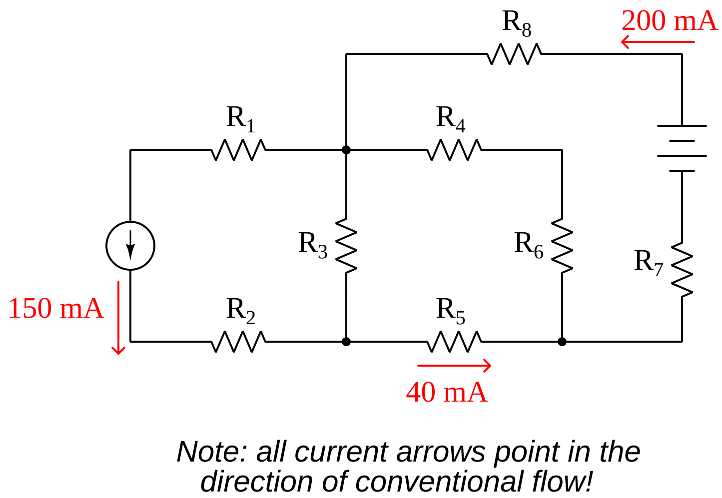
Suppose you have recently installed a pressure transmitter ranged from 40 to 240 PSI, complete with a field-mounted analog loop indicator registering 4 to 20 milliamps. The installation is brand-new, and you have not yet received the custom scale for the analog indicator showing 40 to 240 PSI. Instead, the indicator's face simply reads 4 to 20 milliamps.

For the time being, the operators need a way to translate the "milliamp" number value read on the indicator into a "PSI" number value they can relate to the process. Write simple instructions for calculating PSI from any milliamp value they happen to read off this pressure indicator's face.

file i02452

Question 85

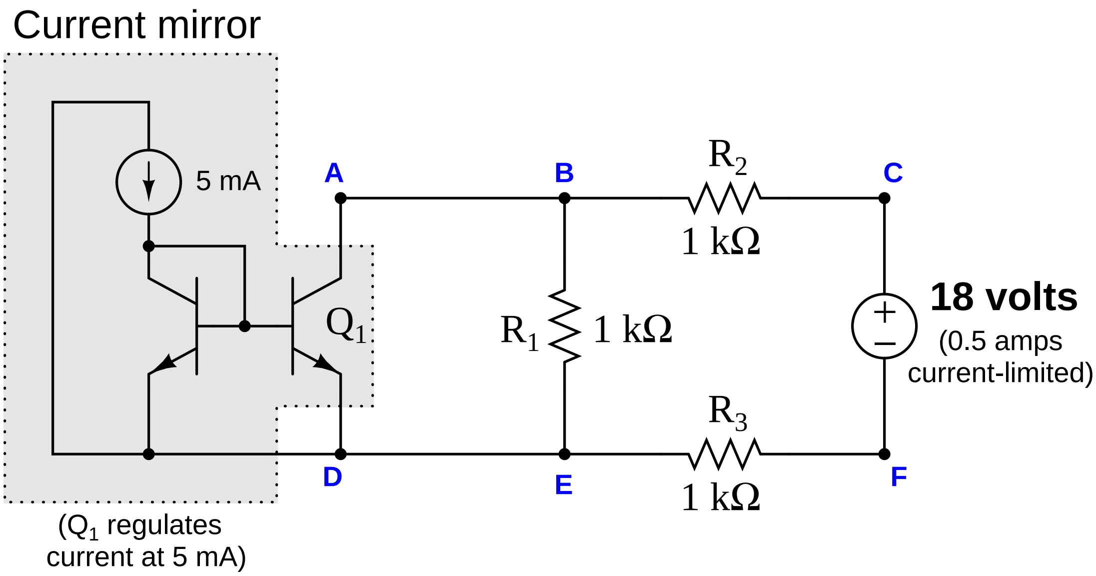
Use Kirchhoff's Current Law to calculate the magnitudes and directions of currents through *all* resistors in this circuit:



file i01162

Question 86

Suppose a voltmeter connected between test points **D** and **F** registers 5 V in this circuit:



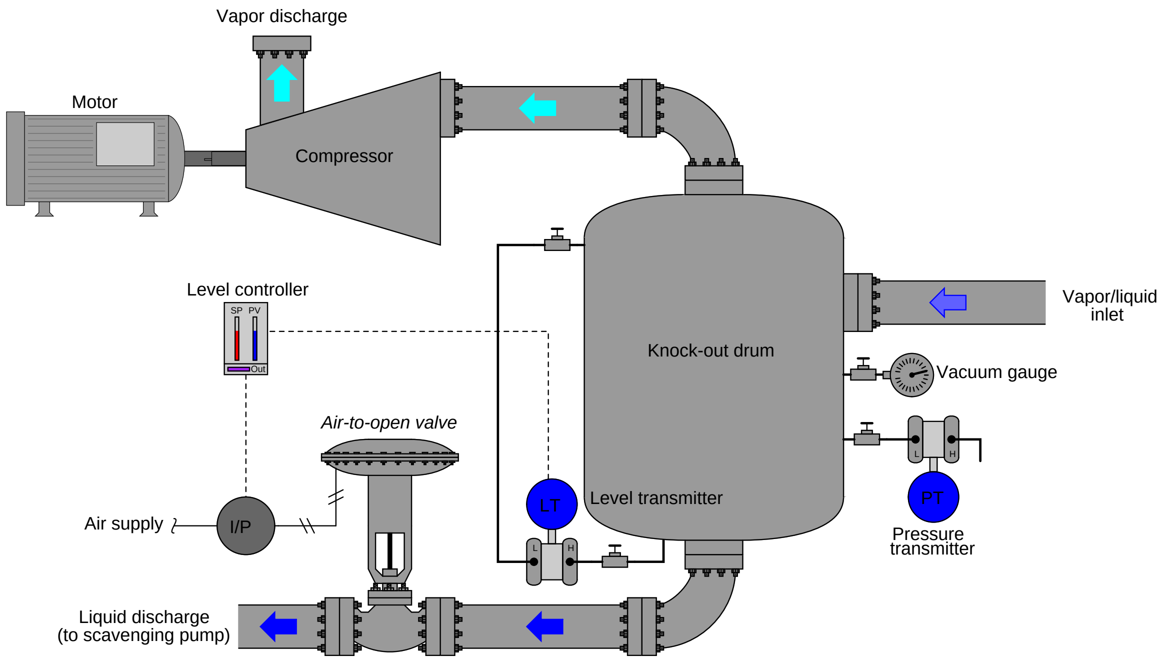
Identify the likelihood of each specified fault for this circuit. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this circuit.

Fault	Possible	Impossible
R_1 failed open		
R_2 failed open		
R_3 failed open		
Q_1 failed open		
R_1 failed shorted		
R_2 failed shorted		
R_3 failed shorted		
Q_1 failed shorted		
Voltage source dead		

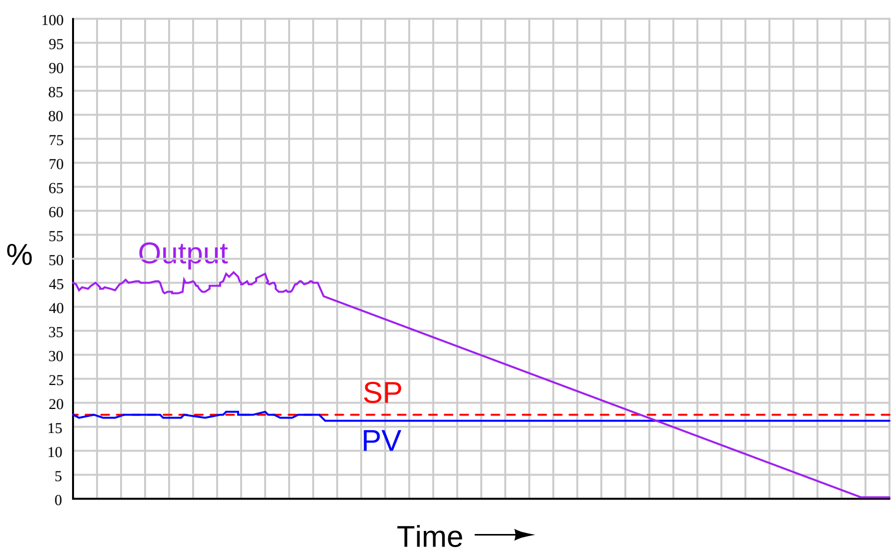
file i03294

Question 87

This level-control system is supposed to maintain a constant liquid level inside the knockout drum, preventing liquid from entering the compressor as well as gas from entering the scavenging pump. Yet, for some reason liquid did manage to enter the compressor, causing the compressor to suffer major damage, and leading to a complete shut-down of the unit:



A trend recording of liquid level and control valve position captured before the explosion holds the only clue as to why this happened. Examine it to see if you can determine the source of the trouble:

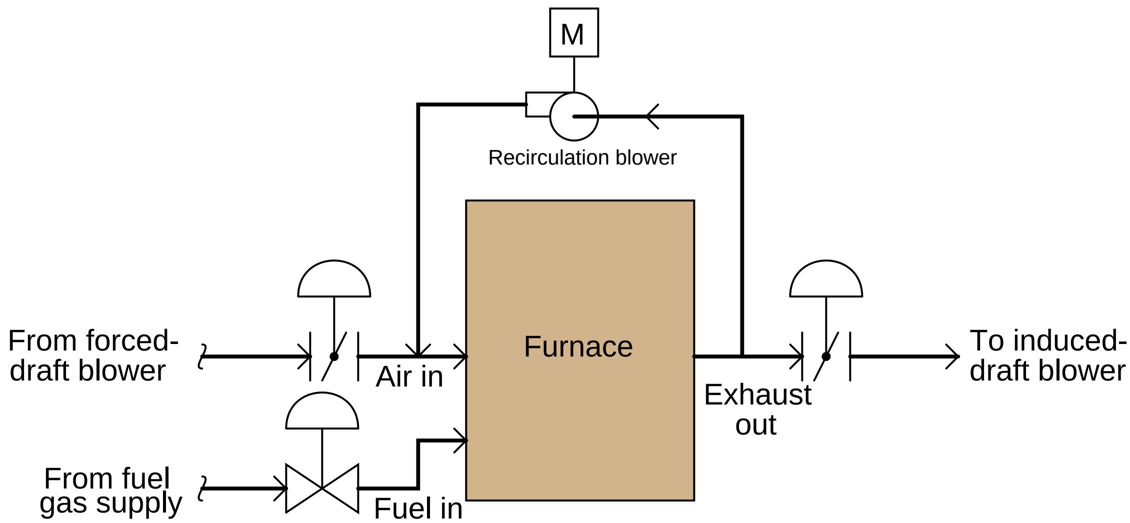


file i02117

Question 88

One of the pollutants generated by high-temperature combustion processes is NO_x: oxides of nitrogen. NO_x forms at high temperatures when nitrogen and oxygen gases in the combustion air combine to form nitrogen-oxygen molecules. These molecules are considered a pollutant because they form nitric acid upon emission to the atmosphere, and they also contribute to the formation of smog.

