Lab

"Smart" valve positioner: *Questions 91 and 92*, **completed objectives due by the end of day 5, section 4**

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
- Determine proper fail-safe mode for a control valve in a given process
- Calculate C_v rating of control valve for liquid (non-cavitating) service
- Calculate split-ranged valve positions given signal value and valve calibration ranges
- Solve for a specified variable in an algebraic formula
- Determine the possibility of suggested faults in a simple circuit given measured values (voltage, current), a schematic diagram, and reported symptoms
- Motor/relay/3phase/PLC Review: Calculate either the full-load current or the horsepower of an electric motor (either single- or three-phase) given the line voltage and one of the other parameters
- INST240 Review: Calculate ranges for hydrostatic (DP) level-measuring instruments given physical dimensions and fluid densities
- INST263 Review: Identify action of "trip" solenoid from P&ID or loop sheet

Recommended daily schedule

Day 1

Theory session topic: Valve positioners

Questions 1 through 20; answer questions 1-9 in preparation for discussion (remainder for practice)

Day 2

Theory session topic: Electric valve actuators and VFDs

Questions 21 through 40; answer questions 21-27 in preparation for discussion (remainder for practice)

Day 3

Theory session topic: Split-ranged control valves

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

Day 4

Theory session topic: Valve sizing

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`

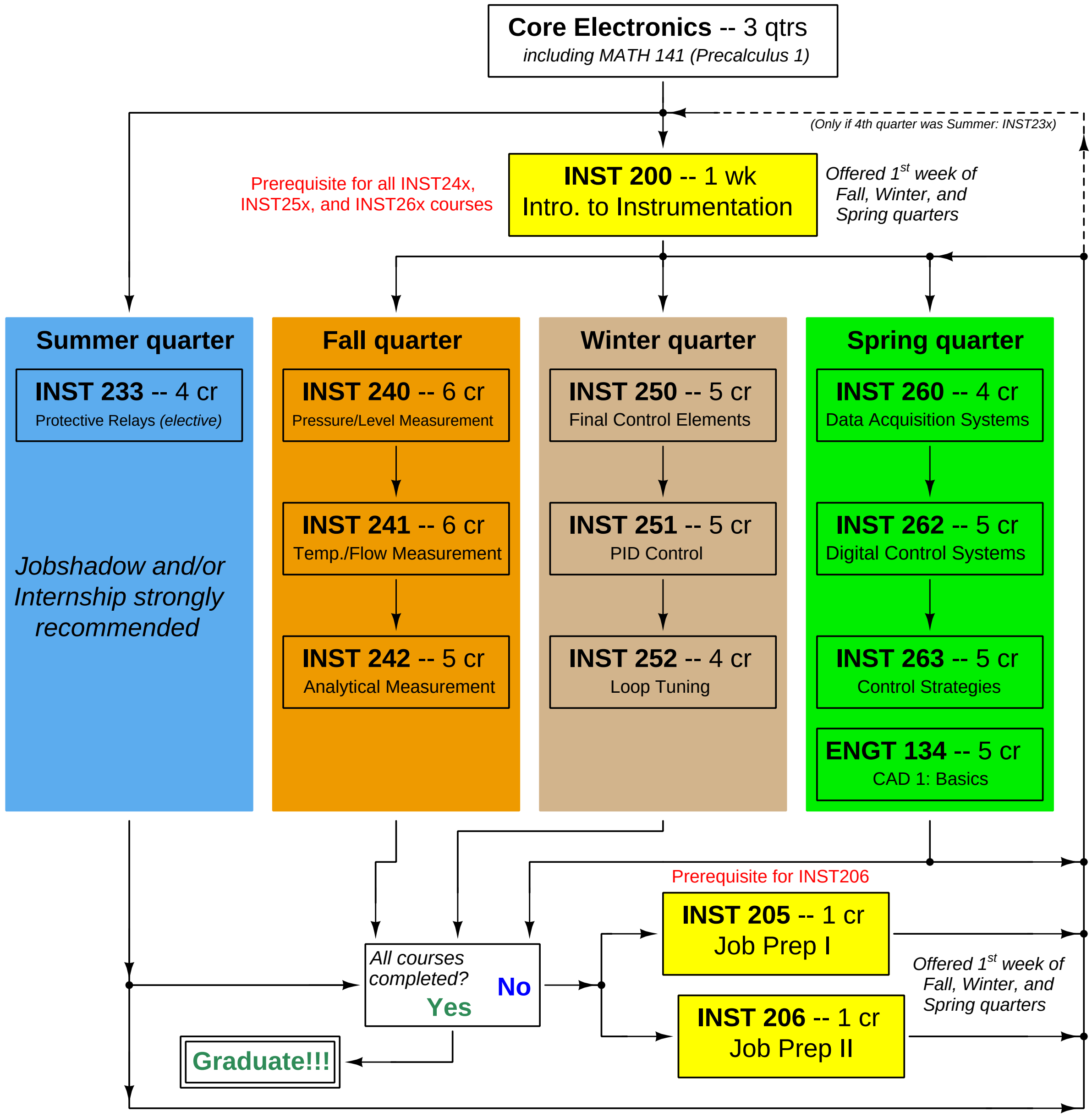
Each and every outcome in this course is assessed at a mastery level (i.e. 100% competence)

- Calculate and annotate voltages and currents in a DC series-parallel circuit. [Ref: Program Learning Outcome #4]
- Calculate voltages, currents, powers, and/or resistances in a DC series-parallel circuit. [Ref: Program Learning Outcome #4]
- Determine response of a pneumatic force-balance mechanism to different conditions. [Ref: Program Learning Outcome #4]
- Determine the effect of a fault in a solenoid-controlled valve system. [Ref: Program Learning Outcome #4]
- Determine proper fail-safe mode for a control valve in a given process. [Ref: Program Learning Outcome #5]
- Calculate C_v rating of control valve for liquid (non-cavitating) service. [Ref: Program Learning Outcome #5]
- Calculate instrument input and output values given calibrated ranges. [Ref: Program Learning Outcome #7]
- Calculate split-ranged valve positions given signal value and valve calibration 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 simple circuits given measured values (voltage, current), schematic diagrams, and reported symptoms. [Ref: Program Learning Outcome #4]
- Demonstrate proper use of safety equipment and application of safe procedures while using power tools, and working on live systems. [Ref: Program Learning Outcome #3]
- Communicate effectively with teammates to plan work, arrange for absences, and share responsibilities in completing all labwork. [Ref: Program Learning Outcomes #1 and #2]
- Completely rebuild a pneumatically-actuated control valve. [Ref: Program Learning Outcome #4]
- Calibrate an I/P signal converter to specified accuracy using industry-standard calibration equipment. [Ref: Program Learning Outcome #7]
- Construct and commission a working hand control loop consisting of a PID controller, signal wiring, and control valve with positioner. [Ref: Program Learning Outcome #5]
- Calibrate a control valve equipped with a smart positioner, using industry-standard calibration equipment. [Ref: Program Learning Outcome #7]
- Generate accurate loop diagrams compliant with ISA standards documenting your team's hand control systems. [Ref: Program Learning Outcome #8]
- 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]

- Wire and program a VFD (Variable Frequency motor Drive) for variable-speed control of an AC induction motor, measuring motor line current with a clamp-on ammeter. [Ref: Program Learning Outcome #5]
- Diagnose random faults placed in other team's hand control systems by the instructor within a limited time using no test equipment except a multimeter and a pressure gauge, logically justifying your steps in the instructor's direct presence. [Ref: Program Learning Outcome #4]

file `outcomes_INST250`


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.

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

Lab sessions

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

(1) Start of practical (lab) session: announcements and planning
  (a) The instructor makes general announcements to all students
  (b) The instructor works with team to plan that day's goals, making sure each team member has a clear idea of what they should accomplish

(2) Teams work on lab unit completion according to recommended schedule:
(First day) Select and bench-test instrument(s), complete prototype sketch of project
(One day) Connect instrument(s) into a complete loop
(One day) Each team member drafts their own loop documentation, inspection done as a team (with instructor)
(One or two days) Each team member calibrates/configures the instrument(s)
(Remaining days, up to last) Each team member troubleshoots the instrument loop

(3) End of practical (lab) session: debriefing where each team reports on their work to the whole class

Troubleshooting assessments must meet the following guidelines:

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

Distance delivery methods

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

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

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

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

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

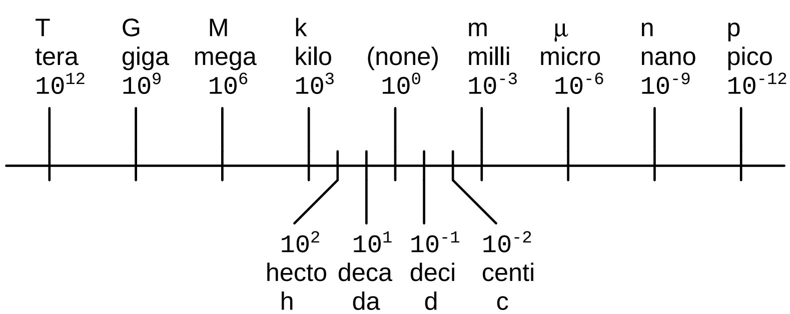
Conventional students may opt to switch to "distance" mode at any time. This has proven to be a benefit to students whose lives are disrupted by catastrophic events. Likewise, "distance" students may switch back to conventional mode if and when their schedules permit. Although the existence of alternative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

file `distance`

Metric prefixes and conversion constants

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

METRIC PREFIX SCALE



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

Conversion equivalencies for distance

1 inch (in) = 2.540000 centimeter (cm)

1 foot (ft) = 12 inches (in)

1 yard (yd) = 3 feet (ft)

1 mile (mi) = 5280 feet (ft)

Conversion equivalencies for volume

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

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

Conversion equivalencies for velocity

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

Conversion equivalencies for mass

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

Conversion equivalencies for force

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

Conversion equivalencies for area

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

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

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

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

Conversion equivalencies for absolute pressure units (only)

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

Conversion equivalencies for energy or work

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

Conversion equivalencies for power

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

Acceleration of gravity (free fall), Earth standard

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

Physical constants

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

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

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

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

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

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)

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, writing an exact man, and conference a ready man" – Francis Bacon

Francis Bacon's advice provides 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 what they have learned. The ability to independently acquire and apply knowledge is a powerful skill, well worth the effort to attain. To this end, students should read these educational resources closely, write their own outline and reflections on the reading, and discuss in detail their new knowledge with classmates and instructor(s). You should be able to do all of the following after reading an 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 be questioned on them by classmates and by your instructor. Outlining helps ensure complete reading and is a good self-test of reading comprehension because you cannot outline what you do not comprehend or have not read.

$\boxed{\surd}$ Demonstrate ACTIVE READING STRATEGIES, including verbalizing your thoughts as you read, simplifying long sentences to convey the same ideas using fewer words, annotating text and illustrations with your own thoughts, 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. The purpose of these strategies is to clarify the text and develop metacognition: the habit of monitoring your own thoughts.

$\boxed{\surd}$ Identify any IMPORTANT IDEAS, especially GENERAL LAWS or PRINCIPLES, expounded in the text and express them in the simplest of terms. Imagine explaining these ideas to an intelligent child, avoiding obscure words and assumptions of prior knowledge. The purpose of this is to develop your ability to analyze complex concepts and communicate them to anyone.

$\boxed{\surd}$ Specifically identify any CONFUSING points. The reason for doing this is to help diagnose misconceptions, as well as practice both metacognition and critical thinking.

$\boxed{\surd}$ DEVISE YOUR OWN QUESTIONS based on the reading, and then pose them to your instructor and classmates for their consideration. Prepare both correct and incorrect answers, the incorrect answer(s) assuming one or more plausible misconceptions. This is another opportunity to practice metacognition and critical thinking, by anticipating others' responses to the text.

$\boxed{\surd}$ Devise EXPERIMENTS to demonstrate important concepts presented in the reading, and/or disprove misconceptions. Predict possible outcomes of these experiments, and evaluate their meanings: what result(s) would confirm the concept, or would constitute disproof? The purpose of this is to develop scientific and diagnostic reasoning, taking hypotheses and theories to their logical conclusions.

General challenges following a tutorial reading assignment

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

General follow-up challenges for assigned problems

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

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file `license`

Question 1

Read and outline the introduction to the "Valve Positioners" section of the "Control Valves" 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.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Any points of confusion, and precisely why you found the text confusing.
(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

file i04207

Question 2

Read and outline the "Force-Balance Pneumatic Positioners" subsection of the "Valve Positioners" section of the "Control Valves" 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.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Any points of confusion, and precisely why you found the text confusing.
(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

file i01363

Question 3

Read and outline the "Motion-Balance Pneumatic Positioners" subsection of the "Valve Positioners" section of the "Control Valves" chapter in your *Lessons In Industrial Instrumentation* textbook.

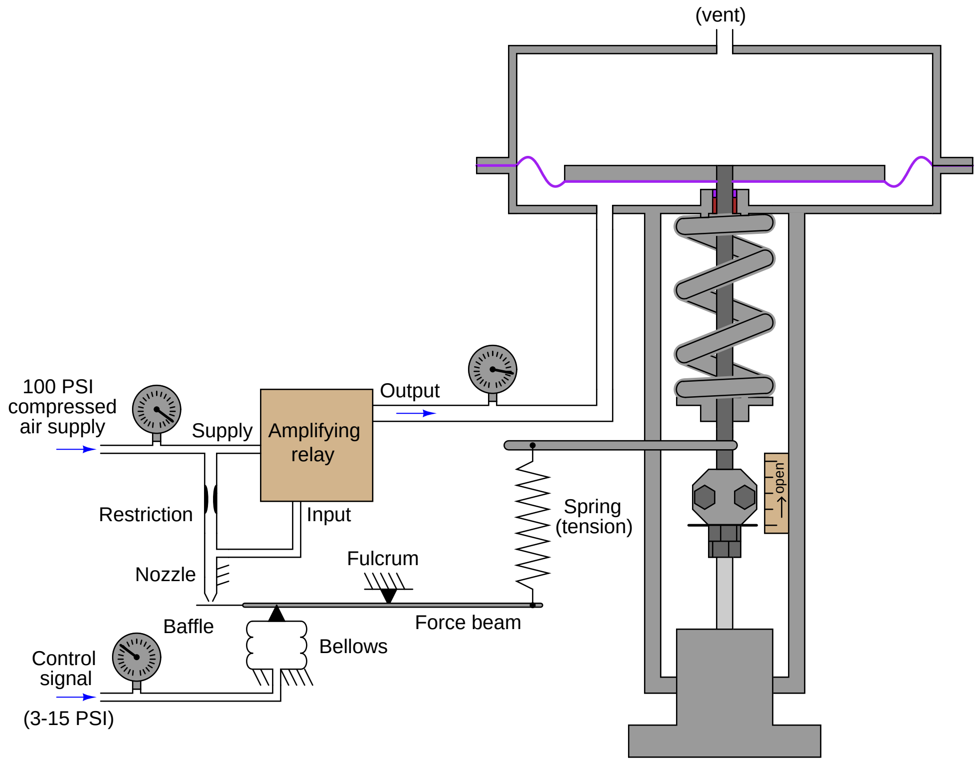
After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

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

file i01364

Question 4

This valve positioner system, shown in the fully-closed position, has a problem. When placed into service, the valve remains at 100% (full open) for *any* applied control signal value:



Looking at the gauges, you notice the supply gauge reads 95 PSI, the control signal gauge reads 4.3 PSI, and the output gauge reads 88 PSI.

Identify the likelihood of each specified fault for this valve positioner. 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.

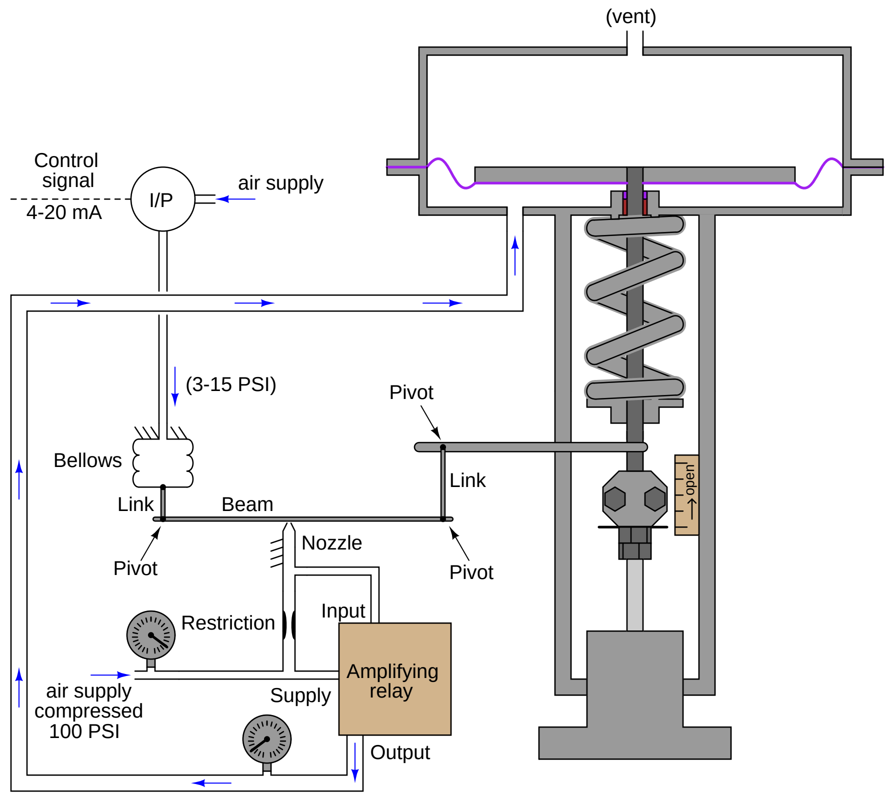
Fault	Possible	Impossible
Plugged restriction		
Plugged nozzle		
Broken spring		
Leak in bellows		
Leak in actuator diaphragm		
Air supply failure		

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

file i01361

Question 5

This valve positioner system has a problem. The valve remains at 0% (fully closed) for *any* applied control signal value:



Looking at the gauges, you notice the supply gauge reads 75 PSI and the output gauge reads 0 PSI while the loop controller output is set at 100% in manual mode.

Identify the likelihood of each specified fault for this valve positioner. 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.

Fault	Possible	Impossible
Plugged restriction		
Plugged nozzle		
Broken link to valve stem		
Leak in bellows		
Leak in actuator diaphragm		
I/P output failed low		
I/P output failed high		
Positioner air supply failure		

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

file i01362

Question 6

Read and outline the "Electronic Positioners" subsection of the "Valve Positioners" section of the "Control Valves" chapter in your *Lessons In Industrial Instrumentation* textbook.