A common method of mitigating NO_x emissions is to recirculate exhaust gas into the intake of the combustion system. Doing so reduces combustion temperature: a critical variable in the production of NO_x:



The reduction in combustion temperature approximately relates to exhaust gas recirculation by the following formula:

$$X = \frac{T_M - T}{T - T_W}$$

Where,

X = Recirculation fraction (between 0 and 1, unitless)
T_M = Maximum (theoretical) flame temperature
T = Actual flame temperature
T_W = Exhaust gas temperature

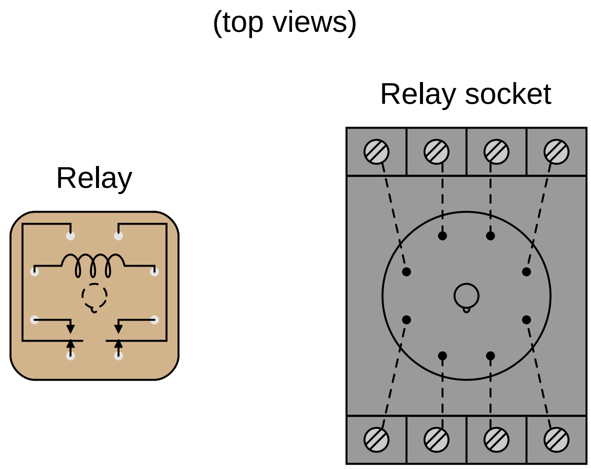
Algebraically manipulate this equation to solve for T, then calculate the actual flame temperature given a maximum theoretical temperature of 3100^o F, an exhaust gas temperature of 480^o F, and a recirculation factor of 22%.

Also, explain why we must have a recirculation *blower* installed at the location shown in the diagram, rather than a simple recirculation *valve*.

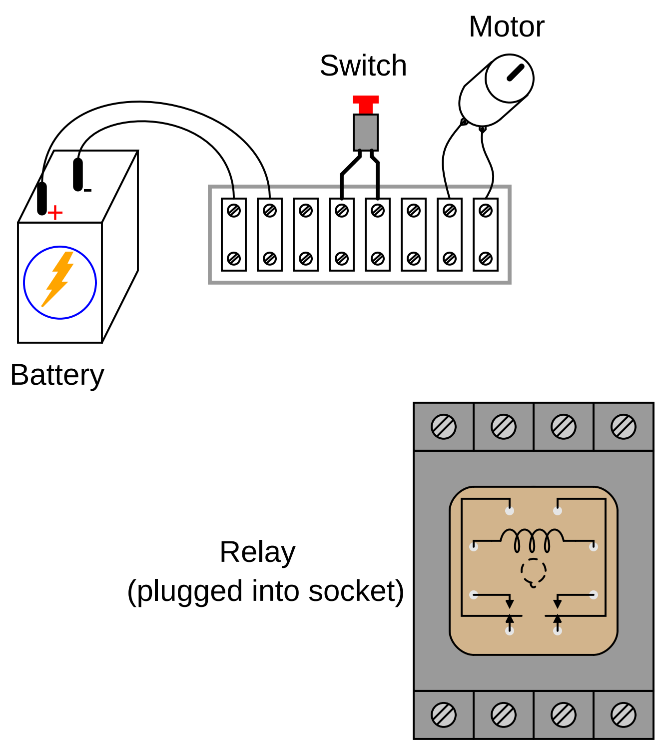
file i01830

Question 89

Small relays often come packaged in clear, rectangular, plastic cases. These so-called "ice cube" relays have either eight or eleven pins protruding from the bottom, allowing them to be plugged into a special socket for connection with wires in a circuit:

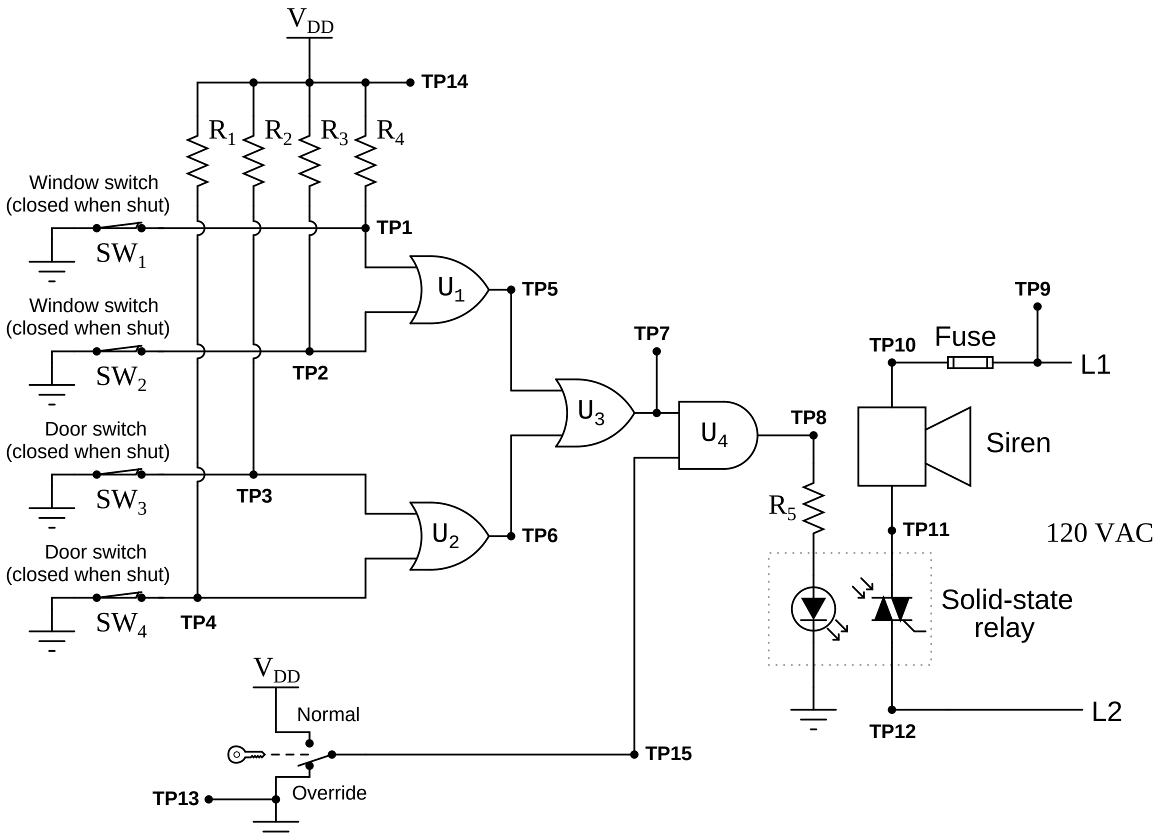


Draw the necessary connecting wires between terminals in this circuit, so that actuating the normally-open pushbutton switch will energize the relay, which will in turn supply electrical power to the motor. The pushbutton switch should not carry any motor current, just enough current to energize the relay coil:



file i03165

Something is wrong with this building alarm system circuit. The alarm siren refuses to energize even when all windows and doors are opened:



Using your logic probe, you measure a high signal at TP1, a high signal at TP15, and a low signal at TP8 with all windows and doors propped open, and with the key switch in the "normal" position. From this information, identify two possible faults (either one of which could account for the problem and all measured values in this circuit). Then, choose one of those possible faults and explain why you think it could be to blame. The circuit elements you identify as possibly faulted 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.

- Explanation of *why* you think one of the above possibilities could be to blame

file i03197

Question 91

Lab Exercise

Your task is to commission, document, and successfully operate a process controlled by a recording PID controller. Several alternative process types exist and are documented in subsequent pages. The working process you commission will be used in future lab exercises this quarter to meet other learning objectives, which means you will *not* disassemble this project at the completion of these lab objectives as you normally would.

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	mastery	–	–	–	–		0
Circuit design challenge	mastery					– – – –	2
Final loop diagram and system inspection	mastery					– – – –	3
Simulated troubleshooting of 4-20 mA circuit	mastery					– – – –	2
Trend graph displays PV and Output	mastery	–	–	–	–		1
PV alarms defined and enabled	mastery	–	–	–	–		1
Process exhibits good control behavior	mastery	–	–	–	–		1
Safety and professionalism	deduction						
Lab percentage score	proportional					– – – –	

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

Sketch a correct circuit for a 4-20 mA instrument "loop" based on random instrument selections by the instructor and reference manuals for each instrument.

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.

Troubleshooting simulation

Logically diagnose the nature and location of a fault simulated by computer in a 4-20 mA transmitter circuit (either loop-powered or externally-powered), using the `TROUBLESHOOT` simulation program. Successful completion of this objective consists of identifying the simulated fault at or below "par" in all measures and logically defending each and every step taken.

Trend graph displays PV and Output

Use the trend graph provided by your controller to show both the process variable and output signals graphed in real time. If your controller does not provide this function, you must connect a data acquisition unit (DAQ) or a digital oscilloscope to the proper circuit points to graph representative voltage signals.

PV alarms defined and enabled

Activate and set process variable high and low values to serve as warnings for anyone operating the control system, alerting them when the PV has drifted too high or too low.

Process exhibits good control behavior

Adjust the P, I, and/or D parameters in your loop's controller to achieve stable automatic-mode control for both varying setpoint values and varying process loads.

Lab Exercise – objectives and expectations (continued)

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.

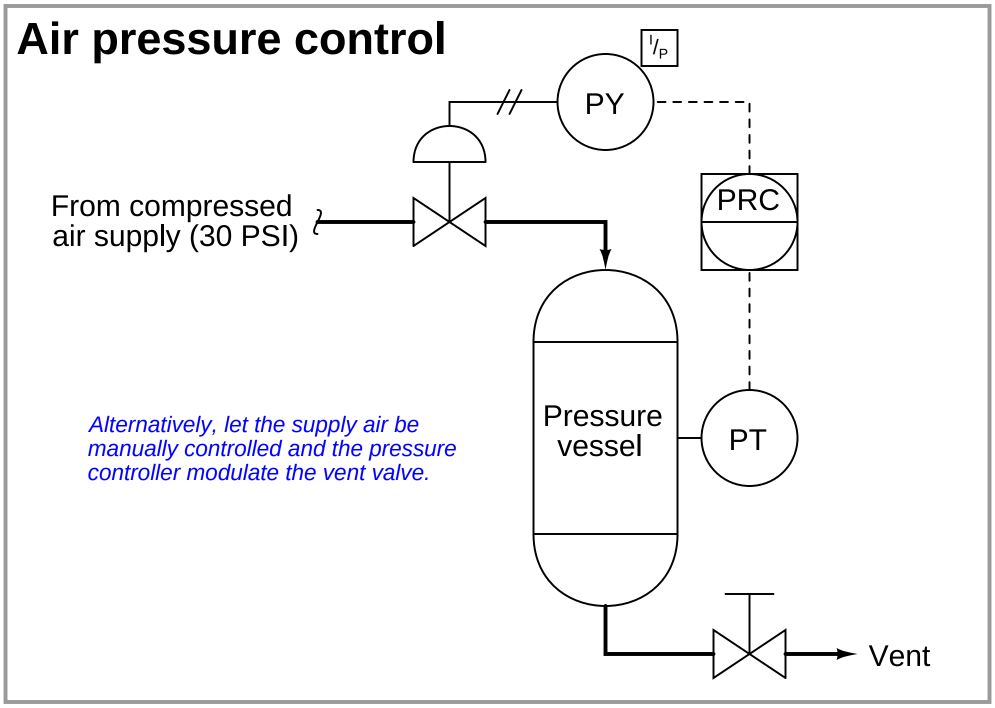
When you require the instructor's assistance to answer a question or to check off an objective, write your name (or your team's name) on the lab room whiteboard. Questions take priority over checkoffs, so please distinguish questions from other requests (e.g. writing a question-mark symbol "?" after 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.

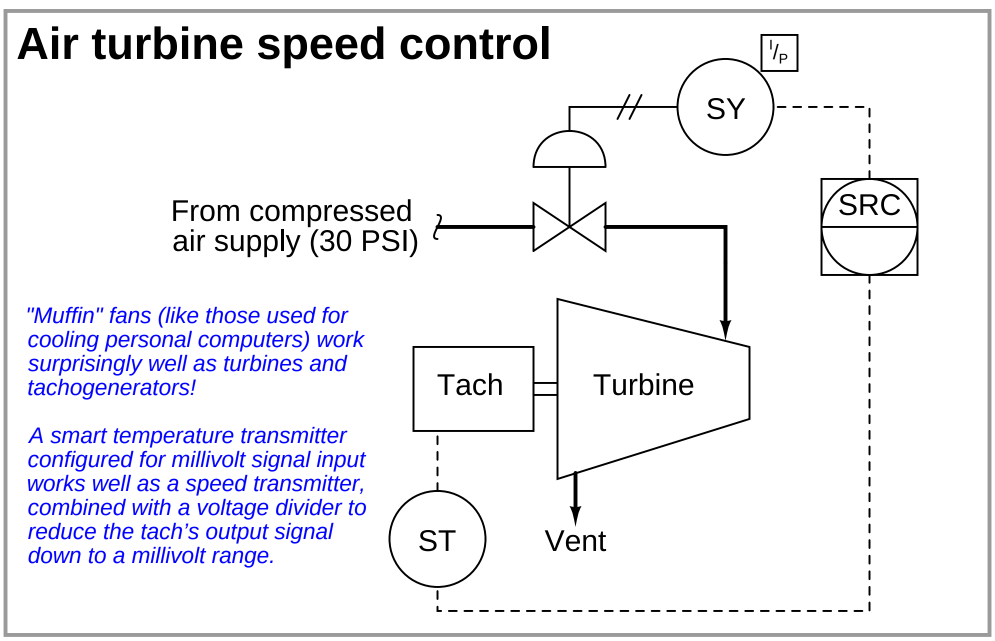
Remember that the lab facility is available to you at all hours of the school day. Students may perform non-hazardous work (e.g. circuit work at less than 30 volts, documentation, low air pressures, general construction not requiring power tools) at *any time during the school day* without the instructor's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

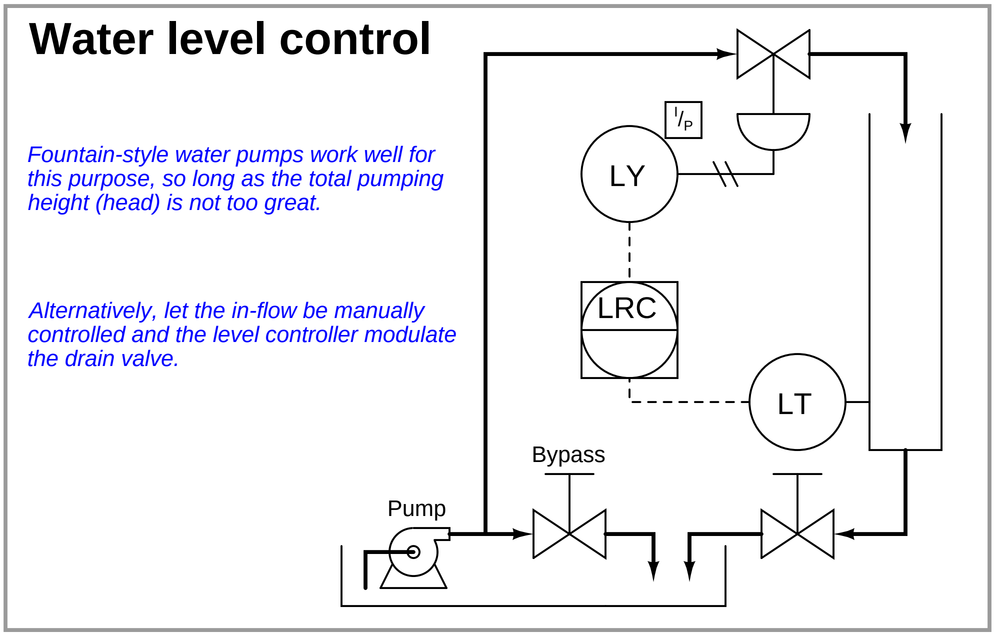
DO NOT TAKE SHORTCUTS when completing tasks! Learning requires focused attention and time on task, which means that most 'shortcuts" actually circumvent the learning process. Read the lab exercise instructions, follow all instructions documented in equipment manuals, and follow all advice given to you 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!

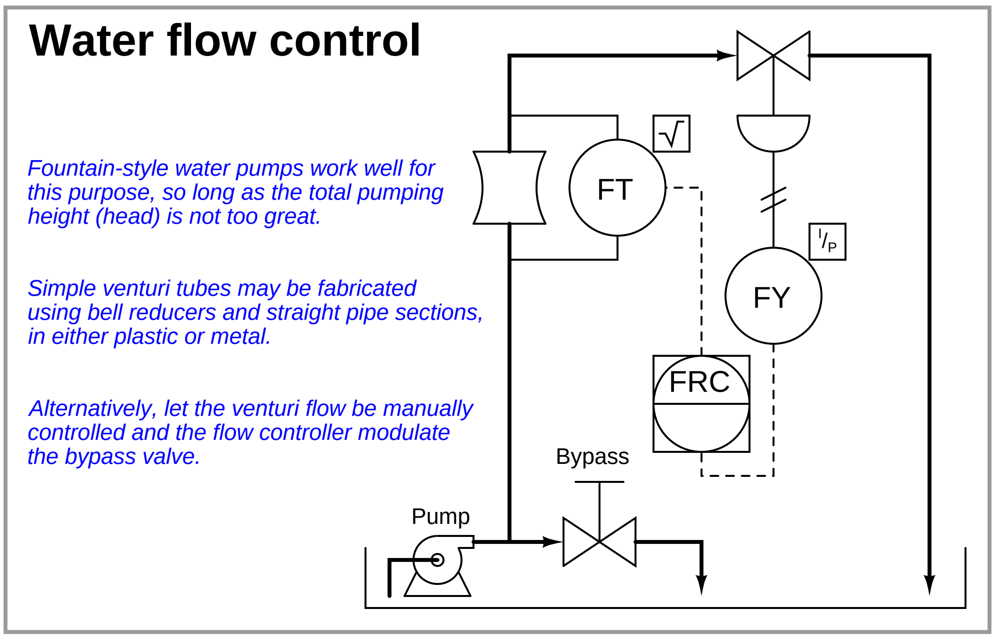
Lab Exercise – choosing a process to commission

There are a number of process types to choose from when selecting the one you will commission with your team. The only non-negotiable limitations is that the process must be safe, legal, and possible to complete in the time allotted for this lab. A number of process units have already been constructed on 2' × 2' plywood boards, but you are welcome to construct your own. Your instructor may assign new process units to be constructed or modified, time permitting. What follows are some examples of physical processes (documented in P&ID form) that work well for the purpose of exploring closed-loop control in the lab:



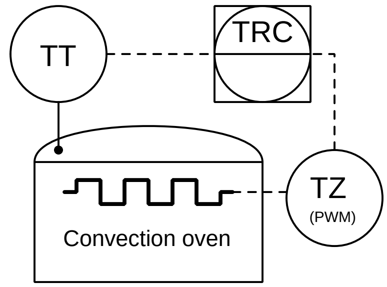



Water level control
Fountain-style water pumps work well for this purpose, so long as the total pumping height (head) is not too great.
Alternatively, let the in-flow be manually controlled and the level controller modulate the drain valve.
I/P
LY
LRC
LT
Bypass
Pump


Water flow control
Fountain-style water pumps work well for this purpose, so long as the total pumping height (head) is not too great.
Simple venturi tubes may be fabricated using bell reducers and straight pipe sections, in either plastic or metal.
Alternatively, let the venturi flow be manually controlled and the flow controller modulate the bypass valve.
√
FT
I/P
FY
FRC
Bypass
Pump

Oven temperature control

A cheap electric toaster oven or convection oven works well for this purpose. The only "hard-to-find" part is the power controller (JC) which modulates AC power to the heating element in accordance with the temperature controller's 4-20 mA output signal.

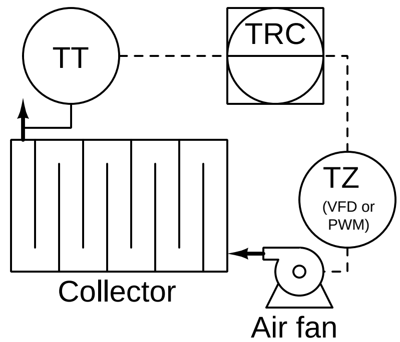


Solar air heater control

For the purposes of this lab exercise, the solar collector may be made out of cardboard with clear plastic food wrap as the cover material.

Paint the inside of the collector flat black for maximum heat absorption capability.

Use a variable-frequency motor drive (VFD) if the fan is turned by an AC motor. If using a DC fan (e.g. computer cooling fan), you may use a simpler PWM power controller.



Other process ideas include:

- Soldering iron temperature control (blowing air over tip with variable-speed fan).
- Draft pressure control (controlling very low air pressure inside of a box).
- Pneumatic piston height control (using lengths of PVC pipe to build a simple piston/cylinder which may be used to lift small weights using modest air pressures). A good way to control air pressure to the piston is to route the I/P transducer's output to a *volume booster* relay and let the relay's output directly drive the piston. Piston height may be sensed using a flexible water tube attached to the piston rod, running to a stationary pressure transmitter.
- Sterno-fired air heat exchanger.
- Miniature steam boiler. *Note: this is an advanced project!*
- Air/Fuel ratio burner control. *Note: this is an advanced project!*
- Servomechanism position control. *Note: this is an advanced project!*
- Inverted pendulum balance. *Note: this is a <u>very</u> advanced 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 electrical schematic and/or loop diagram showing all electrical connections between components, as well as any tubing or piping for fluids. 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 electric current, voltage polarities, and identifying electrical sources/loads. 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.

Your team's prototype sketch is so important that the instructor will demand you provide this plan before any construction on your team's working system begins. *Any team found constructing their system without a verified plan will be ordered to cease construction and not resume until a prototype plan has been drafted and approved!* Similarly, you should not deviate from the prototype design without instructor approval, to ensure nothing will be done to harm equipment by way of incorrect connections. Each member on the team should have ready access to this plan (ideally possessing their own copy of the plan) throughout the construction process. Prototype design sketching is a skill and a habit you should cultivate in school and take with you in your new career.

When selecting field instruments for this lab exercise, choose a *transmitter* suitable for measuring your process variable, and likely an *I/P converter* used to convert the controller's 4-20 mA output signal into an air pressure that a control valve may operate on. Electronic process controllers are in several locations throughout the lab, ready to be used for controlling processes. Your instructor will help you select appropriate instruments for the process you have chosen.

You may also need a *data acquisition unit* (*DAQ*) or a digital oscilloscope set to a very slow timebase value to function as a trend recorder. When used with a personal computer and connected properly to the loop circuit, either device will provide graphical displays of loop variables over time. Students usually find the connection of a DAQ unit or oscilloscope to their loop controller to be the trickiest part of their loop wiring. You will need to consult the manufacturer documentation on the DAQ/scope as well as the field instruments and controller in order to figure out how to wire them together. Even if your process controller already provides trending capability, you may find connection of a DAQ or oscilloscope to your loop circuits a useful exercise because the ability to quickly connect and use these tools to monitor electrical parameters in a system is a valuable diagnostic skill in this career.