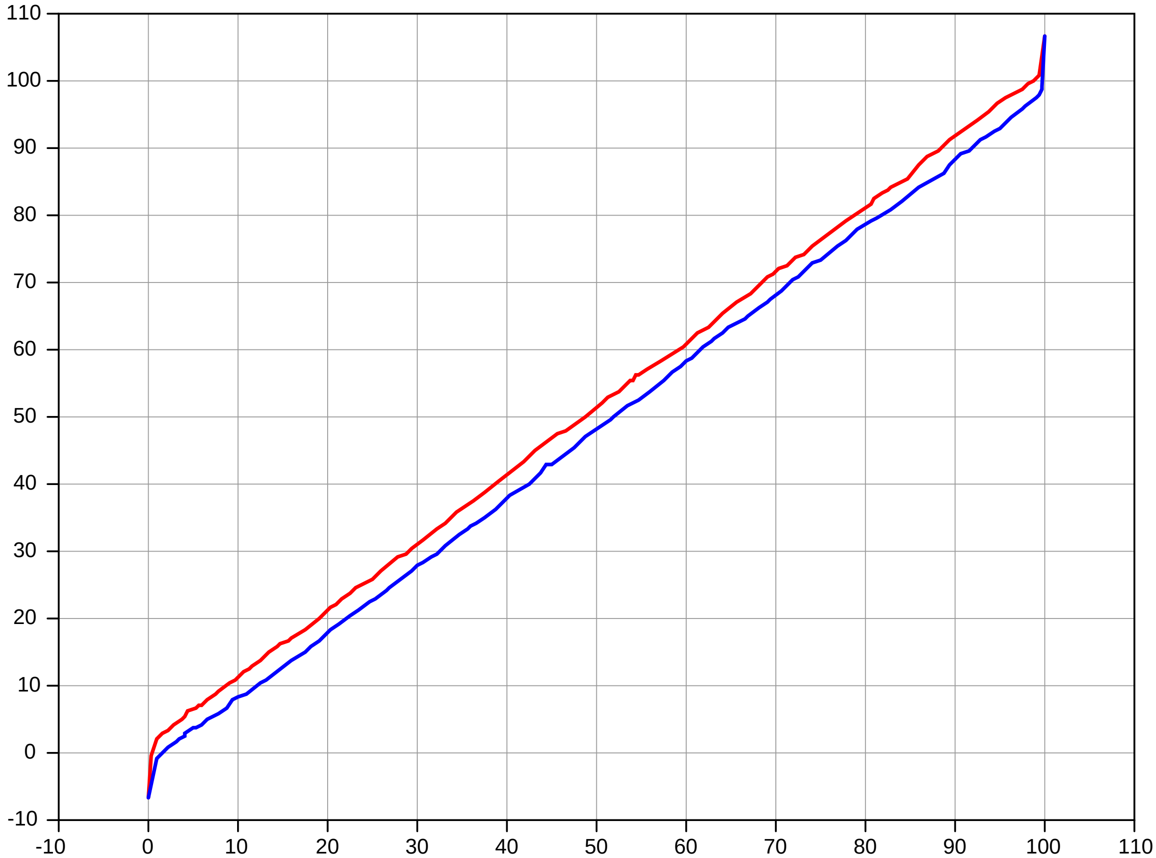
After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

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

file i01365

Question 7

One extremely useful capability of a "smart" valve positioner is the ability to measure and plot the relationship between valve stem position and actuator air pressure. An example *valve signature* is shown here:



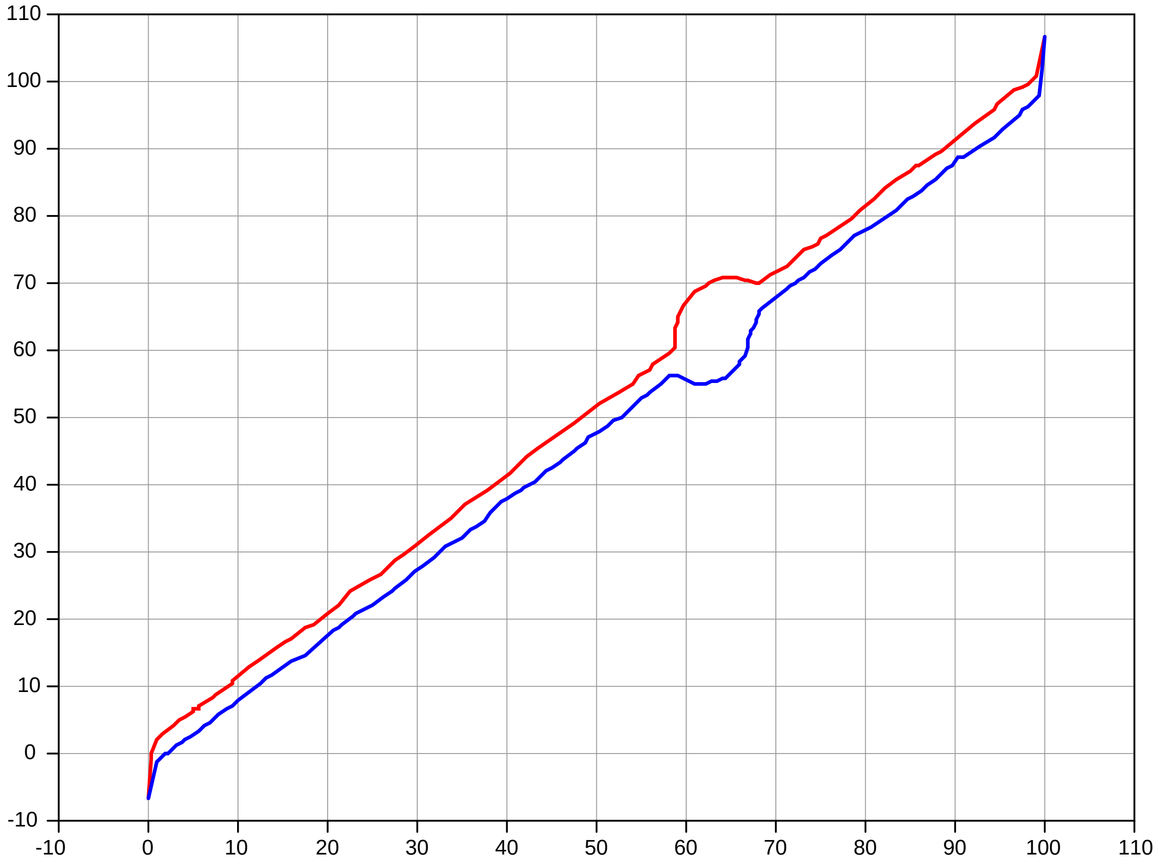
Closely examine this graph of stem position vs. actuator pressure, and answer the following questions:

- Is this an air-to-open valve, or an air-to-close valve?
- Which axis of the graph (horizontal or vertical) represents (percent of) valve stem position? How can you tell?
- Which axis of the graph (horizontal or vertical) represents (percent of) actuator air pressure? How can you tell?
- What principle of physics makes the plots (approximately) linear throughout the bulk of the travel range?
- Which of the two traces plots the valve while it is *opening*?
- Which of the two traces plots the valve while it is *closing*?
- What phenomenon accounts for the separation between the two traces?

file i04185

Question 8

While performing an "As-Found" analysis on a control valve equipped with a smart positioner, an instrument technician records this unusual valve signature:



What do you think the unusual "humps" in the traces represents? What physical problem(s) should the technician begin to look for when examining the valve?

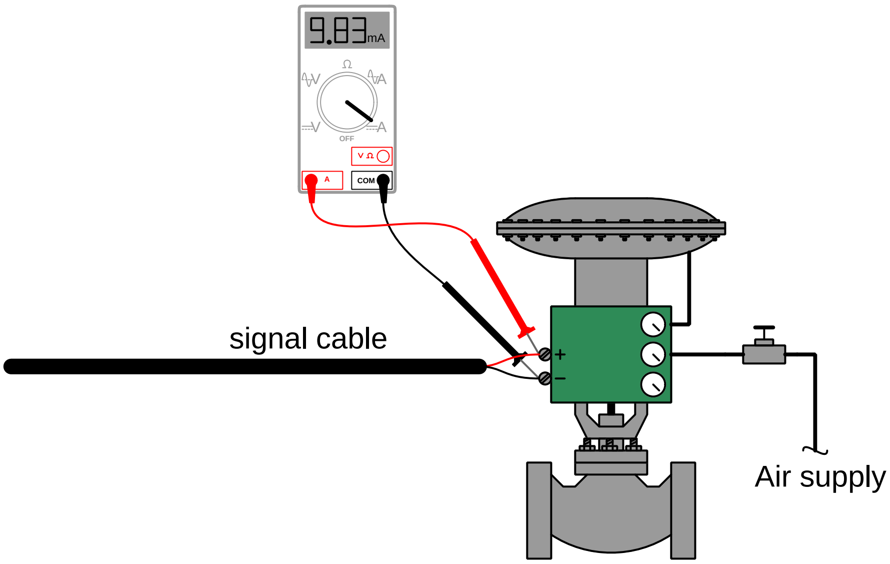
Suggestions for Socratic discussion

- A useful problem-solving technique to apply to any scenario with a graph is to let the graph "tell you" what is happening step-by-step in time as you follow it from one extreme to the other. Try doing this: starting at the lower-left corner, following the upper (red) trace step by step as though you are re-playing the opening of the valve over time, interpreting the graph in terms of stem position and actuator pressure (applied force). Describe what the graph "tells" you as you follow it from one end to the other.
- Explain the significance of performing an "As-Found" test prior to disassembling or otherwise modifying the control valve. How is this similar to "As-Found" tests when calibrating sensing instruments?

file i00746

Question 9

Operators determine a control valve has a problem, because the stem is found to be at the 30% position when the loop controller is set to output 50% in manual mode. A technician goes to this valve to diagnose the problem, and begins by connecting his multimeter to the circuit as shown:



The moment he connects his multimeter to the valve positioner's signal terminals, the valve closes fully and the multimeter reads 9.83 milliamps.

Based on this information, determine where the most likely location of the fault is: in the *loop controller*, the *signal wiring*, the *positioner*, or the *actuator*. Also, critique the technician's diagnostic strategy – would you have done a different test?

Suggestions for Socratic discussion

- If you were the technician and did not have any test equipment on your person such as a multimeter, how would you test the valve? Identify some sources of information available on this valve (with no test equipment) useful for diagnosing the problem.

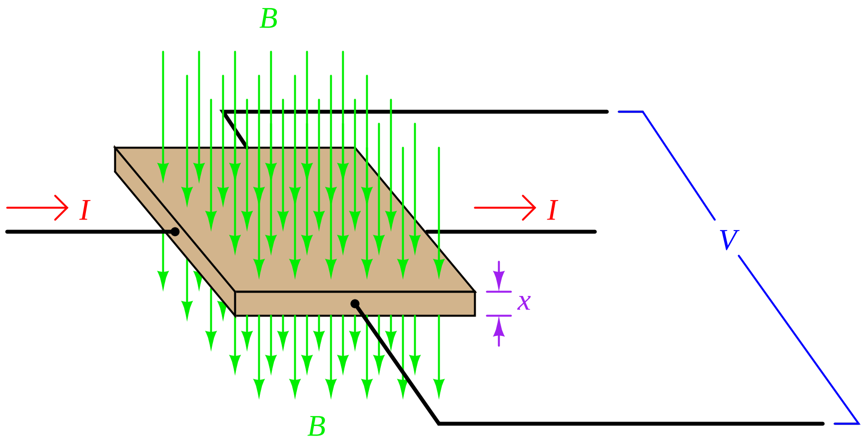
file i00748

Question 10

Digital control valve positioners need a way to sense valve stem position, in order that they may control that position in accordance with the output signal sent by the process controller to the valve. One easy way to do this is to use a *potentiometer* to translate stem position into a voltage that a microprocessor-based positioner can sense. Another way is to use a *Hall Effect sensor*.

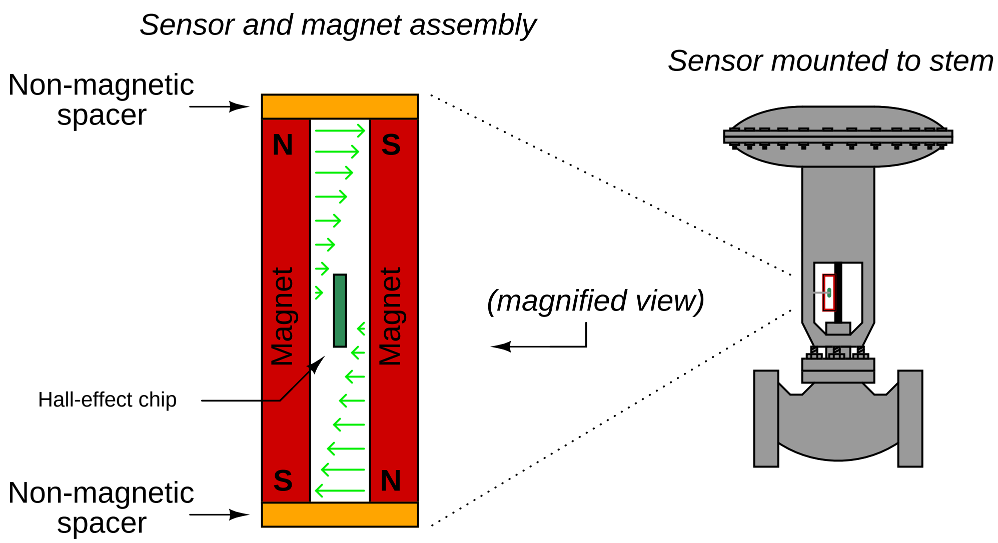
The Hall Effect is the generation of a (small) voltage in relative proportion to an electric current and an external magnetic field, all three being perpendicular to one another:

$$V_{Hall} = K\frac{IB}{x}$$



Given a constant electric current (I) through the Hall Effect chip, then, the Hall voltage becomes a direct expression of the perpendicular magnetic field's intensity and direction.

To exploit this principle for the purpose of linear (sliding stem) valve position detection, we may place a Hall Effect chip between two magnet assemblies as such, the Hall Effect sensor being stationary and the magnet assembly attached to the valve's stem so it moves up and down with it:



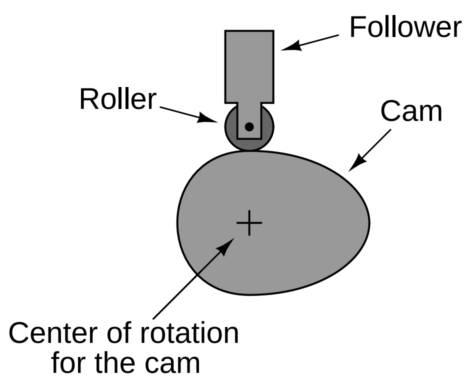
Examine this setup and then explain how the Hall Effect sensor is able to detect valve stem position. In other words, what sort of voltage signal would you expect from the Hall Effect sensor at various stem positions? Be as specific as you can in your answer.

file i01700

Question 11

Many valve positioner mechanisms use a mechanical component called a *cam* to transfer valve stem motion to another form of motion inside the positioner mechanism. Explain what a "cam" is in the general sense, and then identify where one might be used inside a positioner.

To help you in your explanation, examine this illustration of a cam and roller-follower:



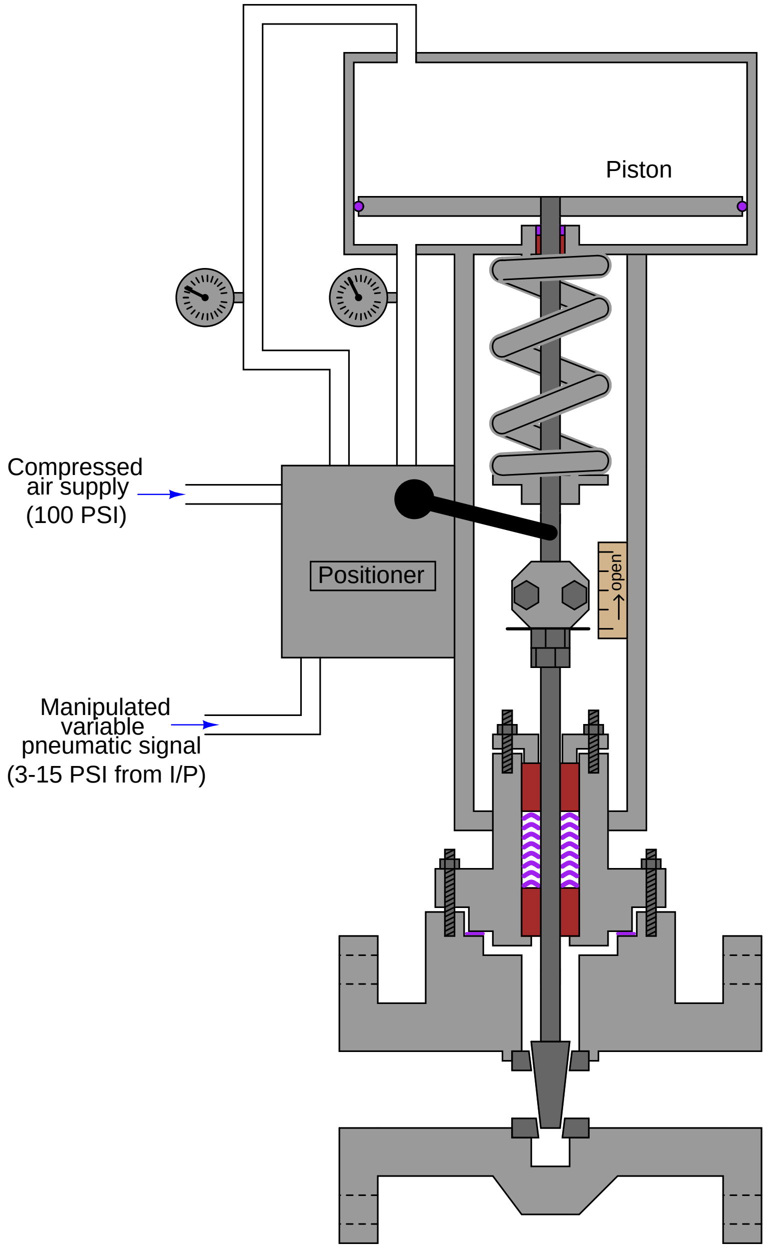
Suggestions for Socratic discussion

- One of the unique benefits of using a cam in a valve positioner is the ability to swap out the cam for one of a different *shape*. Explain what a change in cam shape could do to the behavior of a control valve.

file i01366

Question 12

Identify the pressure readings one would expect to see on the two gauges of this positioner at the following pneumatic signal values, assuming proper signal-to-open calibration:



- Gauge readings at 0% (3 PSI) signal to the positioner
- Gauge readings at 50% (9 PSI) signal to the positioner
- Gauge readings at 100% (15 PSI) signal to the positioner

Finally, identify what these gauges would indicate if the valve were seized in the mid-open (50%) position due to excessive packing friction, assuming the pneumatic input signal was at 9.4 PSI.

file i01401

Question 13

Question 14

Question 15

Question 16

Question 17

Question 18

Question 19

Question 20

Question 21

Read and outline the "Work, Energy, and Power" subsection of the "Classical Mechanics" section of the "Physics" chapter in your *Lessons In Industrial Instrumentation* textbook.