You will find your teammates who have already taken the Measurement course series (INST24X) will be very helpful in showing you how to check, configure, calibrate, and install the measuring instrument(s) you will need for your process!

Planning a functioning system should take no more than an hour if the team is working efficiently, and will save you hours of frustration (and possible component destruction!).

Lab Exercise – circuit design challenge

Your instructor will choose one 4-20 mA field instrument and one control system from the lists shown below, for which you must sketch and annotate an accurate circuit diagram showing how the two instruments would connect to each other. If this interconnection between controller and field instrument requires additional electrical components to function (e.g. DC or AC power source, precision 250 Ω resistor, diode, relay, etc.), those must be incorporated into your diagram as well. The required annotation will consist of denoting all expected directions of current (marked by arrows pointing in the direction of conventional flow) and all expected voltage polarities (marked by + and − symbols), as well as identifying all electrical sources and loads as such. Instruction manuals for all instrument listed are available on the electronic Instrumentation Reference for your convenience. When your sketch is complete, you must show the relevant manual pages to your instructor for verification of correct connections.

This exercise tests your ability to locate appropriate information in technical manuals, to sketch a correct 4-20 mA loop circuit for a given pair of instruments, and to correctly annotate all voltages and currents. The electronic Instrumentation Reference will be available to you in order to answer this question.

Since all 4-20 mA "loops" are basically series DC circuits, it is highly recommended that you approach their design the same as for any other DC circuit: carefully identify all *sources* and *loads* in the circuit, trace directions of all currents, and mark the polarities of all voltages. Most of the mistakes made in this type of circuit design challenge may be remedied by careful consideration of these specific circuit-analysis details.

4-20 mA transmitter options

- Pressure
  → Rosemount 1151 Alphaline (analog), 1151 HART, or 3051 HART
  → Yokogawa DPharp EJX110A or EJX910
  → Honeywell ST3000
- Level
  → Rosemount APEX non-contact radar, 3300 GWR, or 5300 GWR
- Temperature
  → Rosemount 444, 644, 3044, or 3144
  → Foxboro RTT15 or RTT30
  → Moore Industries SPT with sourcing (4-wire) 4-20 mA output
  → Moore Industries SPT with sinking (2-wire) 4-20 mA output
  → Moore Industries TRX or TDY
- Flow
  → Foxboro CFT50 coriolis
- Analytical
  → Rosemount 5081-P (pH)
  → Daniel 700 gas chromatograph (4 analog output channels)
  → Foxboro 876PH (pH/ORP/ISE)

Controller options

- Monolithic
  - → Siemens 352P
  - → Siemens 353
  - → Foxboro 716C
  - → Foxboro 718TC
  - → Foxboro 762CNA
  - → Moore Industries 535
  - → Honeywell UDC2300
  - → Honeywell UDC3500
- Modular – *you choose the appropriate I/O module*
  - → Siemens 353R
  - → Emerson ROC800 SCADA/RTU
- Distributed Control System (DCS) – *you choose the appropriate I/O module*
  - → Emerson DeltaV with M-series I/O
  - → Emerson DeltaV with S-series I/O
  - → Honeywell Experion with 2MLF series I/O
- Programmable Logic Controller (PLC) – *you choose the appropriate I/O module*
  - → Automation Direct "CLICK"
  - → Siemens S7-300
  - → Rockwell ControlLogix (catalog number 1756)
  - → Rockwell CompactLogix (catalog number 1769)

4-20 mA Final Control Element options

- Pneumatic control valve positioners
  - → Fisher 3582i positioner
  - → Fisher DVC6000 positioner
- Electrically actuated valves (MOV)
  - → Limitorque actuator with Modutronic-20 II controller
  - → Rotork AQ with Folomatic controller
- AC motor drives (VFD)
  - → Rockwell PowerFlex 4
  - → Automation Direct GS1

Correct circuit sketch (instructor verifies): ____

Correct voltage annotations (instructor verifies): ____ (+ and − symbols)

Correct current annotations (instructor verifies): ____ (arrows showing conventional flow)

Correct source/load identifications (instructor verifies): ____

Study reference: the "Analog Electronic Instrumentation" chapter of *Lessons In Industrial Instrumentation*, particularly the section on HART.

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. These racks also provide structure for building physical processes, with more than enough weight-bearing capacity to hold any process vessels and equipment. The only wires you should need to install to build a working system are those connecting the field instrument to the nearest junction box, and then small "jumper" cables connecting different pre-installed cables together within intermediate junction boxes.

After getting your prototype sketch approved by the instructor, you are cleared to begin building your system. Instruments attach to 2-inch pipes using special brackets and U-bolts. These brackets and U-bolts are located in the instrument storage area.

Select a specific loop controller for your system. Your instructor may choose the controller for your team, to ensure you learn more than one type of controller during the course of a quarter.

Finally, your process control 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 use the equivalent resistor color-code value for your team's color in the loop number. For example, if you are the "Red" team, your loop number could be "2".

Common mistakes:

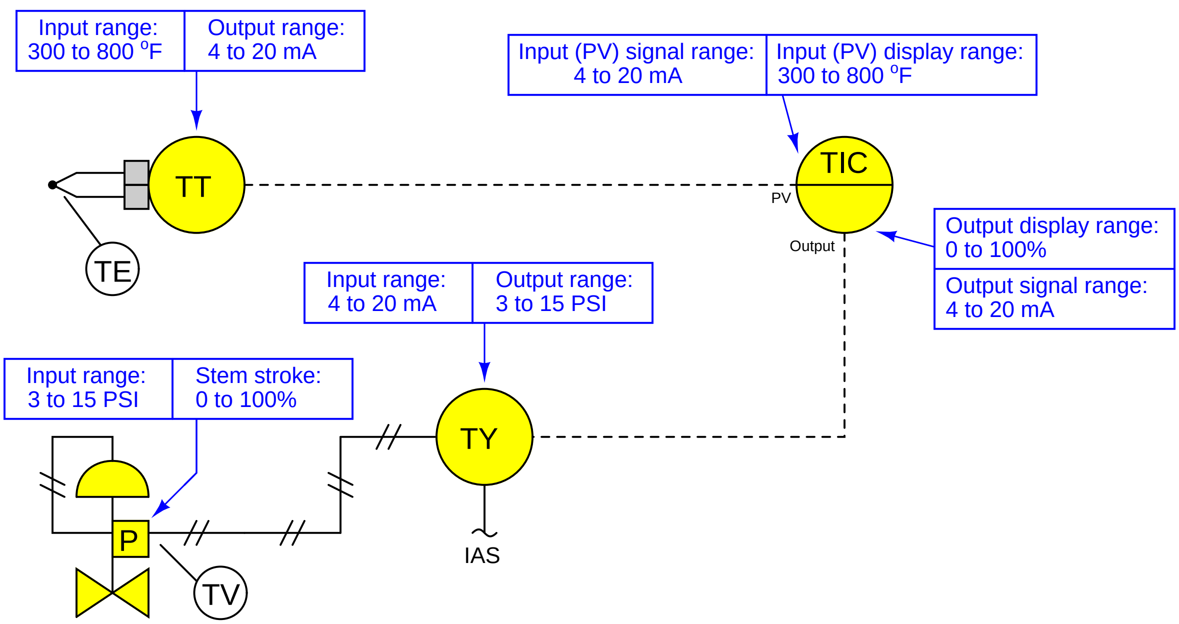
- Neglecting to consult the manufacturer's documentation for field instruments (e.g. how to wire them, how to calibrate them).
- Mounting the field instrument(s) in awkward positions, making it difficult to reach connection terminals or to remove covers when installed.
- Improper pipe/tube fitting installation (e.g. trying to thread tube fittings into pipe fittings and vice-versa).
- Failing to tug on each and every wire where it terminates to ensure a mechanically sound 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 process complete with instrumentation for control typically takes one or two sessions (3 hours each) if all components are readily available and the team is working efficiently!

Notes on instrument ranging

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

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



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

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

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

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

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

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

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

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

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

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

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

file `ranging`

Notes on controller action

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

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

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

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

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

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

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

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

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

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

Notes on controller tuning

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

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

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

file `control`

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 – troubleshooting

An important aspect of this lab exercise is *troubleshooting*, where you demonstrate your ability to logically isolate a fault in a simulated circuit. You will use the open-source software called `TROUBLESHOOT` for this objective, which natively runs on the Linux operating system and is already installed on the caSCADA nodes in the main lab room (under the `/tshoot` directory). You may also compile and run this free software natively on an Apple personal computer, or if running Windows you may install the free `Cygwin` emulator complete with development tools and use that to compile and run `TROUBLESHOOT`.

The `TROUBLESHOOT` software offers multiple simulated circuits to select, *the particular circuit for this lab exercise being specified earlier in this outline.* The software tracks every step you take, and the amount of time taken for each step. Scores are given at the end for such metrics as number of steps taken, total "cost" incurred (with different cost values associated with different actions), and total time taken. The software also provides reasonable "par" scores for each of the randomly-selected faults.

Included with every installation of `TROUBLESHOOT` is a set of PDF files, each one depicting the schematic diagram for a simulated circuit. It is advisable for you to print a paper copy of this schematic so that you can easily annotate measurements you take during the simulation.

In order to successfully pass this objective, you must start up the simulation in the instructor's presence, document the randomly-selected circuit values on paper (in order to later verify it is the exact same simulation scenario), complete the simulation on your own, and then logically defend each of your steps (recounted by the software after your declaration of the fault). You must meet or improve upon *all* of the "par" values given by the software. Like all mastery objectives, multiple re-tries will be permitted. You are also welcome to practice using this software on your own before committing to a graded demonstration.

Failure to achieve all par scores, or failure to apply logical reasoning to the defense of every step take, or simple failure to identify the random fault will disqualify the effort, in which case you must re-try with a different (random) fault.

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

Common mistakes:

- Not practicing the use of the `TROUBLESHOOT` software.
- Relying on voltage measurement across a suspected open wire to confirm that it has failed open. This test only works if there are no other opens (e.g. "off" switch, blown fuse, etc.) in that circuit!

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

Lab Exercise – PV alarms

Most loop controllers have built-in *alarm* capability to signal whenever the process variable (PV) goes outside of prescribed bounds. In this lab exercise you will configure your controller's "high" and "low" PV alarm points to serve as warnings to the operator. A good general recommendation is to set the PV high alarm to 90% and the PV low alarm to 10%, unless specified otherwise by the project engineer (i.e. your instructor). While "tuning" your process for optimal performance, you may determine it to be most stable within a certain range of PV values, in which case you are free to set the high and low alarm limits to the boundary values for that stable range.

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

Alarm settings are especially important when *tuning* a controller, to delineate how far the PV is allowed to stray without adversely affecting the process. This will become an important performance criteria in the *next* lab exercise when students individually tune PID controllers for different processes.

Lab Exercise – operating the system

All networked loop controllers in the lab (DCS, DDC, PLC, single-loop networked) provide graphing functionality so that you may plot your process variable (PV) and output values over time. This graphical data is essential for tuning PID-controlled loops. If you happen to be using a controller that does not provide graphing capability, your team must attach a trend recorder and/or a data acquisition unit (plus a personal computer) to the necessary signal cables so that these values are recorded over time.

PID tuning is a subject worthy of its own course, and so you will not be expected to achieve perfect control on your process. You will find, however, that one of the best ways to learn PID tuning is by "playing" with your process as it responds to different tuning parameters entered into the loop controller. The expectation for "good control behavior" in the context of this lab exercise is for the loop to exhibit response that is no less stable following large setpoint changes than the classic "quarter-wave damping" described by Ziegler and Nichols in their 1942 paper.

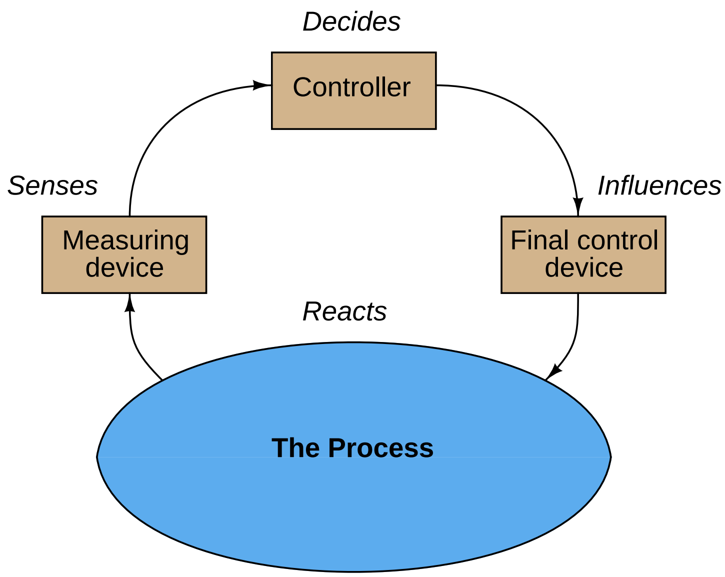
Most student-built processes are quite safe to operate. However, if your process harbors any unique hazards (e.g. overflowing water may present a slip hazard, overheated oven may cause materials to smoke or burn), you must be aware of these hazards and limit everyones' exposure to them. All team members for each process must be familiar with the inherent hazards of their process and how to mitigate them. One operational step to help avoid problems is to configure the controller for *setpoint limits* preventing the setpoint value from being placed at "dangerous" values in automatic mode. Just what these setpoint limit values should be set to varies with the process and the team's experience operating it.

As your time with the process builds, you will no doubt arrive at ideas for improving it. Feel free to work with your team to optimize the process in any way you see fit. The goal is to have your process as robust and "problem-free" as possible for other teams to use it in later coursework!

A tendency of students when they first learn to tune PID control loops is to proceed carelessly because they know the "toy" processes they are learning to tune aren't going to harm anything if their PVs go out of bounds. While this assumption might be true for your team's process, it is not good to form or reinforce bad habits. Thus, the inclusion of alarm point(s) on your process PV – especially if connected to some form of signaling device that is annoying and/or embarrassing to trip such as a loud buzzer – makes for a better teaching tool for others learning PID tuning!

Notes on troubleshooting feedback control loops

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



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

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

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

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

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

A crude closed-loop PID tuning procedure

Tuning a PID controller is something of an art, and can be quite daunting to the novice. What follows is a primitive (oversimplified for some situations!) procedure you can apply to many processes.

Step 1

Understand the process you are trying to control. If you do not have a fundamental grasp on the nature of the process you're controlling, it is pointless – even dangerous – to change controller settings. Here is a simple checklist to cover before touching the controller:

- What is the process variable and how is it measured?
- What is the final control element, and how does it exert control over the process variable?
- What safety hazards exist in this process related to control (e.g. danger of explosion, solidification, production of dangerous byproducts, etc.)?
- How far am I allowed to "bump" the process while I tune the controller and monitor the response?
- How is the controller mode switched to "manual," just in case I need to take over control?
- In the event of a dangerous condition caused by the controller, how do you shut the process down?

Step 2

Understand what the settings on the controller do. Is your controller configured for gain or proportional band? Minutes per repeat or repeats per minute? Does it use reset windup limits? Does rate respond to error or PV alone? You had better understand what the PID values do to the controller's action if you are going to decide which way (and how much) to adjust them! Back in the days of analog electronic and pneumatic controllers, I would recommend to technicians that they draw little arrow symbols next to each adjustment knob showing which way to turn for more aggressive action – this way they wouldn't get mixed up figuring out gain vs PB, rep/min vs min/rep, etc.: all they had to think of is "more" or "less" of each action.

Step 3

Manually "bump" the manipulated variable (final control element) to learn how the process responds. In manual mode, *you* are the controller! What you need to do is adjust the process to learn how it responds: is it an integrating process, a self-regulating process, or a runaway process? Is there significant dead time or hysteresis? Is the response linear and consistent? Many process control problems are caused by factors other than the controller, and this "manual test" step is a key diagnostic technique for assessing these other factors.

Step 4

Set the PID constants to "minimal" settings and switch to automatic mode. This means gain less than 1, no integral action (0 rep/min or maximum min/rep), no derivative action, and no filtering (i.e. damping).

Step 5

"Bump" the setpoint and watch the controller's response. This tests the controller's ability to manage the process on its own. What you want is a response that is reasonably fast without overshooting or undershooting too much, and without undue cycling. The nature of the process and the constraints of quality standards will dictate what is "too much" response time, over/undershoot, and cycling.

Step 6

Increase or decrease the control action aggressiveness according to the results of Step 5.

Step 7

Repeat steps 5 and 6 for P, I, and D, one at a time, in that order. In other words, tune the controller first to act as a P-only controller, then add integral (PI control), then derivative (PID), each as needed.

Step 8

"Bump" a load in the process and watch the controller's response. This tests the controller's ability to manage variations in process load over time. A controller's response to load changes will often differ from its response to setpoint changes. You still want controller response that is reasonably fast without overshooting or undershooting too much, and without undue cycling. However, you may have to find some compromise in tuning between good setpoint response and good load response. How you decide that compromise depends on whether the controller really needs to respond mostly to setpoint changes (e.g. the slave controller of a cascade loop) or to load changes.

Step 9

Increase or decrease the control action aggressiveness according to the results of Step 8.

Step 10

Repeat steps 8 and 9 for P, I, and D, one at a time, in that order. In other words, tune the controller first to act as a P-only controller, then add integral (PI control), then derivative (PID), each as needed.

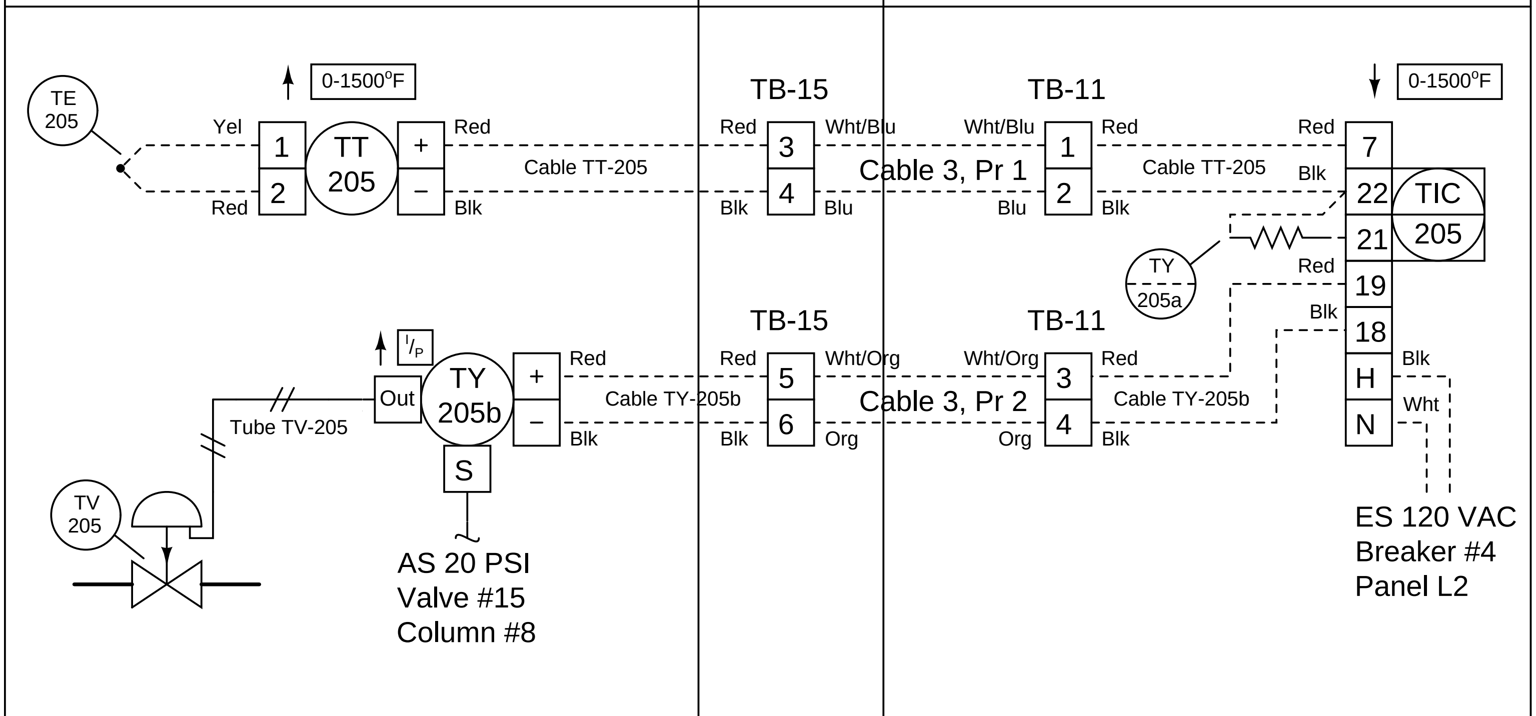
Caveats

The procedure described here is *very* crude, and should only be applied as a student's first foray into PID tuning, on a safe "demonstration" process. It assumes that the process responds predominantly to proportional (P-only) action, which may not be true for some processes. It also gives no specific advice for tuning based on the results of step 3, which is the mark of an experienced PID tuner. With study, practice, and time, you will learn what types of processes respond best to P, I, and D actions, and then you will be able to intelligently choose what parameters to adjust, and what closed-loop behaviors to look for.