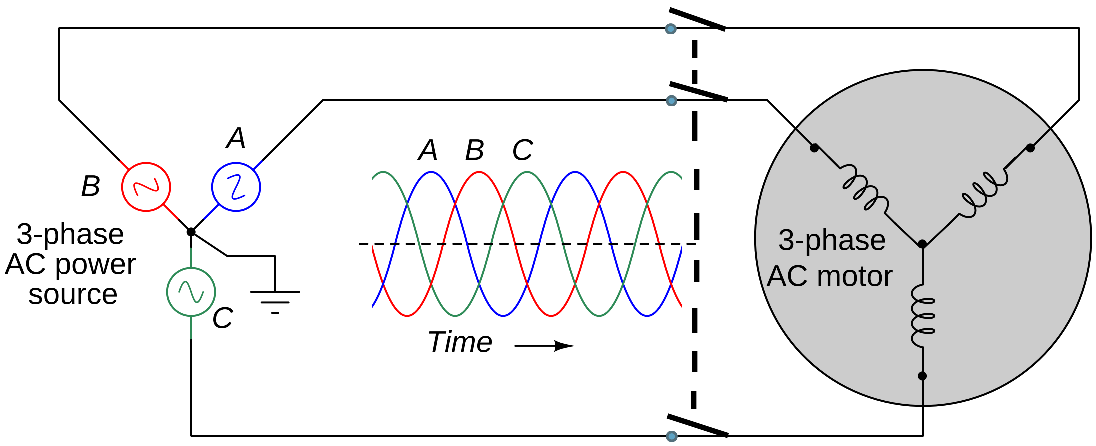
After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

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

file i04028

Question 22

The most common type of electric motor for industrial applications is the *three-phase AC induction motor*. Its basic principle of operation is rather simple: three AC voltage sources – each one 120^o phase-shifted from the other – are connected to energize sets of electromagnet coils inside the motor (called *stator* windings because they are stationary), the result being that each of those coils reaches its full "peak" magnetic force at different times. As these out-of-phase voltages cycle periodically, the stator coils produce a *rotating magnetic field* prompting the motor's rotor to rotate:



A helpful analogy is that of a string of *chasing lights* where electric lamps blink on and off in sequence to create the appearance of motion. Instead of lamps being energized in sequence, a three-phase AC induction motor's electromagnet coils energize in sequence to create the "appearance" of a rotating magnetic field.

Modify the above schematic diagram so that we may start and stop the electric motor at will.

Based on this understanding of a three-phase AC induction motor, identify what factor(s) determining the motor's *rotational speed*. Is the speed of a three-phase AC induction motor something we may easily vary? Why or why not?

Also, identify the factor(s) determining the motor's *direction of rotation*. Is the direction of a three-phase AC induction motor something we may easily alter? Why or why not?

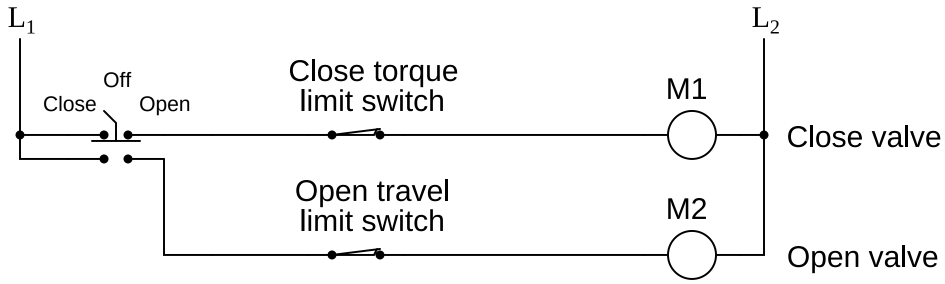
Suggestions for Socratic discussion

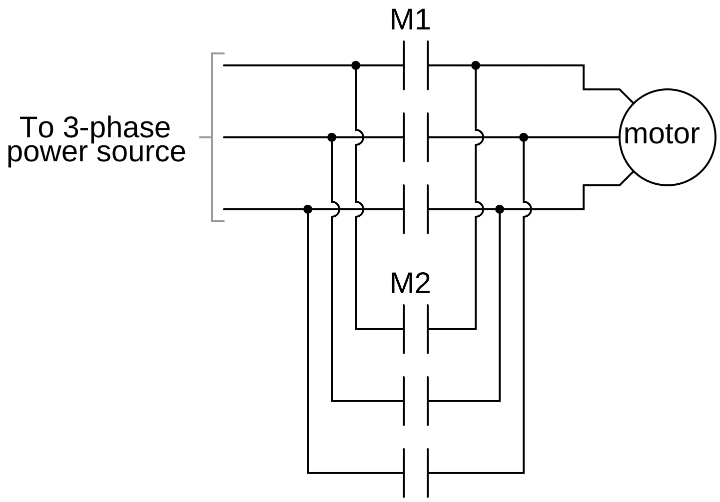
- Apply the same questions and reasoning to a set of chasing lights: how to vary the speed of the lamps' "motion" as well as the direction.
- How do you suppose we generate three-phase AC power? What sort of machine or system might be able to do this?

file i01847

Question 23

Explain how this motor control circuit works for an electrically-actuated gate valve. Note the use of a three-position switch with "Close," "Off," and "Open" positions:





Specifically, explain why the upper limit switch is designed to open when it detects a certain amount of motor torque, and why the lower limit switch is designed to open when it detects a certain distance of valve stem travel. It will help greatly to consider how a gate valve works when answering this question!

Suggestions for Socratic discussion

- Explain how to interpret the symbol used for the "Close/Off/Open" switch.
- Explain what *arc flash* is, and how to protect yourself from it while working on high-voltage motor control circuits such as this one.

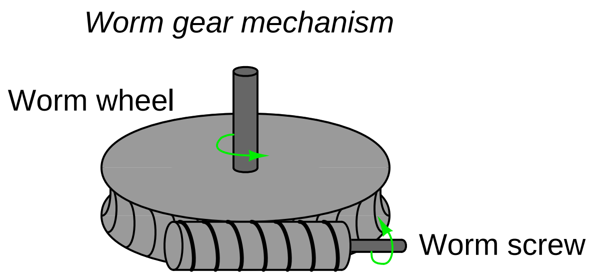
file i01392

Question 24

Read selected portions of the Limitorque L120 series actuator (L120-10 through L120-40) manual published by FlowServe (document FCD LMENIM1201-01, 07/06), and answer the following questions:

Page 24 shows an "exploded view" of the actuator mechanism. Examine this illustration and identify the locations of the *worm gear*, *electric motor*, *limit switch assembly*, and *torque switch assembly*.

Note: a "worm" gear is a type of gear set where a screw engages with the teeth of a gear wheel to form a large speed reduction ratio:



Page 18 shows an optional handwheel for the L120-40 actuator. Examine this drawing and identify the gears used to multiply torque from the handwheel to the actuator mechanism. Note: there are actually *two* sets of gears used for torque multiplication in this large handwheel: a set of *spur gears* and a set of *bevel gears*. Identify both and try to explain their operation from the drawing.

Page 21 shows an electrical schematic for the L120 actuators. Identify some of the different *limit switches* used to detect valve position and shaft torque, and explain how they work to indicate valve status and also protect the valve and actuator from overload.

Referencing the schematic diagram on page 21, identify the effect(s) of the purple wire failing open.

Suggestions for Socratic discussion

- Explain the significance of the optional jumper wire around limit switch #8.
- Explain how to interpret the "Limit Switch Contact Development" table shown at the bottom of the schematic page.
- Explain how to interpret the Local/Off/Remote switch symbol, particularly how its switch contact positions relate to the actuator lever.
- Explain why the primary winding of the control power transformer has multiple taps.

file i04223

Question 25

Read and outline the introduction to the "Variable-Speed Motor Controls" chapter as well as the "Metering Pumps" section of that same 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.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Any points of confusion, and precisely why you found the text confusing.
(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

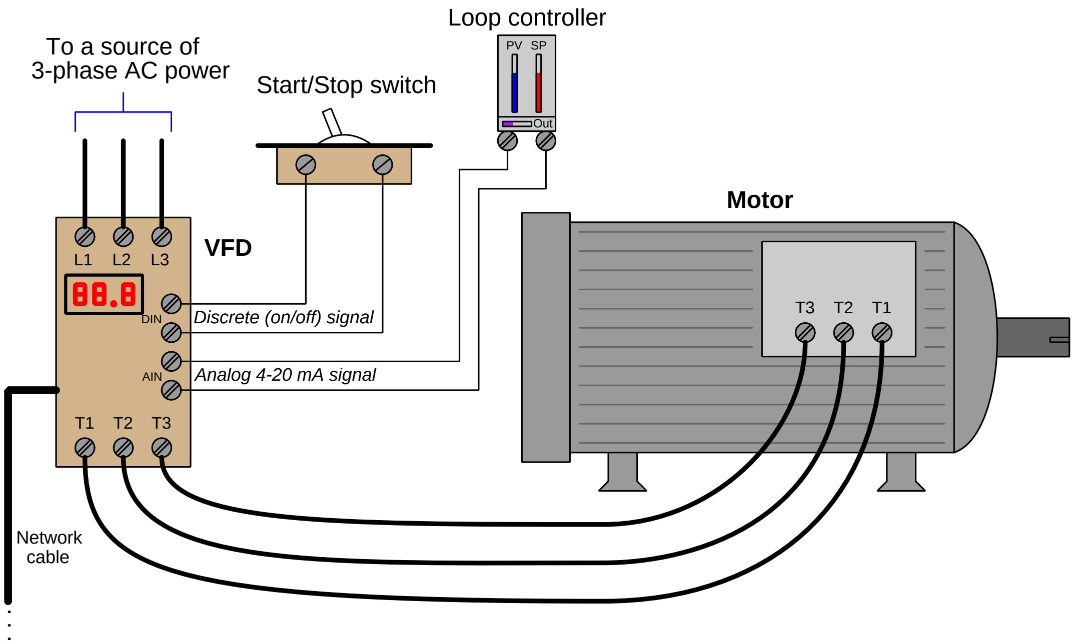
Suggestions for Socratic discussion

- When programming an electronic motor "drive" to control the speed of that motor, it is vitally important for that drive to be properly configured with the motor's nameplate data (e.g. rated voltage, rated current, maximum speed, etc.). Explain why this is so important to get right, and what could happen if these "base" parameters are misconfigured.

file i04231

Question 26

A *Variable Frequency Drive* or *VFD* is an electronic power controller designed to exert control over the operation of a three-phase AC induction motor. VFDs are extremely versatile devices, able to control the motor's speed and direction via command signals sent to it by external devices such as switches, potentiometers, loop controllers, and even computers. A typical VFD-controlled motor appears in this illustration:

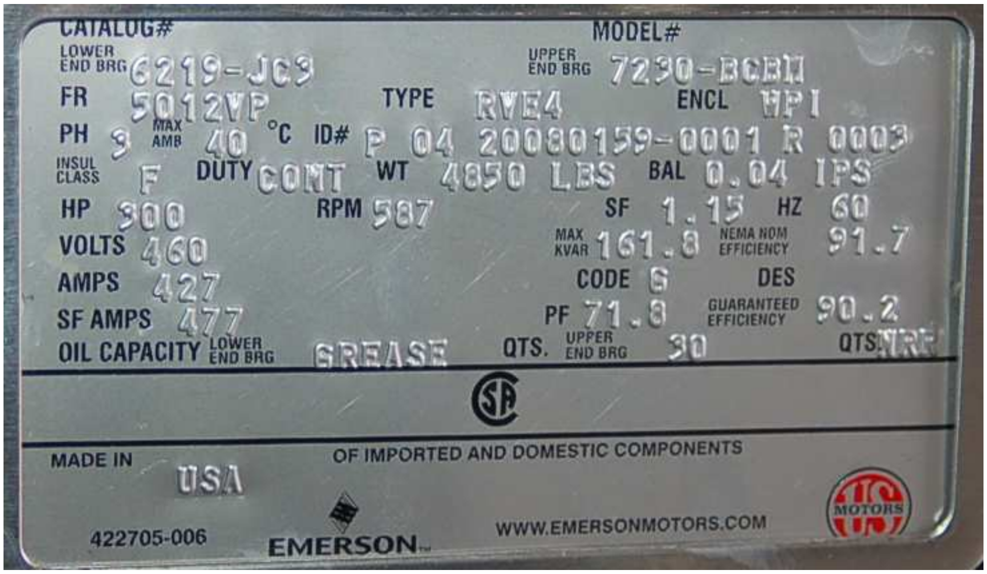


The VFD takes AC input power, rectified it into DC, then converts it into three-phase AC at a frequency matching the desired motor speed. In addition to varying the frequency of the power sent to the motor, the VFD also adjusts the output voltage in order to create the desired amount of torque (i.e. twisting force) at the motor shaft.

In this system, a discrete (on/off) signal from a SPST switch commands the VFD to start and stop the motor, while an analog 4-20 mA current signal commands the motor's speed. A network cable allows other data to be written or read by a computer, PLC, or other digital control device. The ability to externally control a VFD makes it very useful as a final control element in an automation system.

Being programmable devices, VFDs typically have dozens if not hundreds of user-configurable *parameters* defining such important factors as the motor's nameplate ratings, acceleration and deceleration time limits, maximum speed, braking methods, etc. Arguably the most important VFD parameters are those associated with the electric motor's ratings. Improper setting of these VFD parameters may result in premature motor failure and/or destruction of the VFD!

Suppose you were tasked with programming a VFD's parameters to match it to a large electric motor turning a water pump at a wastewater treatment plant. This motor will be started and stopped by a computer digitally communicating with the VFD via a Modbus network, with motor speed set by a 4-20 mA analog signal (with 4 mA being completely stopped and 20 mA being full-speed). Assume we wish to limit the motor's speed to a maximum of 500 RPM. The pump motor's nameplate is shown in the following photograph:



Some of the VFD's many parameters are listed below. For each one, provide either a numerical value or "N/A" (not applicable, if you cannot determine) based solely on the data you have about this motor:

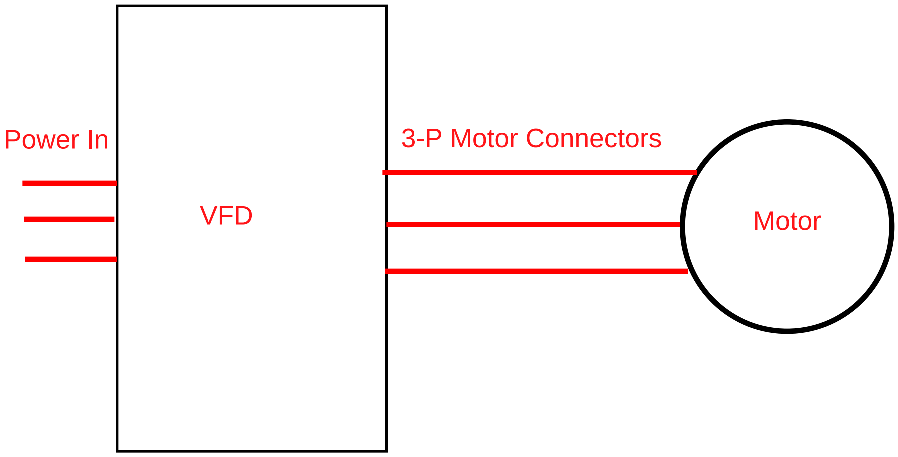
- Parameter 01 (Acceleration Time) = __________ seconds
- Parameter 02 (Deceleration Time) = __________ seconds
- Parameter 03 (Volts/Hz Curve) = __________ 0 (*Default*), 1 (*High Torque*), or 2 (*Fans/Pumps*)
- Parameter 04 (DC Boost) = __________ Percent
- Parameter 05 (Overload Current) = __________ Amperes
- Parameter 06 (Line Voltage) = __________ Volts
- Parameter 07 (Base Frequency) = __________ Hz
- Parameter 08 (Base Speed) = __________ RPM
- Parameter 09 (Speed Reference) = __________ 0 (*Keypad*), 1 (*4-20 mA*), 2 (*Modbus*), or 3 (*Fixed*)
- Parameter 10 (Start Source) = __________ 0 (*Keypad*), 1 (*2-wire switch*), 3 (*3-wire switch*), or 4 (*Modbus*)
- Parameter 11 (Minimum Output Frequency) = __________ Hz
- Parameter 12 (Maximum Output Frequency) = __________ Hz

file i01389

Question 27

Suppose you were asked to configure a Rockwell Powerflex 4 VFD to a three-phase AC induction motor rated at 208 VAC, 15 Amps, 1740 RPM at full load and 60 Hz. The VFD will be started and stopped from its keypad, and the motor's speed must be controlled by a 5 kΩ potentiometer over its full range from 0 to 1740 RPM.

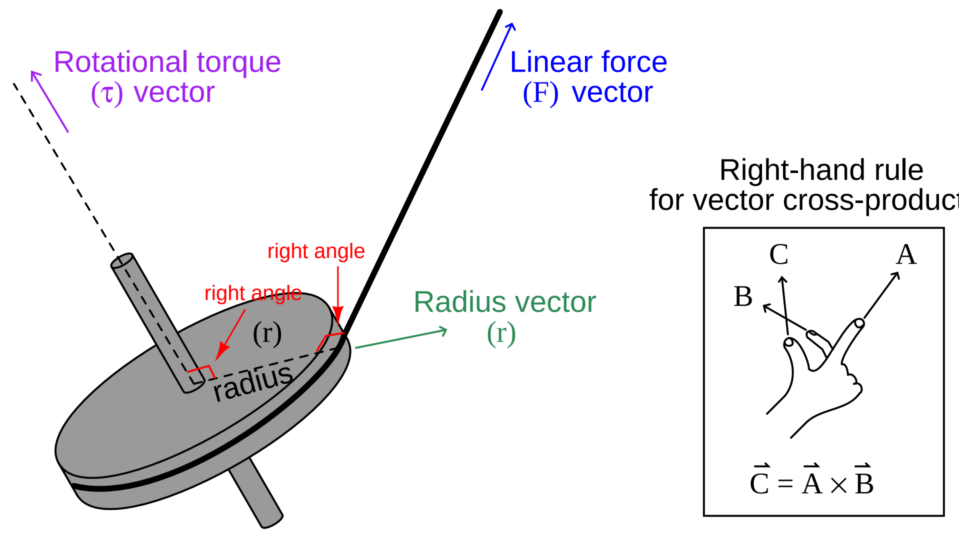
Sketch a simple diagram showing the necessary power conductors connected to the VFD and the motor, and identify the important VFD parameter settings for this application.



file i01895

Question 28

The rotational equivalent of *force* is something called *torque*. The following diagram shows its physical definition in the context of a rope exerting force on the circumference of a pulley:

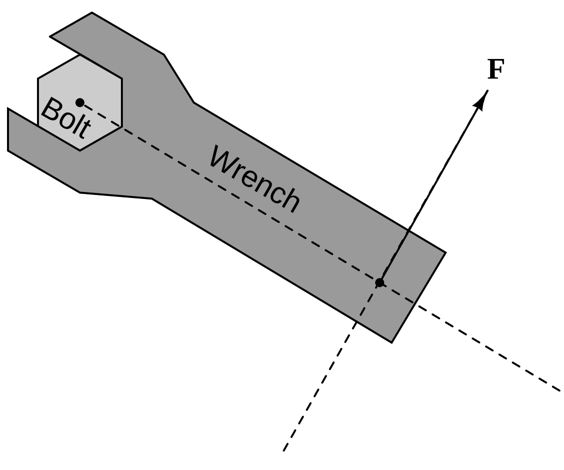


Mathematically, torque is the product of the force vector and the radius vector perpendicular to the force (called the "moment arm"):

$$\vec{\tau} = \vec{r} \times \vec{F}$$

Based on this formula, determine the proper unit of measurement for torque, given force in *pounds* and radius in *feet*.

Next, calculate the amount of torque applied to the bolt head by the wrench, assuming the force measures 82 ounces and the length of the moment arm is 17 inches:



Suggestions for Socratic discussion

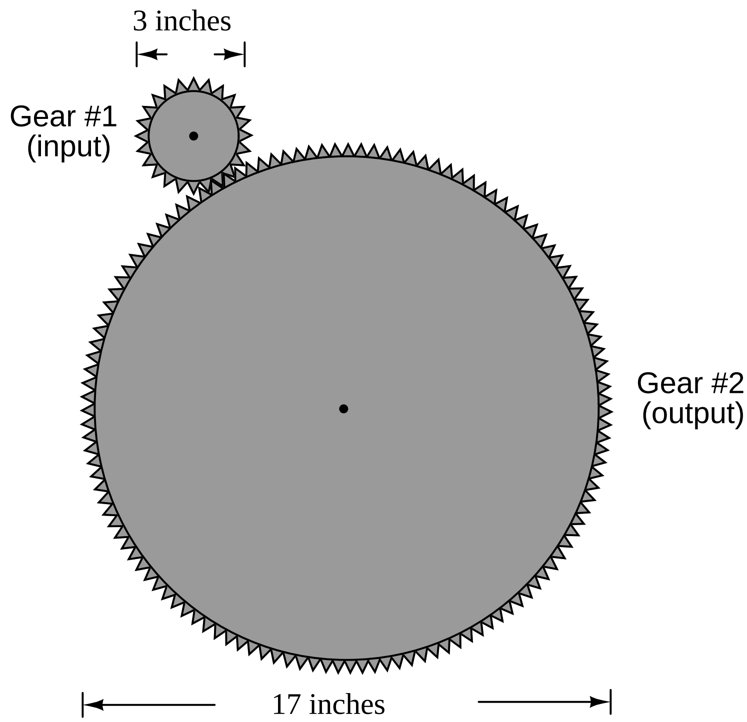
- An important detail to note is that although the formulae for calculating torque involves the multiplication of *pounds* of force and *feet* of distance just like the formula for work ($W = Fx$), torque in pound-feet is definitely not the same thing as work in foot-pounds. Give a practical example illustrating how torque and work cannot be the same quantity despite bearing very similar units of measurement.

  file i01403

Question 29

When two gears mesh together, their rotational speeds and torques are both related to the ratio of diameters (also the same as the ratio of gear teeth, since the teeth on each gear must be identically sized in order to properly mesh). For example, if one gear having 35 teeth meshes with a second gear of equal diameter (also having 35 teeth), the gear ratio will be 1:1, which means they will rotate at exactly the same speed and with exactly the same amount of torque.

Suppose two gears mesh together to form a speed reduction mechanism, with the following diameters:



Based on this diagram of the two gears, answer these questions:

- Calculate the *gear ratio* of this gear set.
- If the first gear's shaft exerts a torque of 600 lb-ft on the gear (the "input" torque), how much torque will be exerted on the second gear's shaft (the "output" torque)?
- If the input gear spins at 200 RPM, how fast does the output gear spin?
- If the small gear has 24 teeth, how many teeth will the large gear have?

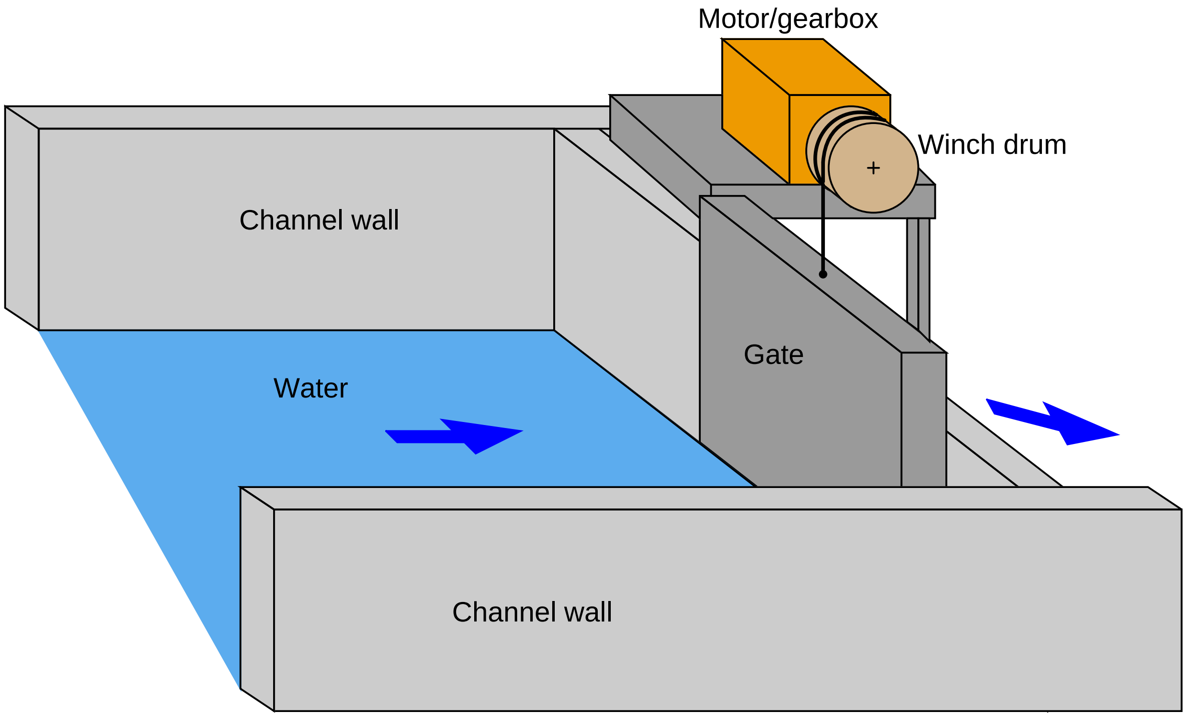
Suggestions for Socratic discussion

- Use the torque formula $\vec{\tau} = \vec{r} \times \vec{F}$ (torque being the product of radius and linear force) to solve for the torque ratio $\left(\frac{\tau_1}{\tau_2}\right)$ knowing the diameter (or radius) ratio of two meshing gears.
- Use the speed formula $v = r\omega$ (rim velocity being the product of radius and rotational speed) to solve for the rotational speed ratio $\left(\frac{\omega_1}{\omega_2}\right)$ knowing the diameter (or radius) ratio of two meshing gears.

file i01405

Question 30

Suppose an electric actuator is used to lift a large concrete gate in an irrigation water flow control facility. The gate effectively acts as a control valve for water flowing through an open irrigation channel, and a powerful winch is necessary to control its position:



The winch drum measures 20 inches in diameter, and the concrete gate weighs 12,740 pounds. Calculate the torque required at the drum to lift the gate, and also the torque required by the electric motor given a gearbox speed-reduction ratio of 1200:1.

Assuming the electric motor powering this speed-reducing gearbox spins at 1720 RPM (at full load), calculate the vertical lifting speed of the gate in feet per minute. Finally, calculate the horsepower output of the electric motor lifting this much weight (12,740 pounds) at this vertical speed.

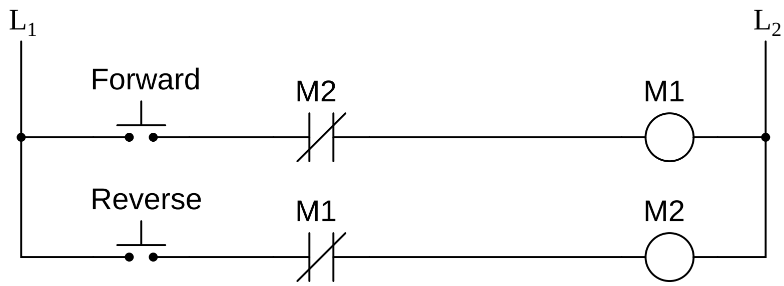
Suggestions for Socratic discussion

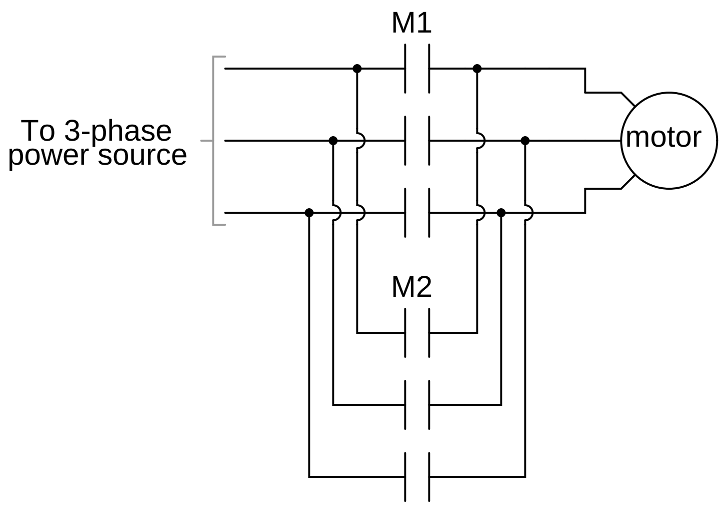
- Like all "story problems" involving mathematical calculation, the most important aspect of your answer is *how* you arrived at it, not the numerical value(s) of your answer. Explain how you were able to set up the proper equations to solve for drum torque, motor torque, lifting speed, and motor output power.
- A useful problem-solving technique is to sketch a simple diagram of the system you are asked to analyze. This is useful even when you already have some graphical representation of the problem given to you, as a simple sketch often reduces the complexity of the problem so that you can solve it more easily. Draw your own sketch showing how the given information in this problem inter-relates, and use this sketch to explain your solution.

file i00584

Question 31

The direction of rotation for a three-phase AC electric motor may be reversed by swapping any two of the three power conductor connections. With this in mind, explain how this reversing motor control circuit works:





In particular, what is the function of the two normally-closed "M" contacts (called *interlock* contacts) in the control circuit? What do you think might happen if those contacts were not there?

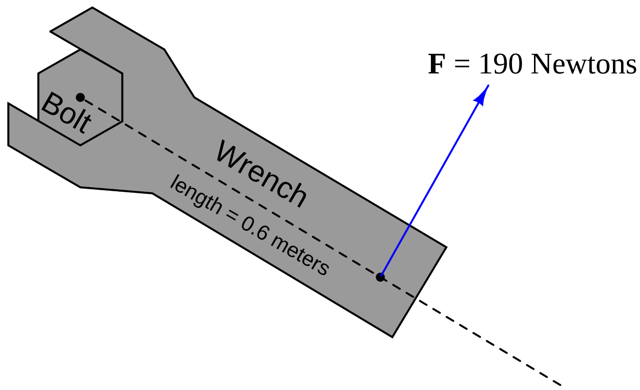
Suggestions for Socratic discussion

- Explain *why* reversing any two phase conductors supplying AC power to an induction motor will cause it to reverse direction.
- Explain what *arc flash* is, and how to protect yourself from it while working on high-voltage motor control circuits such as this one.
- Suppose an electrician tries to force the motor to spin in its forward direction by connecting a temporary jumper wire across relay coil M1. Will this accomplish the desired result? Explain why or why not, and also identify any potential safety hazards in doing this.
- Suppose an electrician tries to force the motor to spin in its forward direction by connecting a temporary jumper wire across the "Forward" pushbutton. Will this accomplish the desired result? Explain why or why not, and also identify any potential safety hazards in doing this.
- Suppose an electrician tries to force the motor to spin in its forward direction by connecting three temporary jumper wires across the M1 contacts. Will this accomplish the desired result? Explain why or why not, and also identify any potential safety hazards in doing this.

file i01391

Question 32

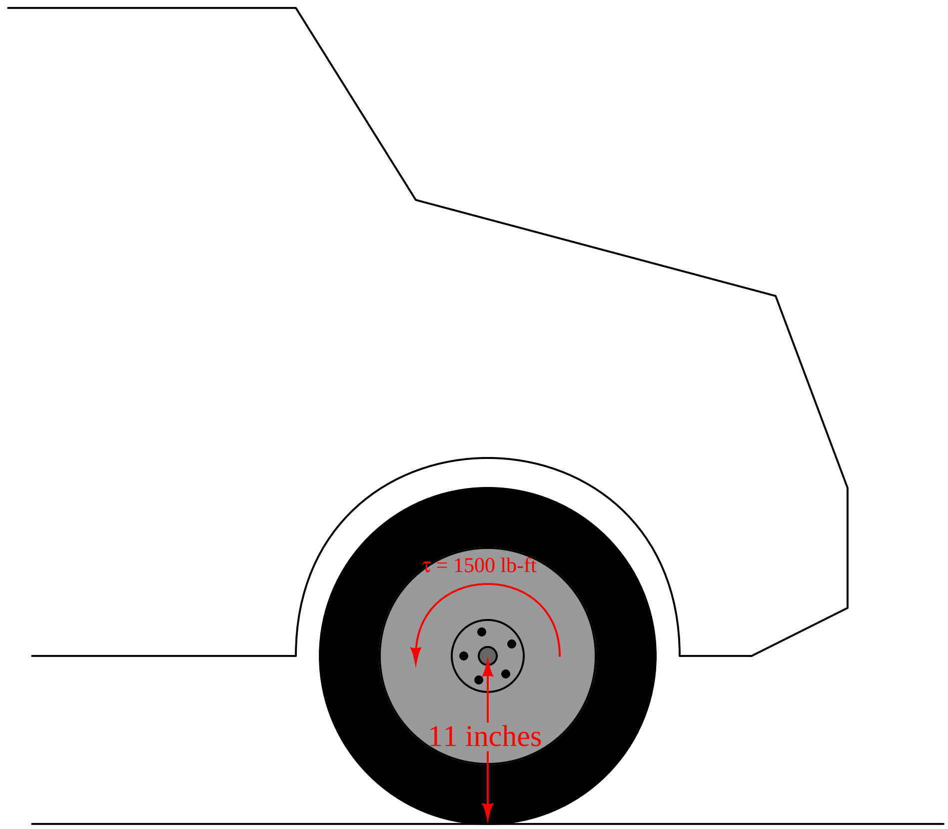
Suppose a mechanic pulls perpendicularly at the end of a wrench 0.6 meters in length with a steady force of 190 newtons for two complete revolutions. Calculate the amount of work done by the mechanic (in newton-meters or joules), and also calculate his power output in watts if those two turns were completed in 6 seconds.



file i03777

Question 33

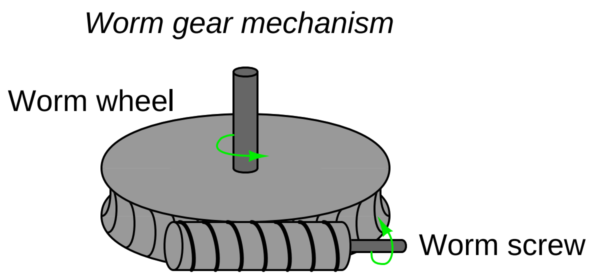
How much linear force will the car's tire exert on the ground if the axle exerts a torque of 1500 lb-ft on the wheel, and the tire's radius is 11 inches?



file i01402

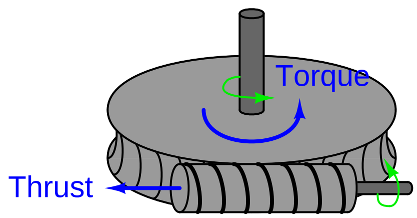
Question 34

Electric motors usually rotate at too high of speed to be used directly as valve actuators. Nearly all electric valve actuators use gear mechanisms to reduce the speed of the electric motor (and multiply its torque). One of the more popular gear mechanisms for achieving great speed reduction (and torque multiplication) is called the *worm gear*:



The worm wheel's teeth match the pitch of the threads on the worm screw, allowing the two pieces to mesh like gears. It should be evident from inspection that it takes many, many turns of the work screw to obtain one revolution of the work wheel. In electric valve actuators, the motor couples to the worm screw and the wheel turns the valve mechanism.

What might not be so evident is how torque on the worm wheel directly translates to linear thrust on the worm screw. In other words, the more twisting force output by the worm wheel, the greater the straight-line force experienced by the screw:

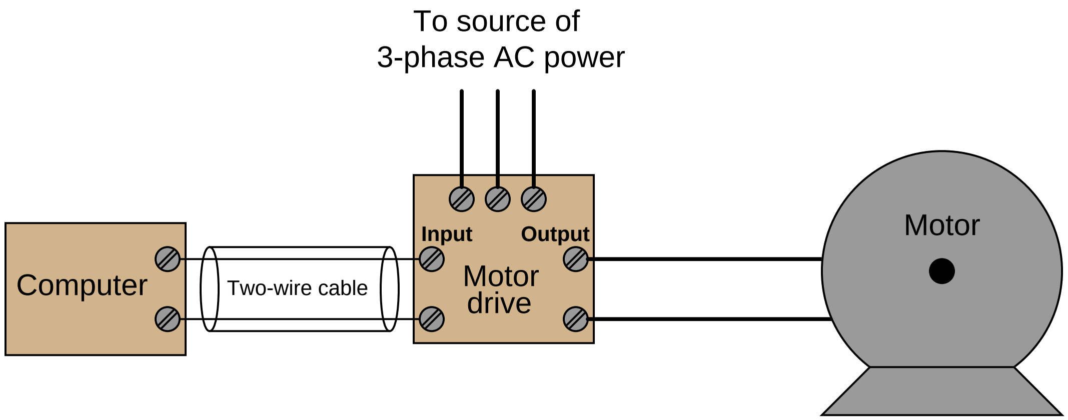


If we can find a way to measure this linear thrust on the worm screw, we may infer the torque output by the wheel. Explain how this could be done in an electric valve actuator mechanism.

file i01390

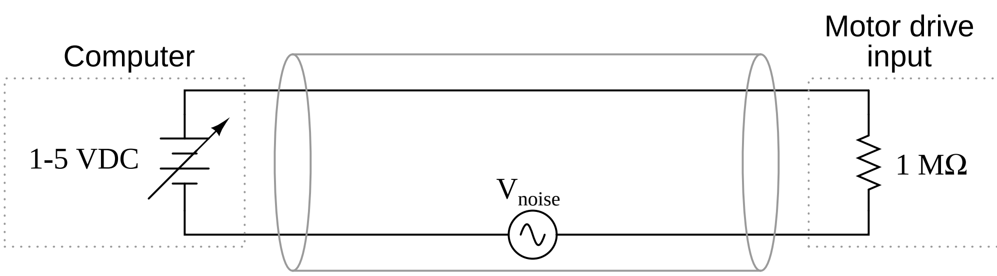
Question 35

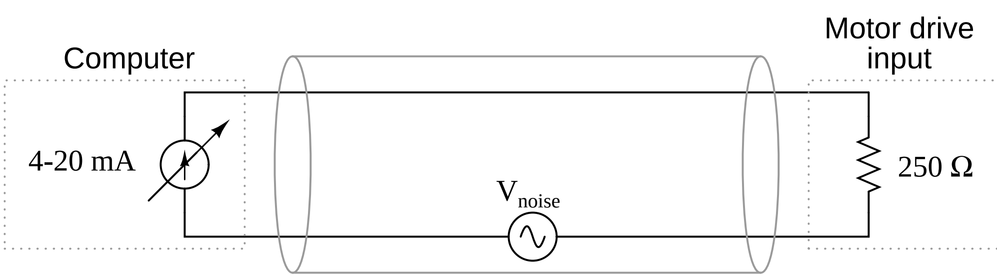
Electrical signals are frequently used in industrial control applications to communicate information from one device to another. An example of this is motor speed control, where a computer outputs a speed command signal to a motor "drive" circuit, which then provides metered power to an electric motor:



Two common standards for analog control signals are 1-5 volts DC and 4-20 mA DC. In either case, the motor will spin faster when this signal from the computer grows in magnitude (1 volt = motor stopped, 5 volts = motor runs at full speed; or 4 mA = motor stopped, 20 mA = motor runs at full speed).