file i01558

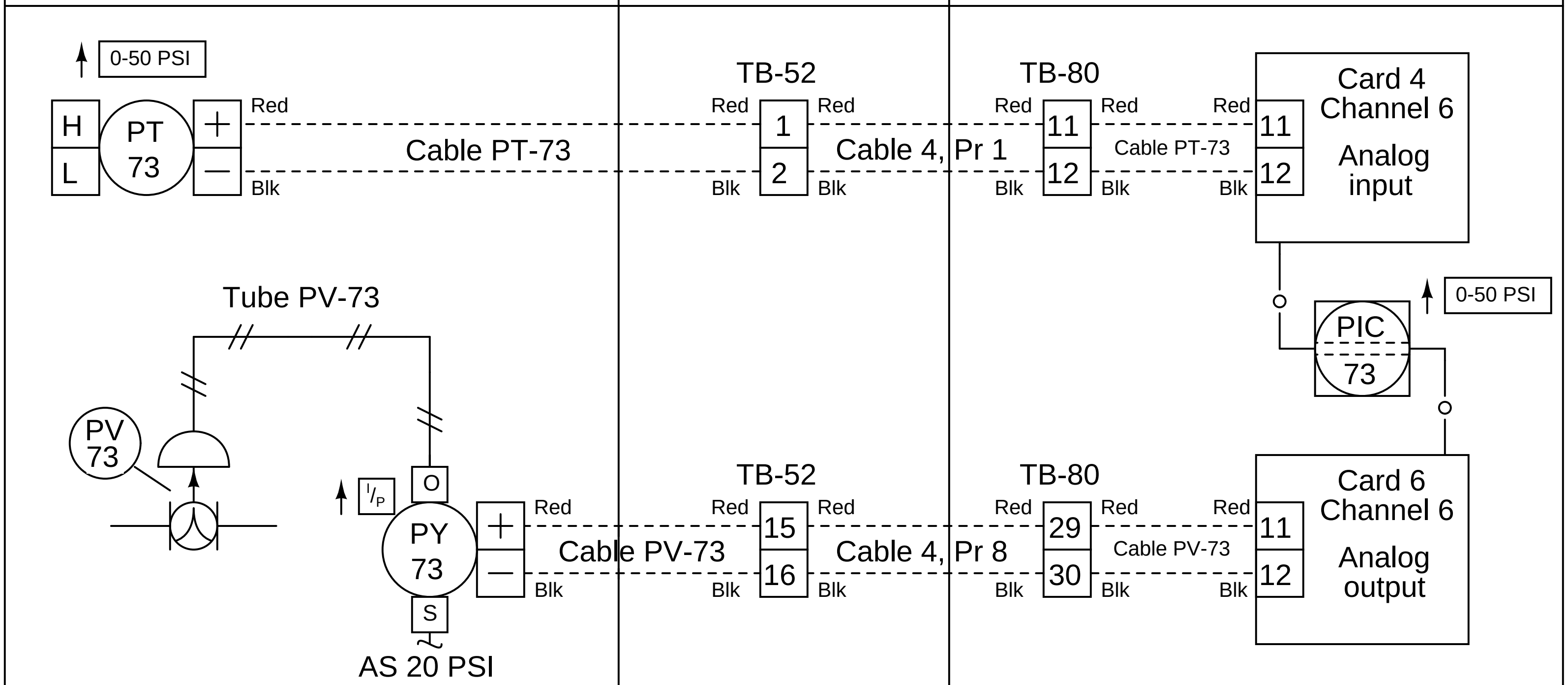
Sample Loop Diagram (using a single-loop controller)

Loop Diagram: Furnace temperature control	**Revised by:** Mason Neilan	**Date:** April 1, 2007
Process area	Field panel JB-12	Control room panel CP-1



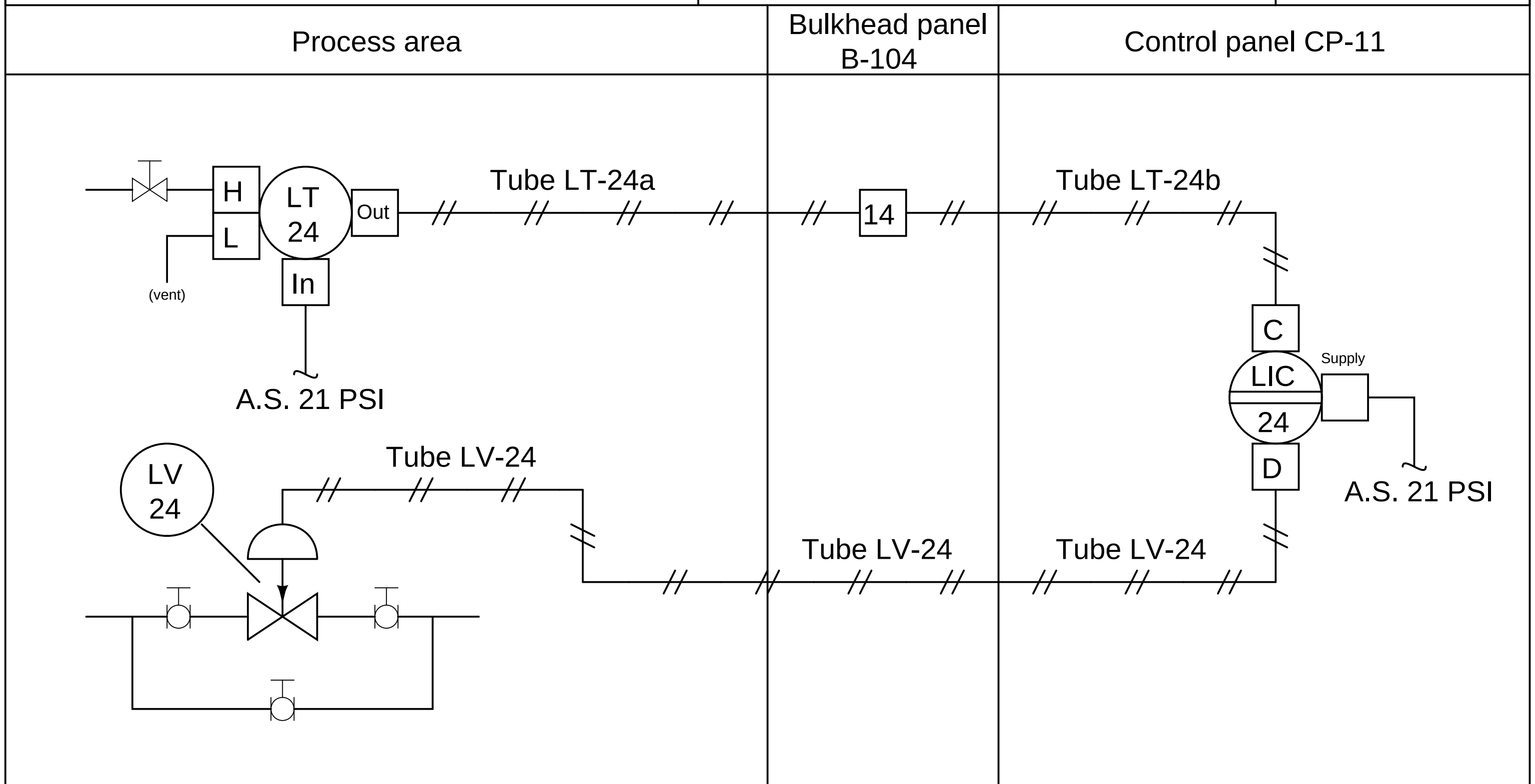
Tag #	Description	Manufacturer	Model	Input range	Output range	Notes
TE-205	Thermocouple	Omega			Type K	Ungrounded tip
TT-205	Temperature transmitter	Rosemount	444	0-1500° F	4-20 mA	Upscale burnout
TY-205a	Resistor	Vishay			250 Ω	
TIC-205	Controller	Siemens	PAC 353	1-5 V	0-1500° F	Reverse-acting control
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
Field process area	Field panel JB-25	DCS cabinet



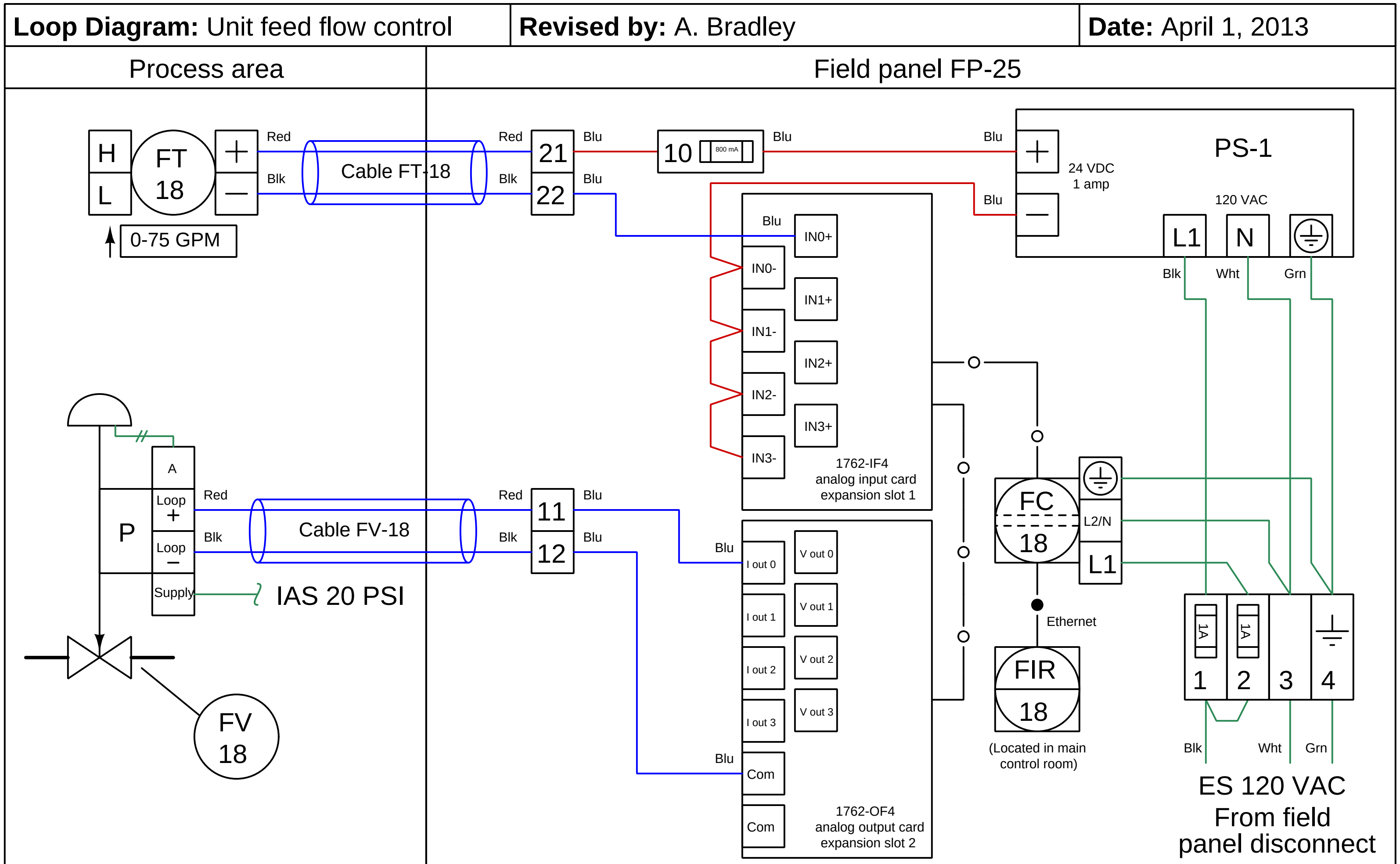
Tag #	Description	Manufacturer	Model	Input range	Output range	Notes
PT-73	Pressure transmitter	Rosemount	3051CD	0-50 PSI	4-20 mA	
PIC-73	Controller	Emerson	DeltaV	4-20 mA	4-20 mA	HART-enabled input Direct-acting control
PY-73	I/P transducer	Fisher	846	4-20 mA	3-15 PSI	
PV-73	Control valve	Fisher	Vee-ball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

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



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)



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.
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- 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.
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- Each location (e.g. field, junction box, control room) must be clearly delineated with vertical seperation lines on the diagram.
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- 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

Answer 3

Answer 4

Answer 5

Partial answer:

- Controller #1 needs to be *reverse-acting*
- Controller #3 needs to be *direct-acting*
- Controller #5 needs to be *direct-acting* (i.e. PV input is "+" and SP input is "−")
- Controller #7 needs to be *reverse-acting* (i.e. PV input is "−" and SP input is "+")

Answer 6

Answer 7

Answer 8

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

Answer 9

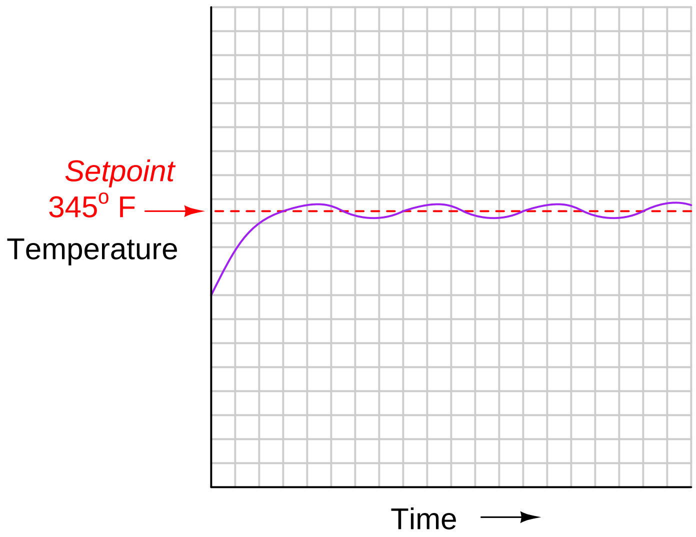
A *load* is any variable in a process (besides the manipulated variable) that has influence over the process variable being controlled.