At first, it would seem as though the choice between 1-5 volts and 4-20 mA as control signal standards is arbitrary. However, one of these standards exhibits much greater immunity to induced noise along the two-wire cable than the other. Shown here are two equivalent schematics for these signal standards, complete with an AC voltage source in series to represent the "noise" voltage picked up along the cable's length:





Use the Superposition theorem to qualitatively determine which signal standard drops the greatest amount of noise voltage across the motor drive input's resistance, thereby most affecting the motor speed control.

file i00128

Question 36

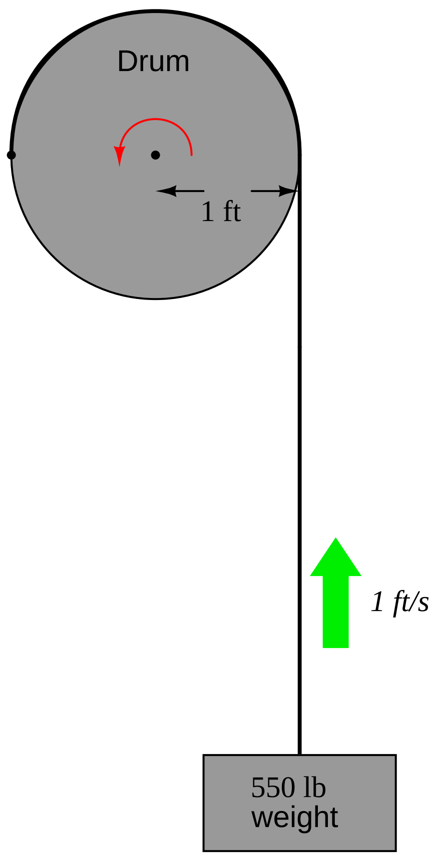
A *horsepower* is defined as 550 ft-lbs of work done in one second of time. An example of this would be a 550 pound weight lifted vertically at a speed of one foot per second, or a one pound weight lifted vertically at a speed of 550 feet per second.

There is a way to relate this to rotary motion, not just linear motion. In the case of rotary motion we must deal with torque (τ) in lb-ft and angular speed (S) in revolutions per minute (RPM) rather than force in pounds and linear speed in feet per second.

Just as linear power is proportional to the product of force and velocity ($P \propto Fv$), rotary power is proportional to torque and rotary speed ($P \propto \tau S$). What we need to turn this proportionality into an equality is a multiplying constant (k):

$$P = k\tau S$$

We may determine the value of this constant by setting up a "thought experiment" that translates between linear power and rotary power:

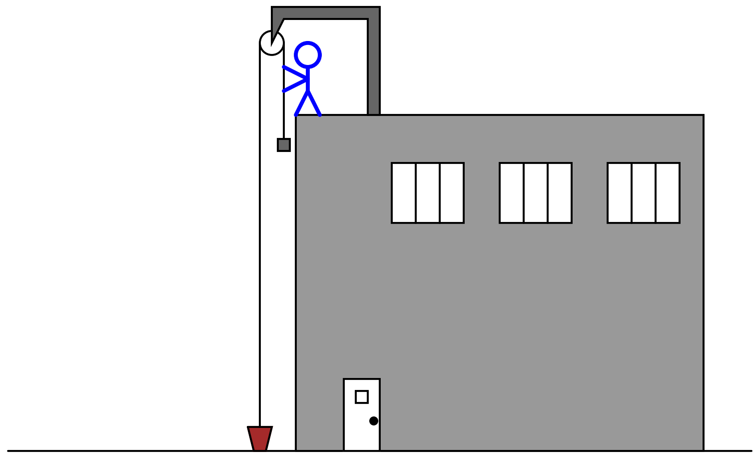


In this case, we have a 1 foot radius drum hoisting a 550 pound weight at a linear velocity of 1 foot per second, the definition of one horsepower. Translate the linear force and linear velocity to rotary force (torque) and rotary velocity (revolutions per minute), and then calculate the necessary k factor to make your own torque/speed/horsepower equation.

file i01430

Question 37

A laborer working on the top of a building uses a hoist to lift 20 gallons of water in a bucket to the top of a building:



The rope is counterweighted with a mass equal to that of the bucket (empty), so that the bucket's weight does not have to be lifted, only the water inside the bucket. Assuming a vertical lift distance of 31 feet, how much work does the laborer do in lifting the water up? Please express your answer in both English and metric units of work.

Suppose it takes laborer "A" one minute to lift the 20-gallon bucket of water up 31 feet to the top of the building. A few hours later, laborer "B" does the same thing, but in less time: 40 seconds. Which laborer performs more work in lifting 20 gallons of water to the roof?

Now suppose someone smart decides to equip the hoist with an electric motor, so that the laborers do not have to exert so much effort in lifting water to the roof. If the motor exerts 1.5 horsepower in lifting the 20 gallons of water to the roof, how long will it take to lift it the 31 foot vertical distance?

How long would it take a 1.5 horsepower *pump* to lift 20 gallons of water to the same height?

Challenge question: if we were to drop the 20-gallon bucket full of water off the roof, how fast would it be falling just before it hit the ground? Disregard the effects of air friction on the bucket's free-fall.

file i00428

Question 38

If 40 pounds of books are lifted from floor level to a bookshelf 5 feet above, then later those same books are taken off the shelf and returned to floor level, what is the total amount of work done by the person moving the books?

file i02620

Question 39

Read selected portions of the Rotork "AWT range" actuator manual (document E320E, issue 10/02), and answer the following questions:

Page 3 shows a "cutaway view" of the actuator mechanism. Examine this illustration and identify the locations of the *worm gear*, *electric motor*, and *limit switch assembly*.

Page 5 discusses the switch features of this actuator, including limit (travel) and torque switches. Identify the types of valves recommended for "Torque" versus "Limit" seating.

Page 12 shows a schematic diagram for this electric actuator. Examine this diagram, then explain how the electric motor's direction of rotation is controlled (i.e. what switching occurs to reverse the motor's rotation).

Using the schematic diagram on page 12 as a guide, identify potential faults that could cause the valve to refuse to open (assume C1 is the "open" contactor and C2 is the "close" contactor), and how you could confirm each one of these potential faults using a multimeter:

- Identify at least one specific problem in the three-phase power contacts to the motor
- Identify at least one specific problem in the contactor coil(s)
- Identify at least one specific problem in the main control circuit board

file i04224

Question 40

Question 41

Read and outline the "Complementary Valve Sequencing" subsection of the "Split-Ranging" section of the "Control Valves" 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.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Any points of confusion, and precisely why you found the text confusing.
(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

file i04208

Question 42

Read and outline the "Exclusive Valve Sequencing" subsection of the "Split-Ranging" section of the "Control Valves" 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.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Any points of confusion, and precisely why you found the text confusing.
(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

file i04220

Question 43

Read and outline the "Progressive Valve Sequencing" subsection of the "Split-Ranging" section of the "Control Valves" 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.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Any points of confusion, and precisely why you found the text confusing.
(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

file i04221

Question 44

Read and outline the "Valve Sequencing Implementations" subsection of the "Split-Ranging" section of the "Control Valves" chapter in your *Lessons In Industrial Instrumentation* textbook.

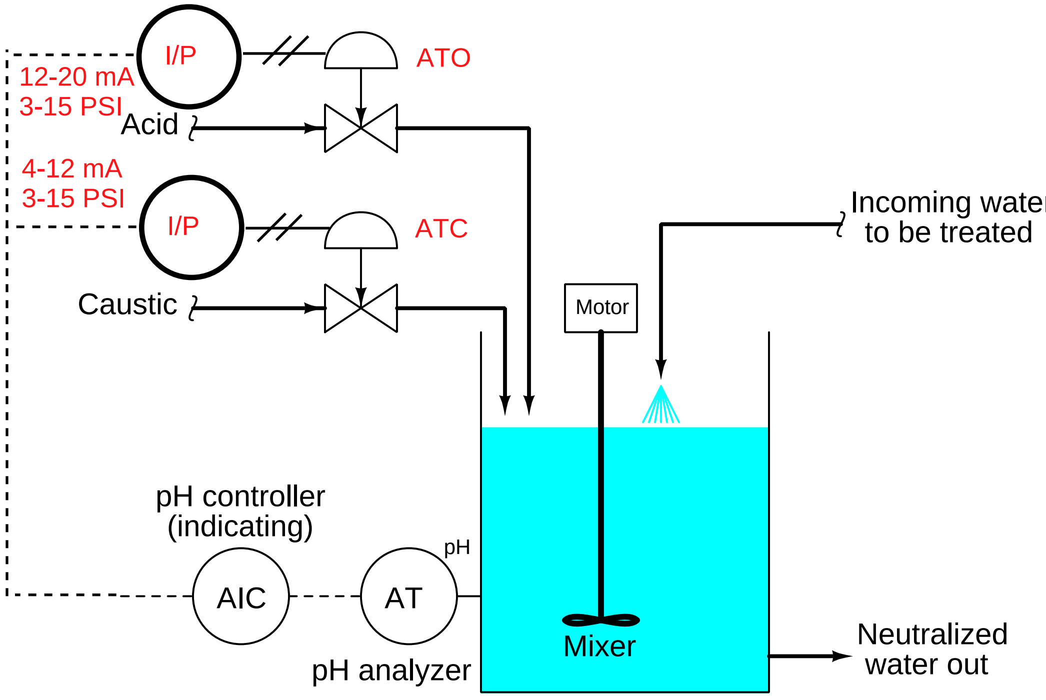
After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

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

file i04209

Question 45

A mixing vessel in a wastewater treatment plant receives water at varying levels of pH, and the control system's task is to maintain the outgoing water pH around 7 (neutral) by adding acid or caustic as needed. If the incoming water is too acidic (pH below 7), the system should add more caustic; if the incoming water is too alkaline (pH above 7), the system should add more acid:



If the incoming pH is below 7 (acidic), then the control system needs to open the caustic valve to increase the outflow pH. If the incoming pH is above 7 (caustic), then the control system needs to open the acid valve to decrease the outflow pH. It would be wasteful, however, to add both acid *and* caustic to the mixing vessel at the same time, as they would tend to nullify each other.

How is it possible to operate the acid/caustic valves in such a manner from a single controller? Sketch a solution into the above P&ID to show how you would accomplish this.

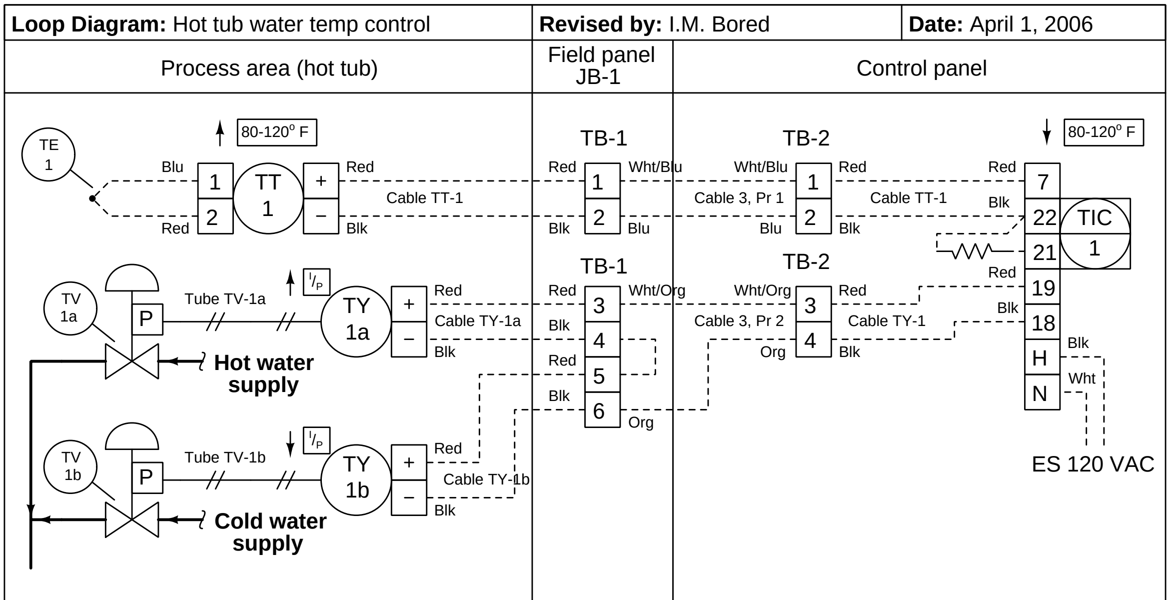
Suggestions for Socratic discussion

- A good problem-solving technique to apply in cases where we need to determine the direction of a change is to consider *limiting cases*. Instead of asking ourselves what would happen if the pH changes slightly, we ask ourselves what would happen if the pH changes *dramatically*. Explain how this problem-solving technique applies to this particular system where we must determine necessary controller action and final control element sequencing.
- What do the arrow symbols on the valve stems represent?
- Identify the consequence of losing instrument air to the control valves – what will happen to the effluent pH?
- Identify the consequence of a failed-open 4-20 mA cable in your proposed solution – what will happen to the effluent pH?
- Identify alternative split-range sequencing configurations (other than the one you proposed in your answer).

file i01395

Question 46

A very bored and overpaid instrument technician decides to equip her hot tub with this temperature control system, which works by varying the ratio of hot to cold water added to the tub:



Tag number	Description	Manufacturer	Model	Calibration	Notes
TE-1	Thermocouple	Omega		Type T	Ungrounded tip
TT-1	Temperature transmitter	Rosemount	3144	80-120°F 4-20 mA	
TIC-1	Controller	Siemens	PAC 353	1-5 V 80-120°F	Reverse-acting control
TY-1a	I/P transducer	Fisher	546	4-20 mA 3-15 PSI	Direct-acting calibration
TY-1b	I/P transducer	Fisher	546	20-4 mA 3-15 PSI	Reverse-acting calibration
TV-1a	Control valve	Fisher	Easy-E	3-15 PSI	Air-to-open
TV-1b	Control valve	Fisher	Easy-E	3-15 PSI	Air-to-open

Examine this loop diagram closely, and then answer the following questions:

- Where does the "split-ranging" (sequencing) take place in this system?
- What will happen in the event that cable 3 becomes completely severed?
- What will happen in the event of total instrument air pressure loss?
- Determine the positions of both valves at a controller output signal of 13.5 mA.
- How much voltage will the controller have to output between terminals 19 and 18 when the output signal is at 100% of range? Assume a coil resistance of 176 ohms for each of the model 546 I/P transducers.

Suggestions for Socratic discussion

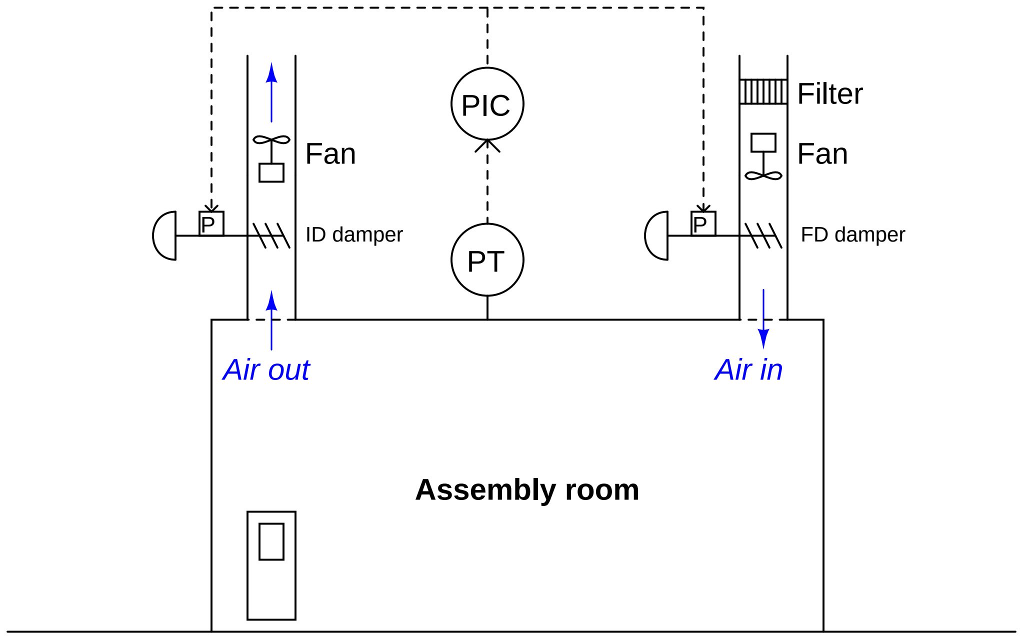
- Identify an alternative scheme for accomplishing the same sequence of split-ranging. In other words, wherever the split-range sequencing happens in this system, devise a way the sequencing could be done in different components.

- Would connecting the I/P transducers in parallel be a viable alternative to connecting them in series? Explain why or why not.

file i01397

Question 47

This room pressure control system maintains a slightly positive pressure in a precision electronic assembly room to prevent dust from entering from the outside, while always ensuring a rapid flow rate of air through the room. It regulates pressure by modulating two dampers: one introducing air to the room ("forced draft") and one venting air from the room ("induced draft"). A pressure transmitter outputs 4 mA at 0 "W.C room pressure and 20 mA at 2 "W.C. room pressure:



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

Forced draft damper position	Controller output signal
Fully shut (0%)	??? mA
Wide open (100%)	??? mA

Induced draft damper position	Controller output signal
Fully shut (0%)	??? mA
Wide open (100%)	??? mA

Suggestions for Socratic discussion

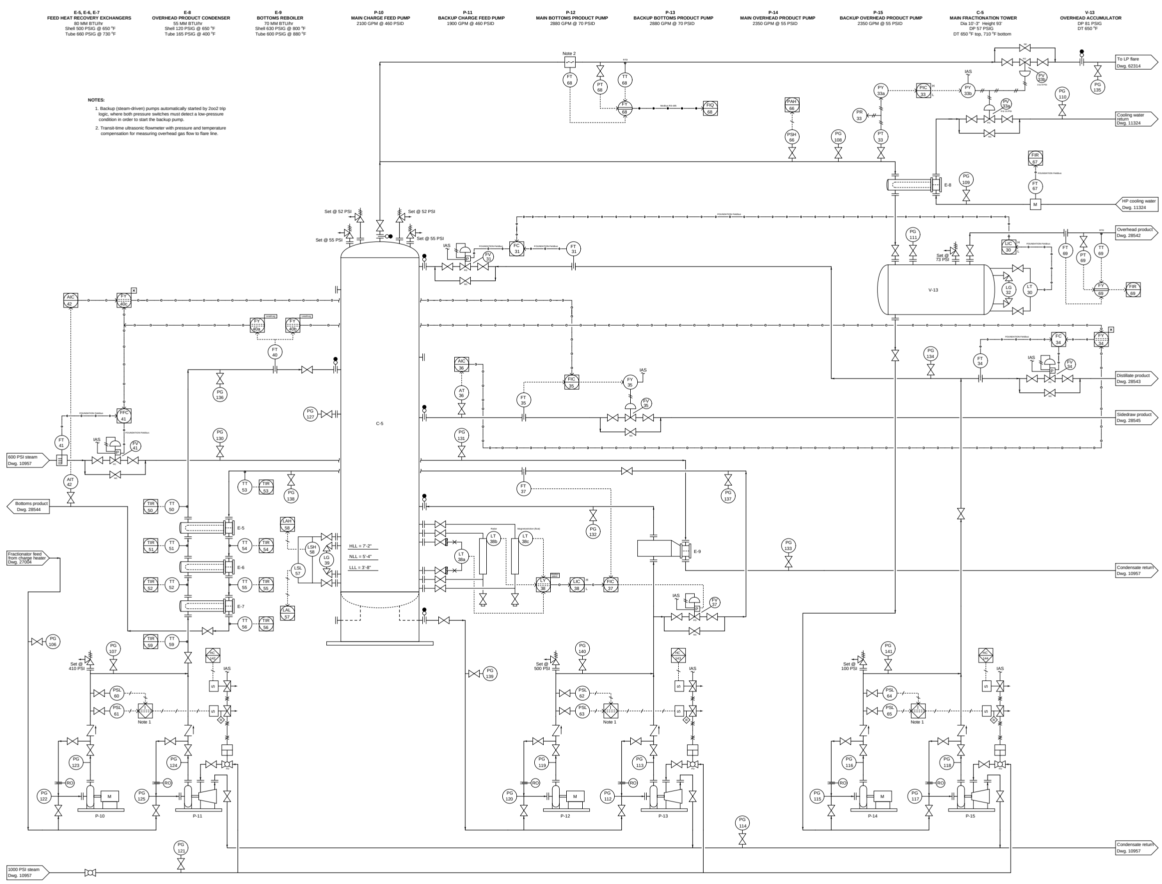
- A good problem-solving technique to apply in cases where we need to determine the direction of a change is to consider *limiting cases*. Instead of asking ourselves what would happen if the room air pressure changes slightly, we ask ourselves what would happen if the room air pressure changes *dramatically*. Explain how this problem-solving technique applies to this particular system.
- Can you think of a more energy-efficient way of regulating air pressure in this "clean room" than using dampers?
- Identify how this control system could be augmented to provide *air flow rate* control in addition to room pressure control.
- What is the purpose of having an induced draft (ID) fan at all, since eliminating it entirely would *guarantee* positive pressure in the room so long as the forced draft (FD) fan was running?

- Determine the most likely fail-states of each damper, assuming we wish to default to a condition where the room remains as clean as possible.
- What would happen if the 4-20 mA signal cable between the controller and valves failed open in this system? Explain your answer in detail.
- What would happen if the 4-20 mA signal cable between the controller and valves failed shorted in this system? Explain your answer in detail.
- What would happen if the 4-20 mA signal cable between the controller and transmitter failed open in this system? Explain your answer in detail.
- What would happen if the 4-20 mA signal cable between the controller and transmitter failed shorted in this system? Explain your answer in detail.

file i03785

Question 48

Explain how the two control valves PV-33a and PV-33b work in conjunction with one another to control the overhead pressure inside the fractionation tower:



Do you suppose these two control valves are split-ranged *progressively*, *exclusively*, or *complementarily*?

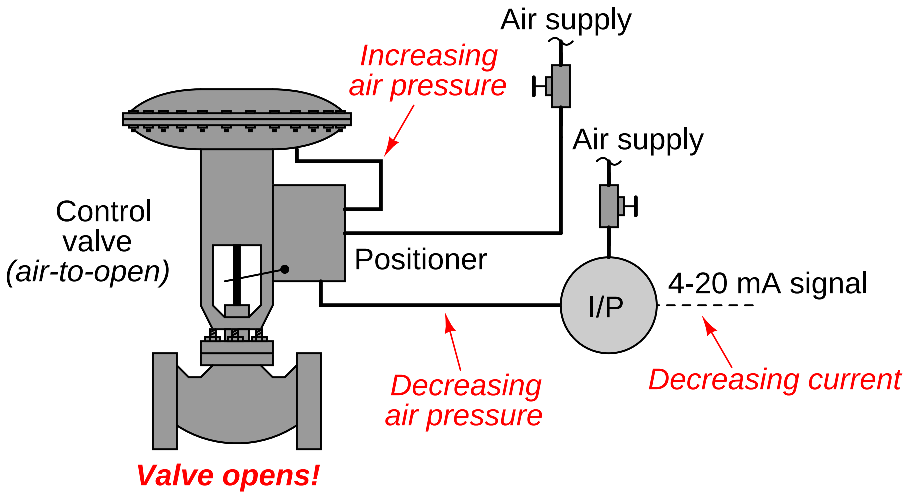
Suggestions for Socratic discussion

- A good problem-solving technique to apply in cases where we need to determine the direction of a change is to consider *limiting cases*. Instead of asking ourselves what would happen if the fractionator overhead pressure changes slightly, we ask ourselves what would happen if the pressure changes *dramatically*. Explain how this problem-solving technique applies to this particular system where we must analyze the split-ranged sequence of multiple valves.
- Is the controller PC-33 direct or reverse acting? Is this possible to tell from the given information, or must we know more in order to make this determination?
- During typical unit operation, do you suppose PV-33a will be fully shut, wide open, or throttling? Explain why.
- During typical unit operation, do you suppose PV-33b will be fully shut, wide open, or throttling? Explain why.

file i03569

Question 49

It is often possible to configure a valve positioner in such a way to reverse the action (signal-to-open or signal-to-close) of a control valve. One reason to do this is to create one-half of a split range, where the other valve acts in the opposite (either complementary or exclusive) manner. Consider the following control valve, whose positioner has been configured to respond in "reverse:"



While this may be possible, it might not be the best thing to do from a perspective of fail-safe. Explain why the fail-safe mode of this valve may be compromised with such a positioner calibration. Then, explain what the *best* way would be to reverse the action of the valve.

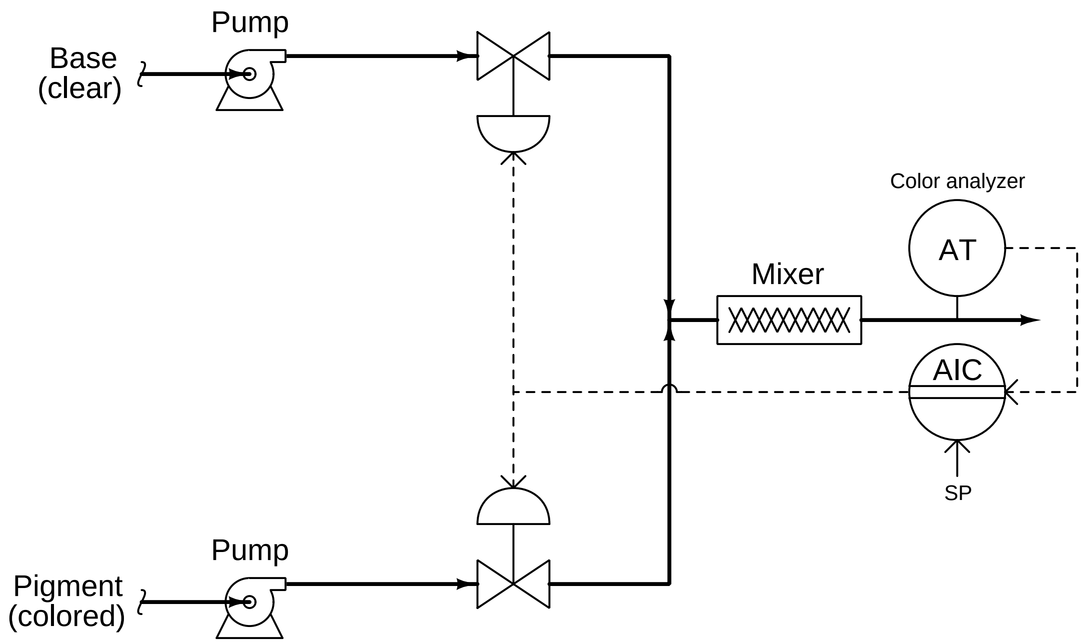
Suggestions for Socratic discussion

- A powerful problem-solving technique is performing a *thought experiment* where you mentally simulate the response of a system to some imagined set of conditions. Describe a useful "thought experiment" for this system, and how the results of that thought experiment are helpful to answering the question.
- Identify a practical reverse-acting range for a control valve, and an application where it might be used.

file i01399

Question 50

This paint mixing system blends a ratio of clear base to colored pigment in order to produce a paint of the desired color. A color analyzer senses how dark the mixed paint is, producing a 4-20 mA signal varying with color (4 mA = clear ; 20 mA = dark):



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

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

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

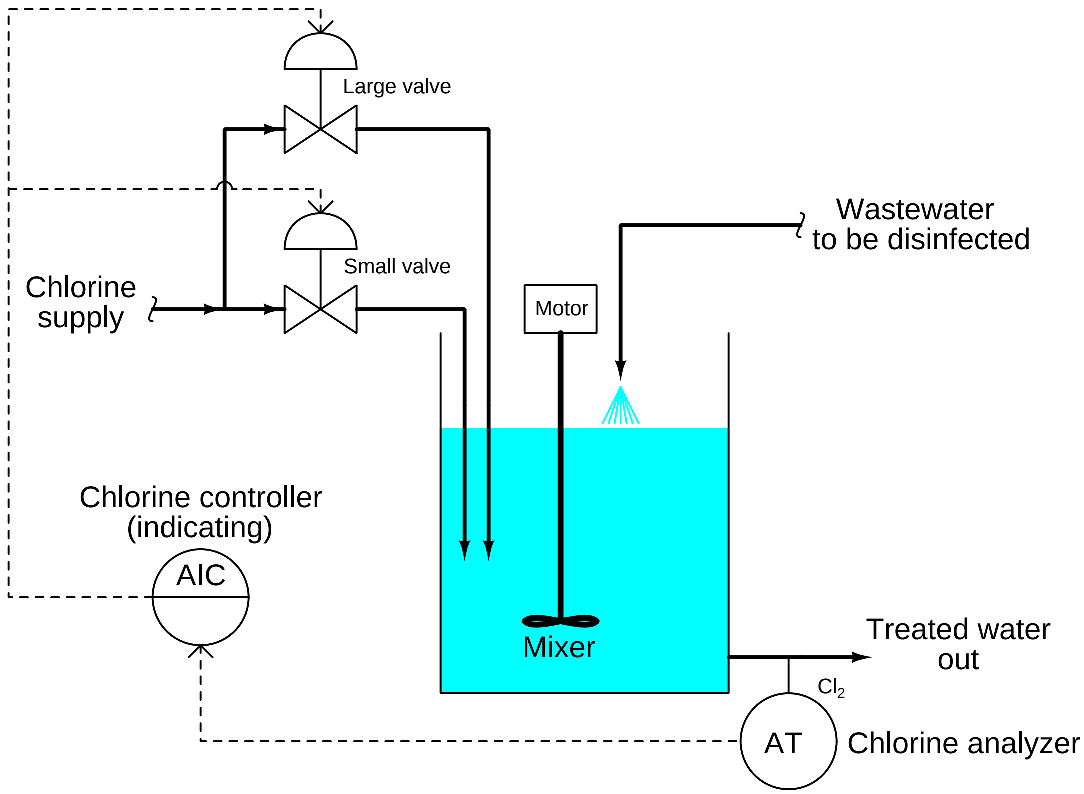
Suggestions for Socratic discussion

- How might a *mixing valve* be used in lieu of two split-ranged control valves in this particular process? Would there be any benefit(s) to doing so?

file i03781

Question 51

This chlorination control system adds chlorine to a wastewater stream to disinfect it before discharging to a natural body of water. Two chlorine valves of vastly different size exist to throttle the flow of chlorine to the water: a small valve intended for low-flow operation, and a large valve that opens up when high flow is needed. A residual chlorine analyzer outputs 4 mA with no chlorine in the water and 20 mA with high levels of chlorine in the water:



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

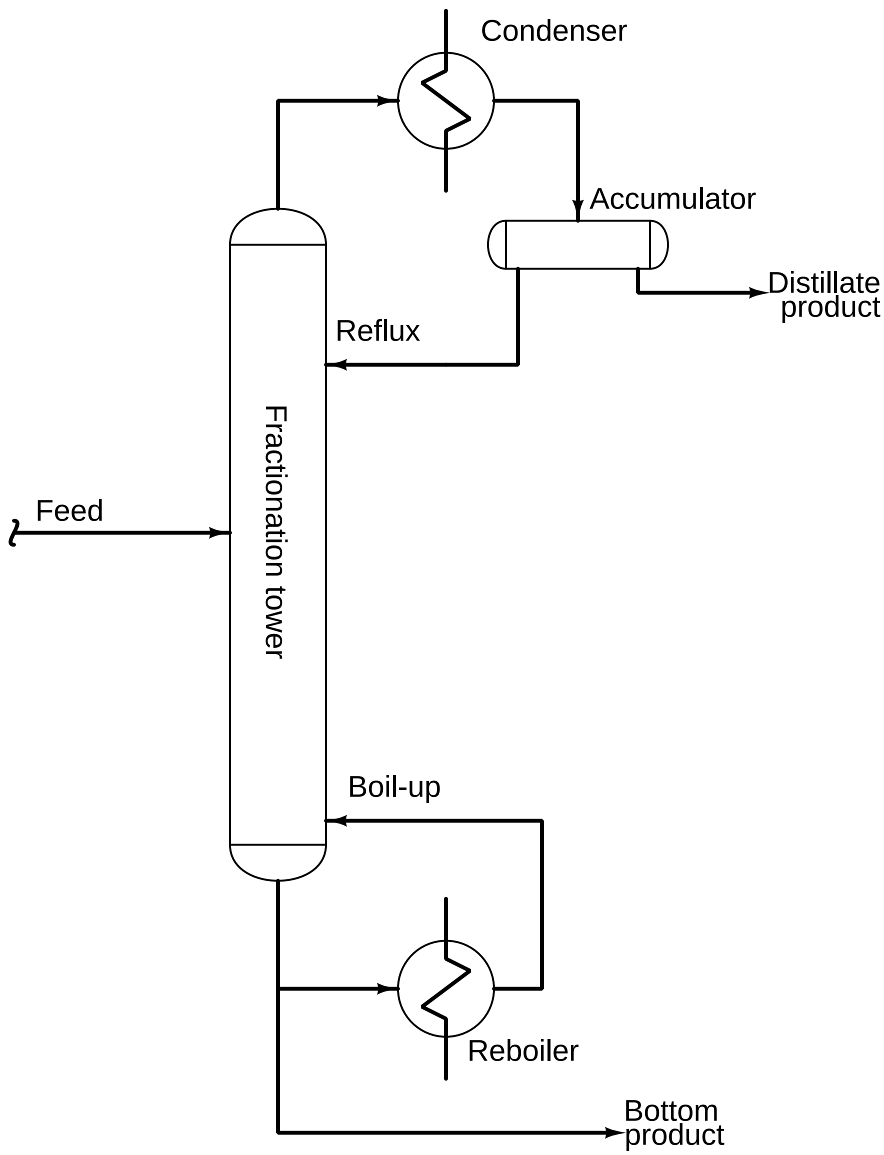
Small valve position	Controller output signal
Fully shut (0%)	??? mA
Wide open (100%)	??? mA

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

file i03783

Question 52

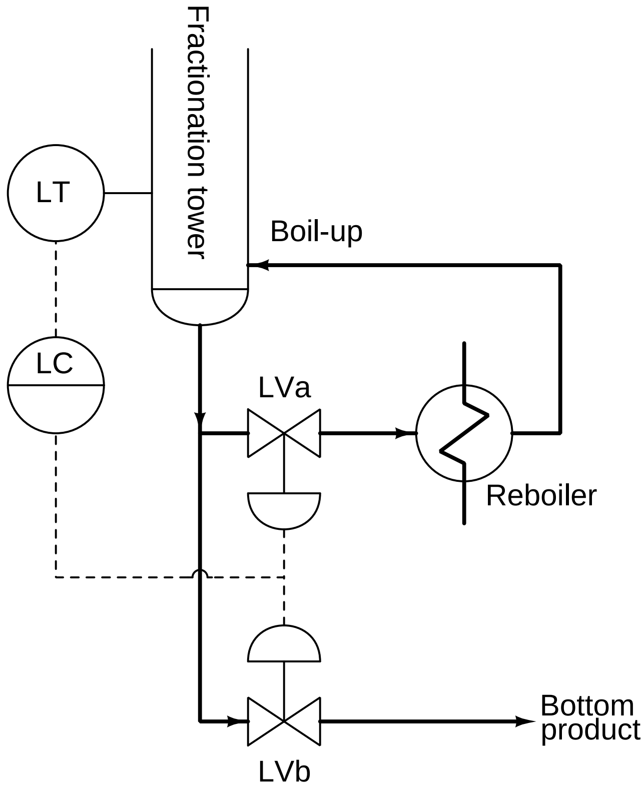
Shown here is a distillation tower, used to separate a liquid mixture of substances into its constituent components. The process of *distillation*, or *fractionation* as it is sometimes called, is very common in heavy process industries, most notably petrochemical processing:



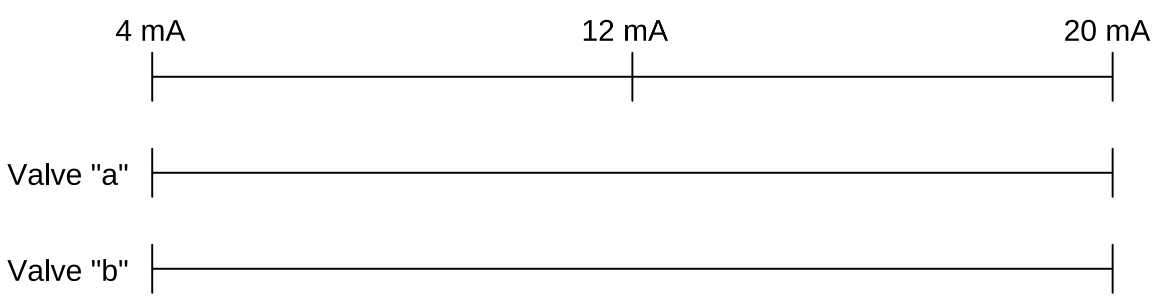
Distillation of this nature works on the principle of different boiling points. The distillation of alcohol (to separate a water/alcohol mix in order to obtain a purer alcohol product) is a well-known application of this technology. In a fractionation tower, the process of boiling and condensation of the mixture's constituent components is repeated endlessly, assuring a high degree of separation between them.

The light vapors extracted from the top of a distillation tower are re-condensed into an "accumulator" vessel and re-introduced into the fractionation process as "reflux." The heavy vapors condensing at the bottom of the tower are re-boiled into vapor form again and re-introduced into the fractionation process as "boil-up." It is necessary for reflux and boil-up to be re-introduced into the tower in order to purify the final products as much as possible. The P&ID shown here is devoid of any instrumentation for the sake of simplicity.