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

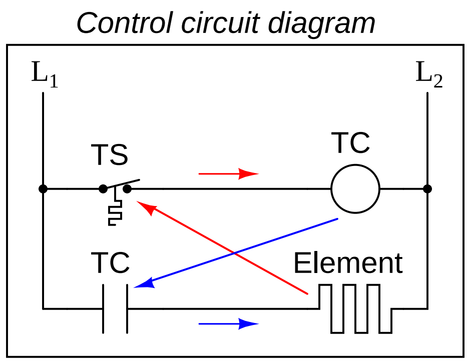
Answer 10

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.

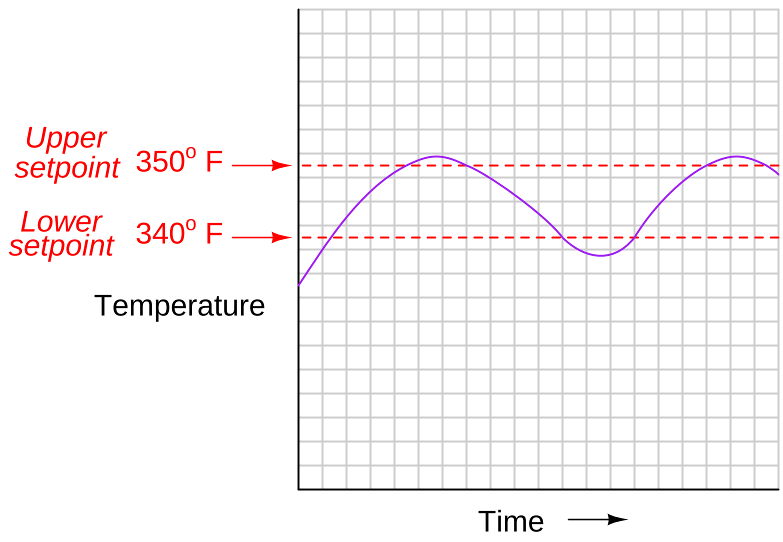


As you can see, the temperature can never settle at any one temperature, since the control action is all-or-nothing, and changes based on a simple "greater-than" or "less-than" relationship between the process variable and the setpoint.

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 11



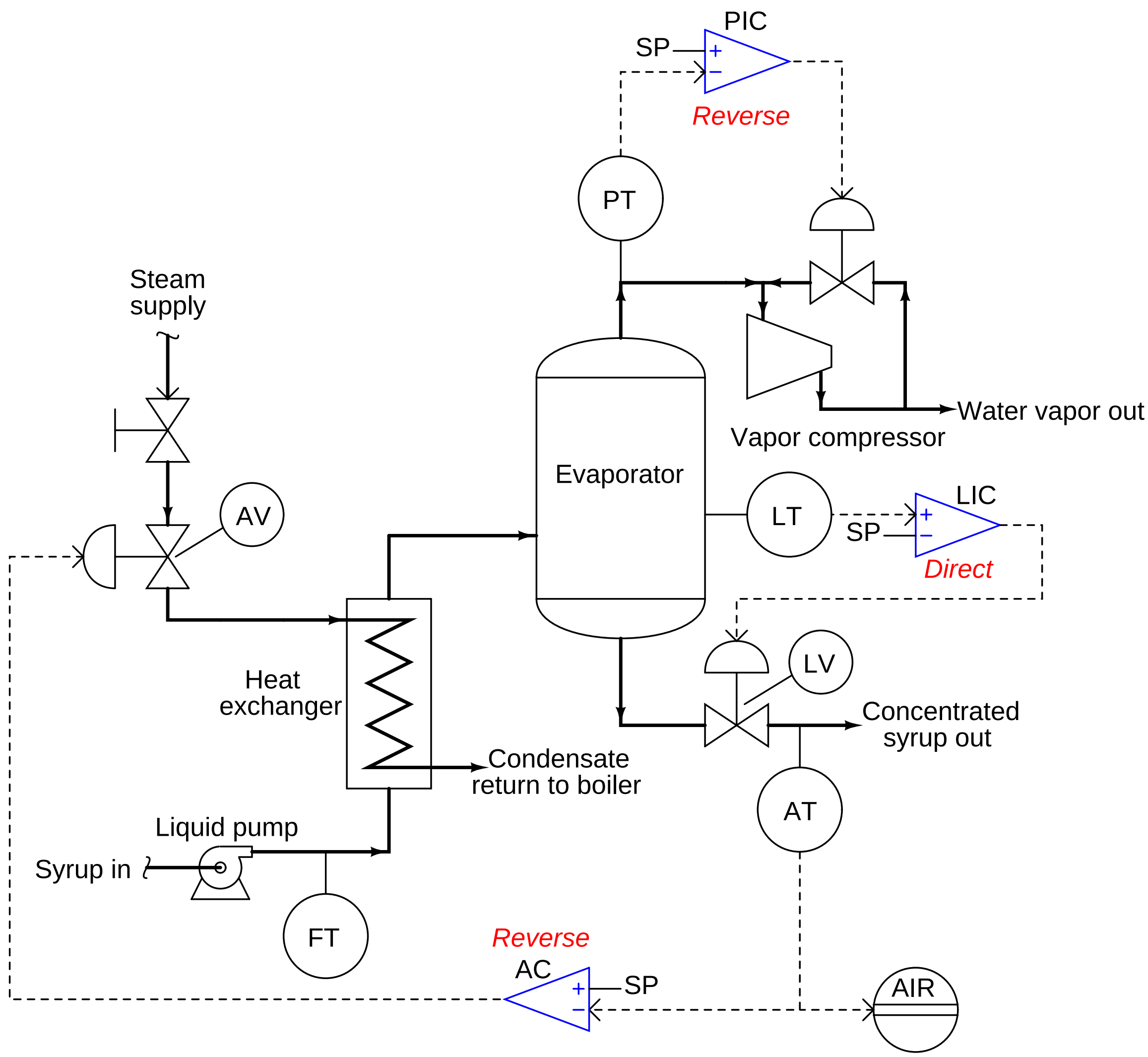
Answer 12

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 13

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



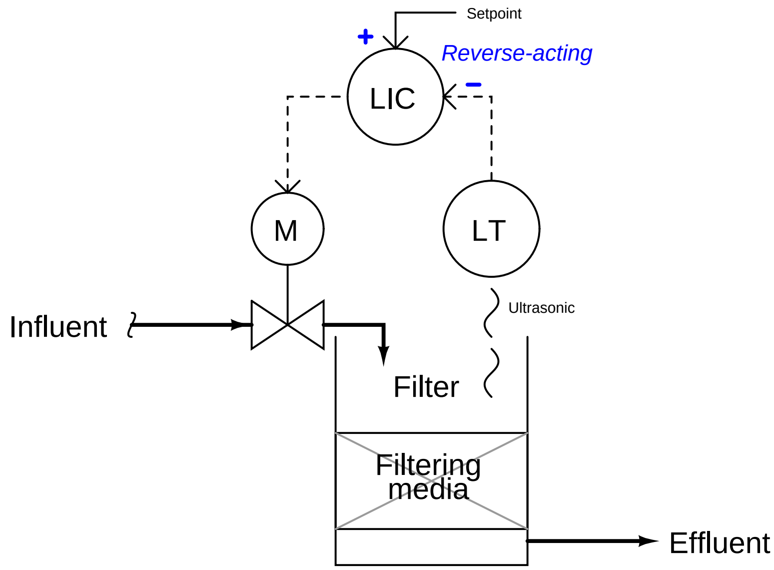
The analytical controller (AC) is reverse-acting in order to close off the steam valve if the sugar concentration of the syrup increases.

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

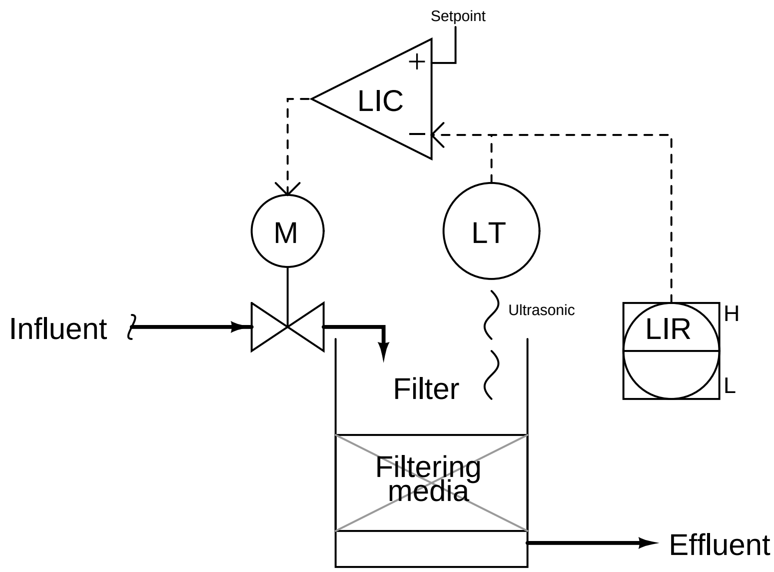
The pressure indicating controller (PIC) is reverse-acting in order to open up the compressor recycle valve if the pressure inside the evaporator decreases (i.e. if the vacuum becomes too strong).

Answer 15

This controller needs to be *reverse-acting*:



This re-drawing of the control system uses an opamp symbol in place of the ISA-standard circle used to represent a loop controller:



- A sudden increase in effluent flow rate (clean water demand): *controller output increases*
- Level transmitter fails high (indicating 100% full water level): *controller output decreases*
- Control valve actuator fails, driving valve fully open (ignoring controller signal): *controller output decreases*

Answer 16

One possible fault has to do with the control valve: perhaps something has happened to make it fail closed (loss of air supply, signal, etc.). Other possible problems include the following:

- Pump not running (no source of fluid power to motivate flow)
- Very poor controller tuning
- Wrong controller action
- Valve failed closed (loss of air supply, signal, etc.)
- Transmitter failed, showing no flow when in fact there is

A good "first test" for troubleshooting the loop is to check the controller output: is it trying to open up the valve?