Looking closer at the reboiler process loop, we see that the flow out of the bottom of the tower splits: part of it goes out as finished "bottom" product while the rest goes through the reboiler to re-enter the fractionator as "boil-up". This split is accomplished with a pair of split-range level control valves:



Suppose both the transmitter and the controller are direct-acting (increased level = increased output signal). Determine the proper calibration ranges for both of these valves. It may be helpful to express the valve ranges graphically on this scale, showing where along the 4-20 mA controller output signal range each valve will be fully open, fully shut, etc.:



Suggestions for Socratic discussion

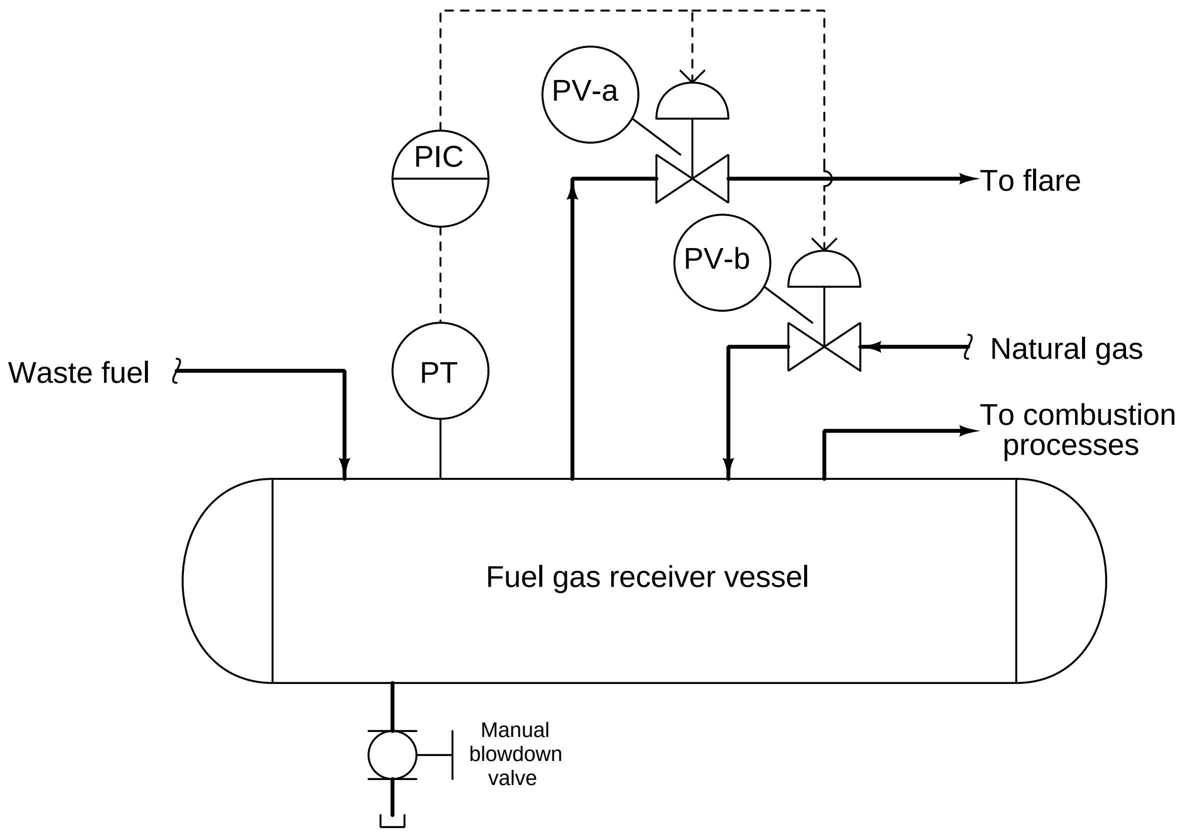
- A good idea in this control system is to install a *minimum travel stop* in level valve A, so that it cannot close beyond a certain point. Explain why this might be important to the overall control of the fractionation tower.

file i03215

Question 53

Many industries produce flammable waste products that may be used as fuel in furnaces, steam boilers, and process heaters. If this "waste fuel" is a gas rather than a liquid, we may collect it in a large pressure vessel (called a "receiver") and control the pressure within that vessel so that all the combustion processes receive fuel gas at a steady pressure.

If we have a surplus of waste fuel coming in to the receiver vessel, the pressure will rise above setpoint. In this event, a pressure control system opens up a control valve to vent excess fuel gas to the flare (a continuously-burning "torch" where waste products may be safely disposed of) to maintain receiver pressure at setpoint. Conversely, if we aren't getting enough waste fuel coming in to the receiver vessel to meet the demands of all the combustion processes, the pressure will drop below setpoint. In this event, the same pressure control system opens up a different control valve to introduce natural gas to the receiver vessel and bring the pressure back up to setpoint:

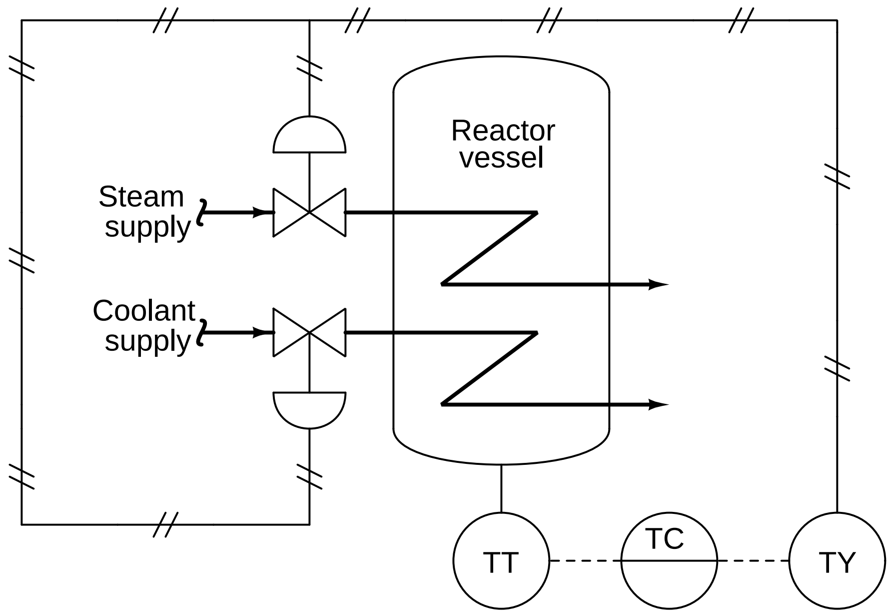


Explain how the two control valves, PV-a and PV-b, may be *split-ranged* so that a single pressure controller operates both valves simultaneously. Assuming a direct-acting transmitter and reverse-acting controller (that output 4-20 mA each), determine the calibration range for each control valve.

file i03221

Question 54

Examine this temperature control system P&ID, where a chemical processing reactor may be heated or cooled by a temperature control system:



The temperature controller (TC) compares the process temperature against a setpoint, and commands the steam and coolant valves accordingly. When the controller output is 100% (20 mA output signal to the I/P transducer), the steam valve should be fully open and the coolant valve fully closed. When the controller output is 0% (4 mA output signal to the I/P transducer), the steam valve should be fully closed and the coolant valve fully open. To avoid wasting energy, the steam and coolant valves should never be open simultaneously. One of the two valves should be closed at any given time.

Assuming a standard 3-15 PSI output range for the I/P transducer (TY), and standard pneumatic diaphragm-and-spring actuators on the valves, determine what types of valve actions to use for each valve:

- Air-to-open or air-to-close?
- Calibrated air pressure range?

Also, determine whether the temperature controller needs to be direct-acting or reverse-acting, assuming that the temperature transmitter (TT) produces an increasing signal for an increasing process temperature.

Suggestions for Socratic discussion

- Identify alternative schemes for split-ranging these two valves other than using a single I/P converter.
- Identify the consequence of losing instrument air to the control valves – what will happen to the reactor temperature?

file i01394

Question 55

Suppose a pair of control valves powered by a common I/P transducer have the following bench set ranges:

- FV-14a = 3 PSI to 9 PSI, air to open
- FV-14b = 9 PSI to 15 PSI, air to open

Calculate the respective positions of these two split-ranged control valves given the following 4-20 mA current signal values. Assume "0%" means fully shut and "100%" means fully open:

Current	FV-14a position	FV-14b position
4 mA		
7.5 mA		
13 mA		
18.5 mA		

Also, describe the type of split-ranging this represents.

file i04784

Question 56

Suppose a pair of control valves powered by a common I/P transducer have the following bench set ranges:

- TV-99a = 3 PSI to 15 PSI, air to open
- TV-99b = 3 PSI to 15 PSI, air to close

Calculate the respective positions of these two split-ranged control valves given the following 4-20 mA current signal values. Assume "0%" means fully shut and "100%" means fully open:

Current	TV-99a position	TV-99b position
4 mA		
9 mA		
14.2 mA		
19 mA		

Also, describe the type of split-ranging this represents.

file i04783

Question 57

Suppose a pair of control valves powered by a common I/P transducer have the following bench set ranges:

- LV-50a = 3 PSI to 9 PSI, air to close
- LV-50b = 9 PSI to 15 PSI, air to open

Calculate the respective positions of these two split-ranged control valves given the following 4-20 mA current signal values. Assume "0%" means fully shut and "100%" means fully open:

Current	**LV-50a position**	**LV-50b position**
4 mA		
8.6 mA		
15.1 mA		
20 mA		

Also, describe the type of split-ranging this represents.

file i04782

Question 58

Question 59

Question 60

Question 61

Read and outline the "Importance of Proper Valve Sizing" subsection of the "Control Valve Sizing" section of the "Control Valves" 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.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Any points of confusion, and precisely why you found the text confusing.
(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

file i04226

Question 62

If a control valve has a C_v rating of 170, how much gasoline (density $D = 42$ lb/ft^3) will flow through it in a wide-open condition given a differential pressure of 8 PSI?

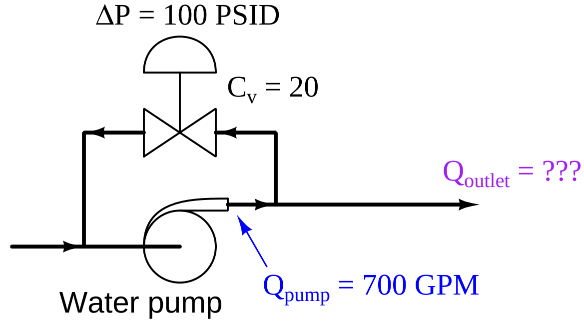
Suggestions for Socratic discussion

- Suppose an instrument technician tells you that a C_v rating of 170 means this control valve has a maximum flow rate of 170 gallons per minute. Explain what is incorrect about this statement, and provide your own definition of C_v that is more accurate.
- If water were substituted for gasoline, but all other factors remained the same, would the flow rate increase, decrease, or remain the same?

file i01370

Question 63

A water pump recirculation valve has a full-open C_v rating of 20. If the pump outputs a flow of 700 GPM of water at a differential pressure (outlet pressure - inlet pressure) of 100 PSID, what will be the total water flow output by the system when the bypass valve is 100% open?



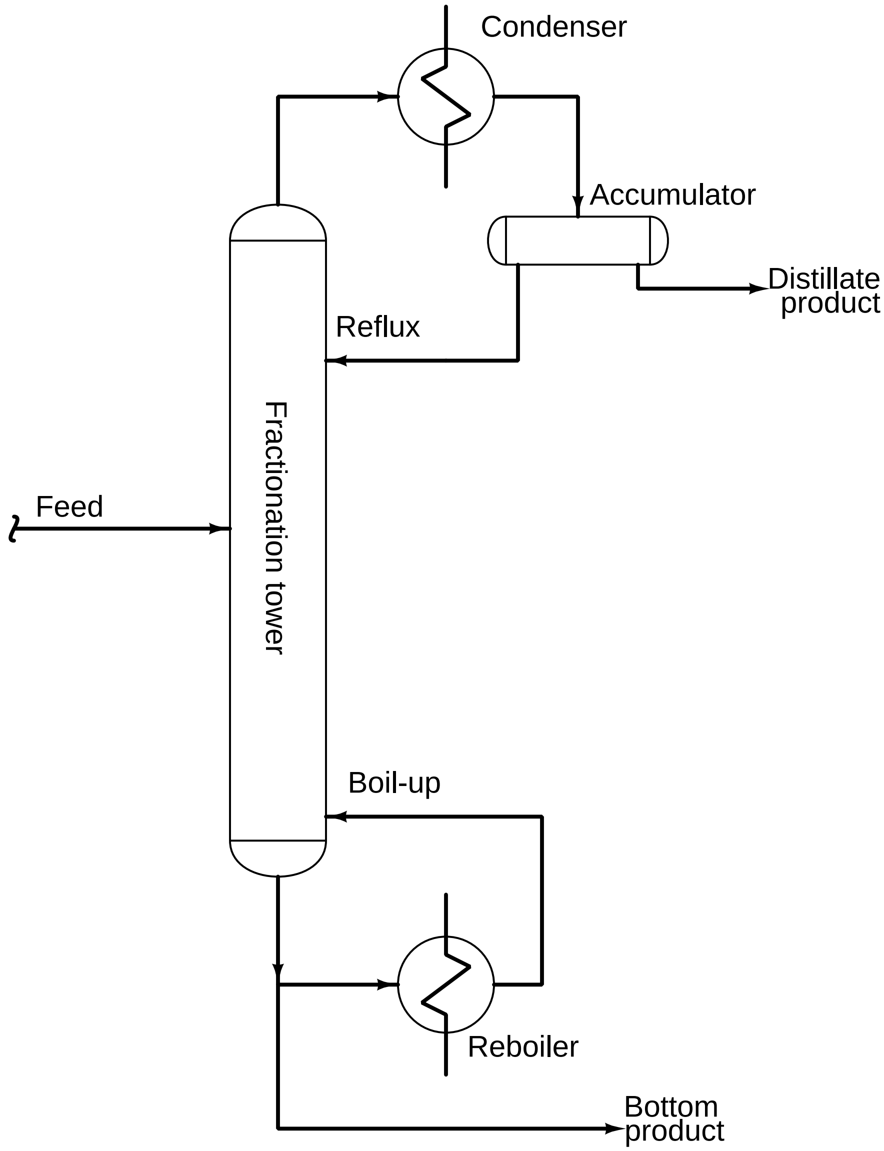
Suggestions for Socratic discussion

- This control valve arrangement – where the valve recirculates water flow from discharge to suction – is far preferable to one where a valve simply blocks off the pump discharge. Explain why recirculation is better than blockage as far as control valve placement is concerned.
- Explain what happens to the outlet flow rate when the control valve is opened wider.
- Suppose this pump was not pumping water, but rather a fluid less dense than water. How would this process fluid change affect the outlet flow rate, assuming all other parameters remained the same?
- Suppose this pump generated a greater pressure than that shown. How would this process fluid change affect the outlet flow rate, assuming all other parameters remained the same?
- Suppose an instrument technician tells you that a C_v rating of 20 means this control valve has a maximum flow rate of 20 gallons per minute. Explain what is incorrect about this statement, and provide your own definition of C_v that is more accurate.

file i01374

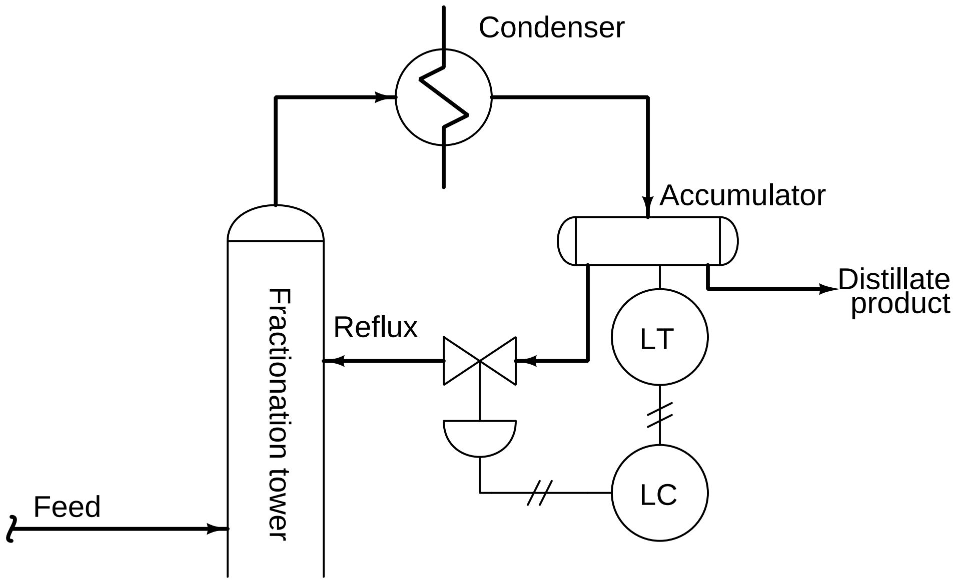
Question 64

Shown here is a distillation tower, used to separate a liquid mixture of substances into its constituent components. The process of *distillation*, or *fractionation* as it is sometimes called, is very common in heavy process industries, most notably petrochemical processing:



The light vapors extracted from the top of a distillation tower are recondensed into an "accumulator" vessel and re-introduced into the fractionation process as "reflux." The heavy vapors condensing at the bottom of the tower are reboiled into vapor form again and re-introduced into the fractionation process as "boil-up." It is necessary for reflux and boil-up to be re-introduced into the tower in order to purify the final products as much as possible. The P&ID shown here is devoid of any instrumentation for the sake of simplicity.

Here, a simple reflux control loop is shown, to control the amount of reflux introduced into the tower from the accumulator:



The tower operates at a controlled pressure of 75 PSI. Reflux flows from the accumulator, through the valve, and into the tower by gravity alone. The elevation difference between the accumulator's constant liquid level and the reflux control valve is 12 feet, and the reflux product is liquid pentane (specific gravity = 0.6262). If a maximum reflux rate of 500 GPM is desired through this valve, what must its C_v be?