Answer 17

Answer 18

Answer 19

Answer 20

Answer 21

Answer 22

Answer 23

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 24

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 25

Answer 26

Answer 27

Answer 28

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 29

- 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 30

Gain = 0.5 and bias = 30%

Answer 31

- "Displ" button = *change display mode*
- "Auto/Man" button = *toggle between automatic and manual modes*
- "Config" button = *Enter the configuration menu*

- "Up" (↑) Button = *increase setpoint*
- "Down" (↓) Button = *decrease setpoint*
- "Left" (←) Button = *decrease output*
- "Right" (→) Button = *increase output*

An operator might wish to manually control a process in the event that the transmitter providing the process variable (PV) signal fails.

Answer 32

Alternatively, you may run this free software on your own computer if you have the Linux operating system running on it. You will need to install the caSCADA source code package, as well as the `ncurses` programming library, then compile the `looptune` exectable by running `make` at the command prompt from within the caSCADA directory.

Additional notes on using SSH to remotely log into a computer running the Linux operating system appear on the following page.

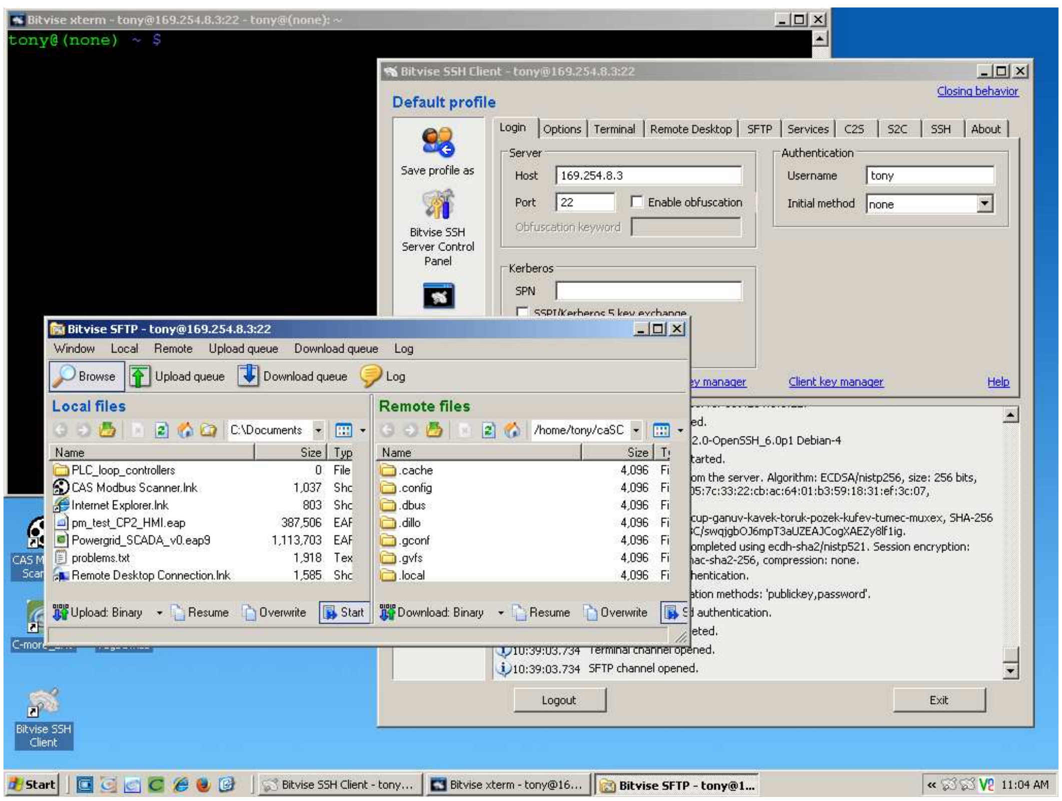
Notes on using SSH for remote administration

Each caSCADA RTU is based on single-board computer running Linux operating system software, located inside an electrical enclosure without convenient physical access. Attaching a keyboard and monitor is impractical, therefore you will need to log in to this computer through some other means.

Fortunately, a digital communication protocol has been developed to permit remote access of Unix-based operating systems called *SSH*, which stands for *Secure SHell*. Any computer running an SSH client program is able to log into any Linux computer running an SSH server program. Any personal computers running a Unix-based operating system (e.g. FreeBSD, Linux, Apple's OS X) have SSH clients built in.

Microsoft Windows operating systems do not have native SSH client software, but one available for free download is `Bitvise`. Another one is called `PuTTY`. For the really ambitious there is even a complete Linux terminal emulation package for Microsoft Windows called `Cygwin`. Any of these programs will suffice, but the easiest to download, install, and use is `Bitvise`. Be sure you download and install the *client* software for `Bitvise`, and not the *server* software (which should already be installed and running on the single-board Linux computer)!

The following screenshot shows `Bitvise` running on a Windows XP machine, communicating with a model of single-board computer called a "Raspberry Pi":



Three windows appear in this screenshot: the `Bitvise` client through which the login connection is established (you must enter the RTU computer's IP address and Linux user name, then later enter the Linux password for that user account), the `Bitvise` SFTP window for file transfer between the two computers, and the `xterm` terminal window (the one with the black background and colorful prompt) where you may enter typed commands to the RTU computer. Since Linux is a multi-user operating system, many people can log into the RTU using their own individual Windows PCs, even under the same user name! All you need is a network connection to the RTU and its IP network address.

Answer 33

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 34

Answer 35

Answer 36

Answer 37

Answer 38

Answer 39

Answer 40

Answer 41

Answer 42

Answer 43

Answer 44

Answer 45

Answer 46

Answer 47

Answer 48

Answer 49

Answer 50

Answer 51

Answer 52

Partial answer:

- If a wire breaks loose at TB56-4, creating an "open" fault in the loop circuit, determine what will happen at the alarm unit (AAH, AAL-41) and also where you would expect to measure voltage in the loop circuit and where you would expect to measure *no* voltage in the loop circuit. *The AAL would trip (but not the AAH), and we would expect to measure voltage between the wires of cable 52 but not between the wires of cable 30.*

- If a fire breaks out near the conduit through which cable 52 runs, causing the conductors inside cable 52 to *short* together, what will happen in this system? Where would you expect to measure voltage in the loop circuit, and where would you expect to measure *no* voltage in the loop circuit? Where would you expect to measure current in the loop circuit, and where would you expect to measure *no* current in the loop circuit? *The AAL would trip (but not the AAH), and we would expect to measure no voltage anywhere in the loop circuit. However, we would still have current at the terminals of the AIT-41 transmitter (although no current to the right of the short).*

Answer 53

Answer 54

Answer 55

Answer 56

Answer 57

Answer 58

Answer 59

Answer 60

Answer 61

Answer 62

Partial answers:

Explain why *instrument transformers* (PTs and CTs with voltage step-down and current step-down ratios) are used to connect the PQM to the power system conductors. **The instrument transformers provide both signal reduction and galvanic isolation between the PQM and the high-voltage, high-current power line conductors.**

Assuming a phase-to-neutral voltage on "B" phase of 7155 volts AC, calculate the voltage seen between the PQM instrument's V_2 and V_N terminals. **119.25 volts**

Answer 63

Answer 64

Answer 65

Each line beginning with a letter "C" is a *comment*, placed there strictly for the benefit of any human being reading the program. Comments are ignored by the controller as it executes the code.

The `.LT.` operator stands for "Less Than" while the `.GT.` operator stands for "Greater Than" and the `.EQ.` operator stands for "Equal To".

The singular GOTO instruction causes the program to *loop*, endlessly repeating the entire program.

Answer 66

Each line beginning with a letter "C" is a *comment*, placed there strictly for the benefit of any human being reading the program. Comments are ignored by the controller as it executes the code.

The `.LE.` operator stands for "Less Than Or Equal To" while the `.GT.` operator stands for "Greater Than".

Answer 67

Answer 68

Answer 69

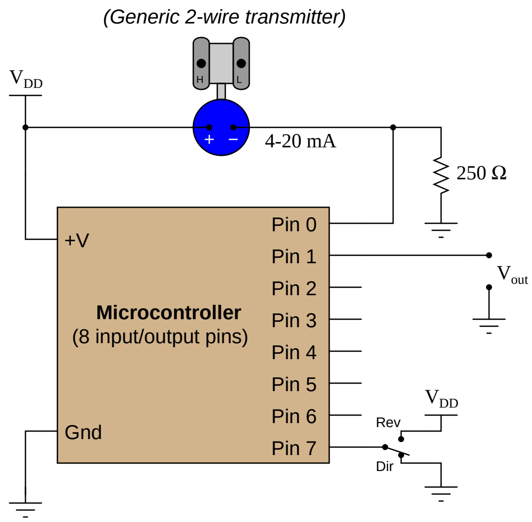
Answer 70

- AI 1-5 VDC *Analog input, requires external 250 Ω resistor and loop power supply*
- AI 4-20 mADC *Analog input, provides loop power for transmitter with no need for external resistor*
- AI 4-20 mADC w/ HART *Analog input, provides loop power and HART communication ability*
- AO 4-20 mA *Analog output, drives 4-20 mA DC to device*
- AO w/ HART *Analog output, drives 4-20 mA DC to device and provides HART communication ability*
- DI 24VDC dry contact *Discrete input, provides power for switch circuit*
- DI 24VDC isolated *Discrete input with electrically isolated channels, requires external 24 VDC power source*
- DI 120VAC isolated *Discrete input with electrically isolated channels, requires external 120 VAC power source*
- DO 24VDC high side *Discrete output, sources 24 VDC to field device when activated*

Answer 71

The controller code as shown implements *direct* action, since the error is calculated as PV − SP.

The following additions give this controller the ability to switch between direct or reverse control action:



Pseudocode listing

```
Declare Pin0 as an analog input (scale 0 to 5 volts = 0 to 1023)
Declare Pin1 as an analog output (scale 0 to 5 volts = 0 to 1023)
Declare Pin7 as a discrete input
Declare SP as a variable, initially set to a value of 614
Declare GAIN as a variable, initially set to a value of 1.0
Declare ERROR as a variable
Declare BIAS as a constant = 614

LOOP
  IF Pin7 = 0, SET ERROR = Pin0 - SP
  ELSE, SET ERROR = SP - Pin0
  ENDIF

  SET Pin1 = (GAIN * ERROR) + BIAS
ENDLOOP
```

While a very slow program execution time could be bad for control, it actually could serve a useful purpose in some processes. In processes with large dead times (transport delays), one control strategy to apply is called *sample-and-hold*, which is precisely what this program would be if a purposeful and substantial delay time were inserted into the loop.

Answer 72

One disadvantage is that while using software such as AMS to view and/or edit HART instrument parameters from the control room display, you do not get the same sort of verification of having the right instrument as you do when connecting a handheld HART communicator directly to the instrument!

Answer 73

- FTA-AI module resistor fails shorted: *temperature reads below-scale, may overheat as controller tries to increase temperature*
- FTA-AI module resistor fails open: *temperature reads above-scale, will shut off all steam to the reactor*
- Ground wire falls off terminal TB40-8: *may suffer extra noise voltage on temperature signal*
- Condensate valve left closed: *reactor will not be able to heat after jacket fills with condensate*
- Corroded wire connection at TB12-3: *steam control valve fails shut, causing reactor to cool down*
- Cable 1 fails open: *steam control valve fails shut, causing reactor to cool down*
- Cable 1 fails shorted: *steam control valve fails shut, causing reactor to cool down*
- Cable 21 fails open: *temperature reads below-scale, may overheat as controller tries to increase temperature*
- Cable 21 fails shorted: *temperature reads above-scale, will shut off all steam to the reactor*

Answer 74

Answer 75

Answer 76

Answer 77

Answer 78

Answer 79

Answer 80

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.