Suggestions for Socratic discussion

- Identify some practical purposes for distillation towers in industry.
- Which of the two heat exchangers *adds* heat to the tower?
- Which of the two heat exchangers *removes* heat from the tower?
- Suppose the liquid in the accumulator were something other than pentane (i.e. suppose the specific gravity was not equal to 0.6262). How would this affect control valve sizing, assuming the same maximum flow rate of 500 GPM was desired?
- Identify the effect(s) of the LT failing with a high signal (100% liquid level) in this control system.
- Identify the effect(s) of the LC being left unattended in manual mode in this control system.
- Calculate the control valve's upstream pressure (P_1).
- Calculate the control valve's downstream pressure (P_2).

file i01376

Question 65

Read and outline the "Relative Flow Capacity" subsection of the "Control Valve Sizing" section of the "Control Valves" 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.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Any points of confusion, and precisely why you found the text confusing.
(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

file i04227

Question 66

Control valve types (e.g. globe, ball, butterfly) may be given relative flow capacity ratings called the C_d factor. This is similar to the concept of flow capacity (C_v), but generalized to a specific type or design of control valve. The equation relating C_d to C_v is as follows:

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

Where,

C_d = Relative flow capacity of the valve type
C_v = Maximum flow capacity of the particular valve
d = Nominal pipe size for the particular valve, inches

Several valve capacity factors (C_d) for different control valve types are shown here, assuming full-area trim and a full-open position:

Valve design type	C_d
Single-port globe valve, ported plug	9.5
Single-port globe valve, contoured plug	11
Single-port globe valve, characterized cage	15
Double-port globe valve, ported plug	12.5
Double-port globe valve, contoured plug	13
Rotary ball valve, segmented	25
Rotary ball valve, standard port (diameter $\approx 0.8d$)	30
Rotary butterfly valve, 60^o, no offset seat	17.5
Rotary butterfly valve, 90^o, offset seat	29
Rotary butterfly valve, 90^o, no offset seat	40

This C_d data for different control valve types allows us to approximate any valve's full-flow C_v factor knowing the type of valve and the pipe size. Calculate the full-flow C_v values for these control valves:

- Segmented ball valve, 4 inch pipe size; C_v = ______
- Single-port, cage-guided globe valve, 6 inch pipe size; C_v = ______
- Double-port, ported-plug globe valve, 2 inch pipe size; C_v = ______
- 90^o butterfly valve with offset seat, 20 inch pipe size; C_v = ______

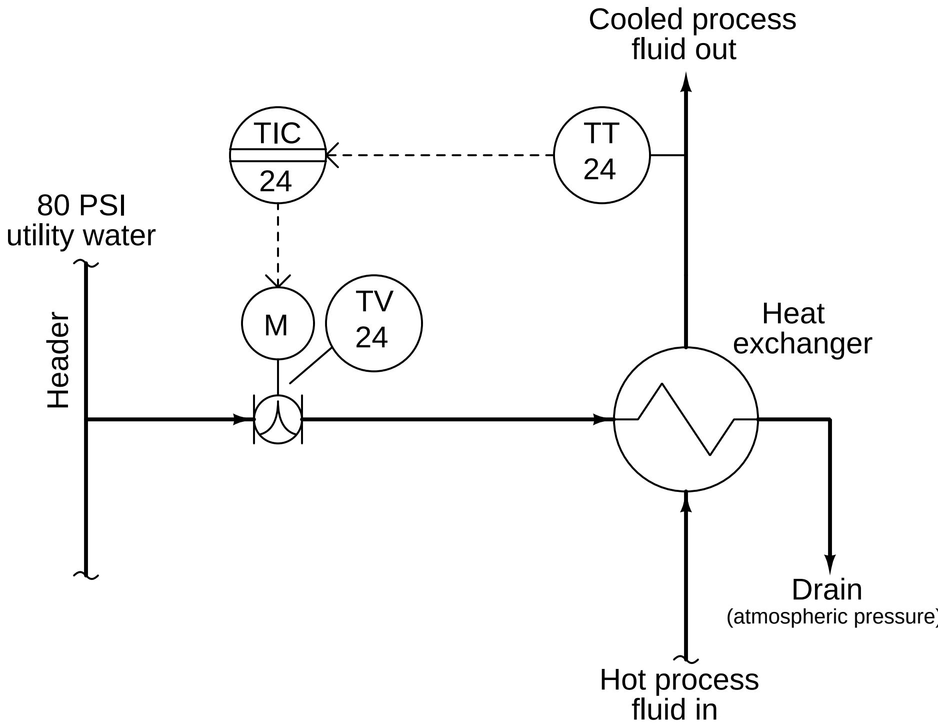
Suggestions for Socratic discussion

- Given a certain required C_v rating, which design of control valve allows the smallest valve (pipe) size?
- Given a certain required C_v rating, which design of control valve requires the largest valve (pipe) size?

file i01371

Question 67

Suppose a control valve is used to throttle the flow of cooling water from a utility water header (constant pressure of 80 PSI) through the tube side of a shell-and-tube heat exchanger:



At full-open, the control valve needs to limit the cooling water flow rate to a maximum of 140 gallons per minute. At that flow rate, the tubes inside the heat exchanger will drop 36 PSI of pressure across their length. Calculate the C_v rating for the control valve, and also estimate the nominal pipe size of the control valve (in inches).

C_v = __________

Nominal pipe size = __________

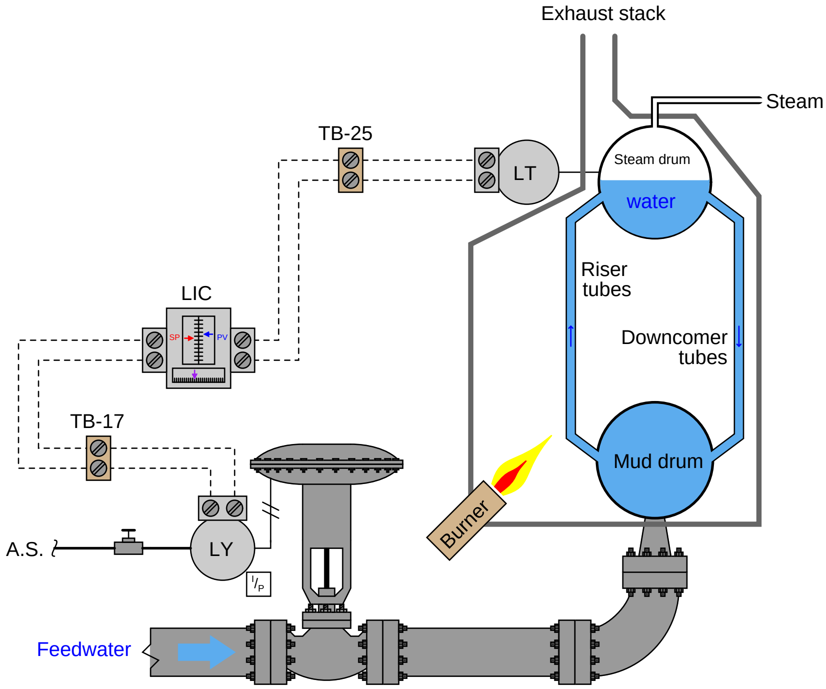
Suggestions for Socratic discussion

- Explain how a shell-and-tube heat exchanger is constructed, and exactly how heat gets transferred from one fluid to another in such a device.
- Identify the proper controller action, assuming a direct-acting temperature transmitter and a signal-to-close valve.
- Identify some of the *loads* in this process control loop. A "load" is some influencing factor on the process variable that is not directly regulated by the control loop.
- What type of control valve and actuator are used in this application?
- Suppose the utility water header pressure increases significantly. Would this process alteration require a larger control valve, a smaller control valve, or would the same size (C_v) control valve be sufficient?
- Suppose the utility water temperature decreases significantly. Would this process alteration require a larger control valve, a smaller control valve, or would the same size (C_v) control valve be sufficient?
- Suppose the heat exchanger is replaced by another model with less restrictive water tubes. Would this process alteration require a larger control valve, a smaller control valve, or would the same size (C_v) control valve be sufficient?

file i03213

Question 68

This boiler steam drum level control system has a problem. The water level in the steam drum is below setpoint (as indicated by the controller display showing 42% water level with a 58% setpoint), and has been for the past several hours despite the operator's attempt to raise water level by raising the setpoint on the controller. Meanwhile, the boiler is operating at full power, making steam at a normal rate of flow:



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

Fault	Possible	Impossible
LT calibration error		
LY calibration error		
Controller failed		
Low air supply pressure		
Excessive resistance in LT circuit		
Excessive resistance in LY circuit		
Feedwater pump worn		
Controller in manual mode		

Finally, identify the *next* diagnostic test or measurement you would make on this system. Bear in mind that this is an *operating system* and cannot be shut down to accommodate any arbitrary test. Explain how the result(s) of this next test or measurement help further identify the location and/or nature of the fault.

Suggestions for Socratic discussion

- Identify the steps you would need to follow in order to safely check the level transmitter's calibration while the boiler is running.

file i01368

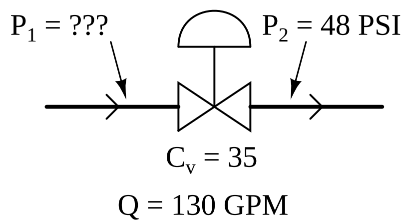
Question 69

If a control valve has a C_v rating of 25, how much water flow will go through it given a differential pressure of 5 PSI when it is wide open?

file i01369

Question 70

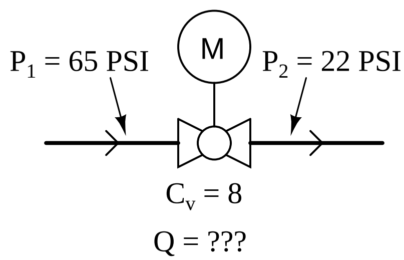
How much upstream pressure is required to get 130 GPM of water (at 60^o F) to flow through this valve when wide open?



file i01377

Question 71

How much water (at 60^o F) will flow through this valve when wide open?



Now suppose the valve is closed off until its $C_v = 4$ instead of 8. Assuming the same upstream and downstream pressures, what will the new flow rate be? Does the flow rate follow C_v linearly, or not? Why is this?

Suggestions for Socratic discussion

- How realistic do you think it is to assume the same upstream and downstream pressures when the valve moves to a different stem position? Do you think those pressures would remain the same for all valve positions in a realistic scenario? Why or why not?
- What type of control valve and actuator are used in this application?

file i01373

Question 72

A control valve with a full C_v rating of 10, when wide open, flows 65 gallons per minute of liquid with a pressure drop of 50 PSID. Assuming that no choked flow or cavitating conditions exist in this valve, what is the density of the liquid in pounds per cubic foot?

file i01375

Question 73

Sam climbs a 130 foot tower with an 8 pound (0.25 slug) textbook. Tony climbs the same tower with a 5 pound (0.16 slug) textbook. Both Sam and Tony drop their textbooks from the top of the tower at exactly the same moment in time. Neglecting the effects of air friction on the books' free-fall, calculate the following:

- Work done by Sam in lifting his textbook =
- Kinetic energy of Sam's textbook just before it hits the ground =
- Velocity of Sam's textbook just before it hits the ground =

- Work done by Tony in lifting his textbook =
- Kinetic energy of Tony's textbook just before it hits the ground =
- Velocity of Tony's textbook just before it hits the ground =

file i00430

Question 74

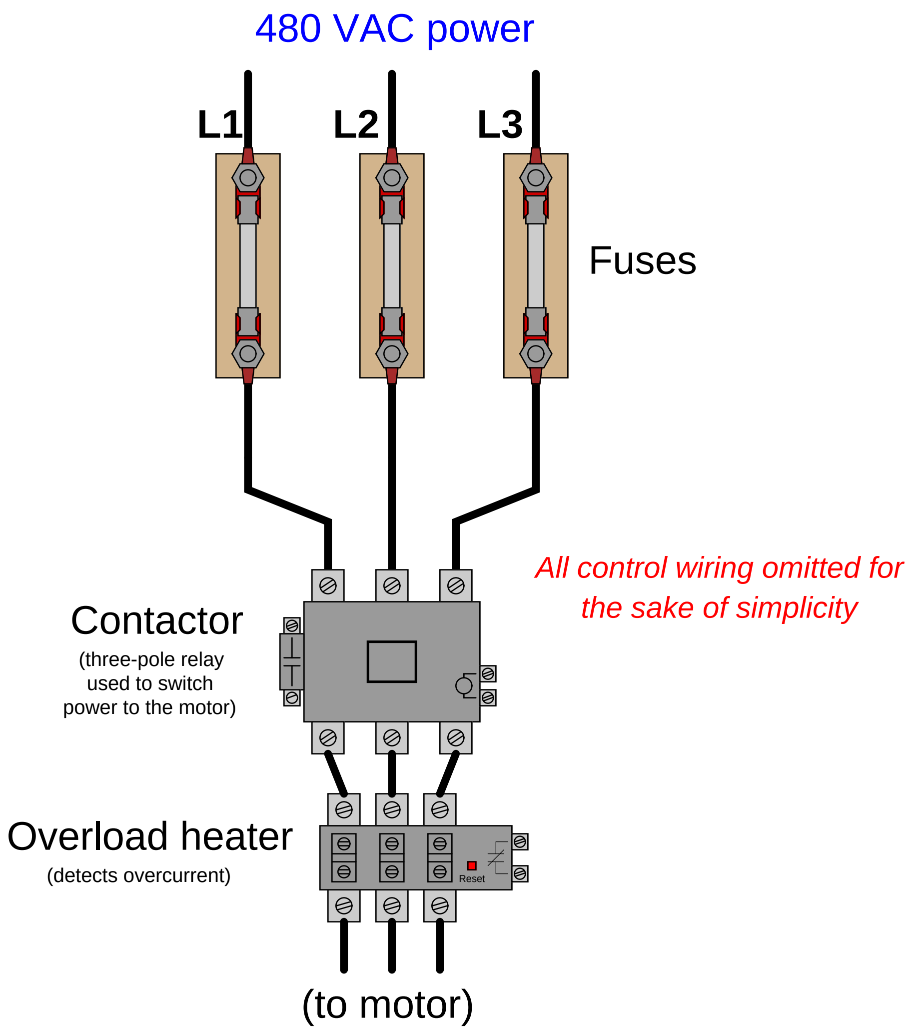
A truck weighing 39,000 newtons (N) is traveling at 10 meters per second when its clutch blows out, disconnecting the engine from the drivetrain (transmission, axle, wheels, etc.). This failure occurs exactly at the base of a steep incline. How many meters (vertical) will the truck coast up the hill with no engine power before it stops, neglecting friction of any kind?

How high would the truck have coasted if it had been traveling twice as fast?

file i00431

Question 75

An electrician goes to troubleshoot a three-phase motor starter ("bucket") that is not functioning. When the operator presses the "Start" switch, the motor refuses to start up. Thinking that perhaps one of the main fuses is blown, the electrician measures AC voltage across each fuse, measuring 0 volts drop for each one. Upon seeing this, he declares all three fuses to be good, and that the trouble must lie elsewhere in the circuit (e.g. bad motor, failed contactor, etc.).



Explain what is wrong with the electrician's reasoning, and how it is possible to measure 0 volts across a fuse that is actually blown.

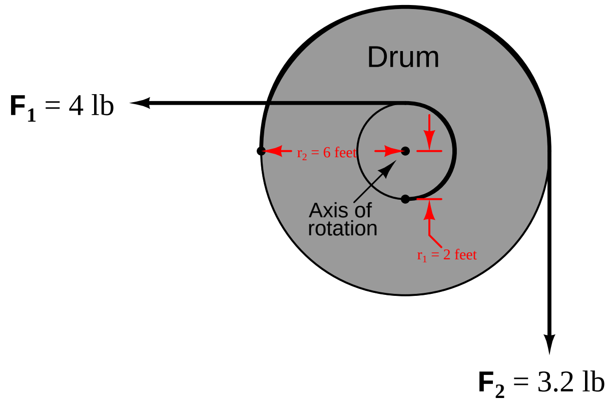
Suggestions for Socratic discussion

- Identify which fundamental principles of electric circuits apply to each step of your analysis of this circuit. In other words, be prepared to explain the reason(s) "why" for every step of your analysis, rather than merely describing those steps.
- This is an example of a logical fallacy known as *illicit conversion*. A general example of this fallacy goes like this: "All rabbits are mammals, therefore all mammals are rabbits." Explain how the electrician's association of 0 volts with a good fuse is an example of this fallacy.

file i03737

Question 76

Calculate the net torque applied to the drum from the two forces shown. The drum's outside radius is 6 feet, and the radius of the smaller pulley (attached to the drum) is 2 feet:



Also, calculate the mechanical advantage of this system, if F_1 is considered the *input* force.

file i01428

Question 77

Roy has the meanest pulling tractor in his county: its engine outputs a maximum torque of 1200 lb-ft, and the total geartrain (transmission combined with rear axle differential gearing) has a 12:1 reduction ratio in the lowest gear. With 5.5 foot tall tires, how much horizontal pulling force can this tractor (theoretically) exert?

If Roy's tractor drags a weight 300 feet along the ground while pulling at maximum engine torque, how much work was done by the tractor?

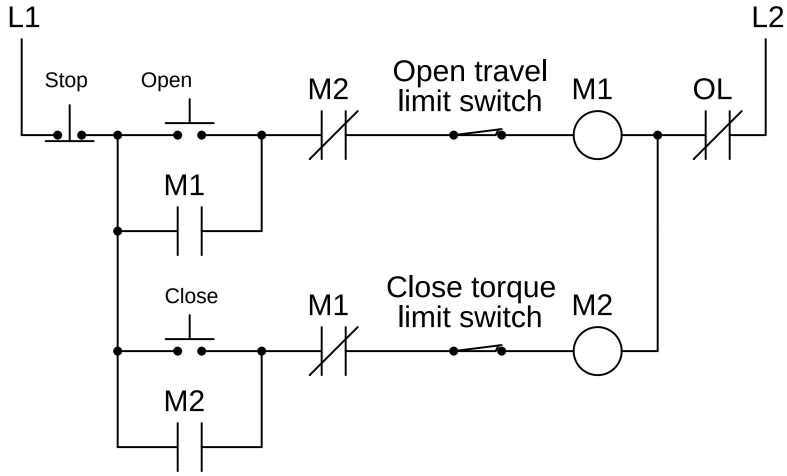
Rate the horsepower of Roy's tractor if it took exactly 1 minute to drag that weight 300 feet along the ground.

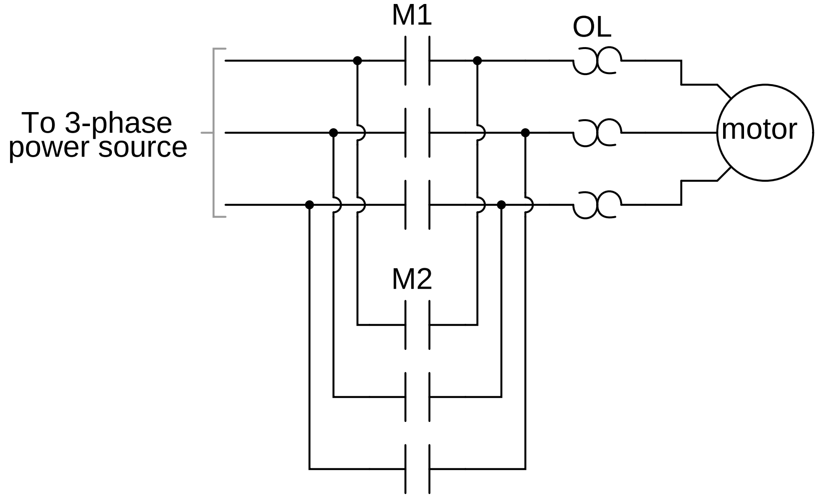
When Roy goes to the county fair to compete in the tractor-pull contest, he notices that the front end of the tractor tends to raise up off the ground when pulling a heavy load. Explain to Roy why this happens.

file i01429

Question 78

Explain how this motor control circuit (sometimes referred to as a "bucket") works for an electrically-actuated gate valve:





Explain the function and purpose of each switch in the ladder logic circuit.

file i01824

Question 79

Question 80

Question 81

Suppose the feedback arm of a valve positioner (the linkage connecting the valve's sliding stem to the positioner mechanism, telling the positioner how far open the valve is) comes loose, leaving the positioner "thinking" the control valve is always 50% open even when it is not.

Determine how this control valve will react when it receives a control signal starting at 4 mA and slowly climbing upward to 20 mA, assuming the positioner's calibration is fully closed at 4 mA and fully open at 20 mA. Be as specific as you can in your answer.

Assume that the control valve is Air-to-Open (Fail Closed).

file i00061

Question 82

Stephanie is considering converting her car from an internal combustion engine to purely electric drive (i.e. an electric motor and batteries). In order to begin planning this conversion, she must determine how much horsepower is required of the electric motor to sustain freeway driving speeds. Unfortunately Stephanie has no way to directly measure the power output of her car's engine in order to experimentally determine horsepower under different driving conditions.

One day Stephanie is driving home from school and notices some stopped cars well ahead of her. She shifts her car's transmission into neutral and coasts a little while before braking to a stop behind the last stopped car. As her car is coasting, Stephanie has an epiphany: the rate at which her car is slowing down should be indicative of how much power is required to maintain its speed when the transmission is in gear, because the forces slowing the car down as it coasts are the same forces the engine must overcome to maintain cruising speed.

With this principle in mind, Stephanie tries an experiment. At the next available opportunity driving at 70 miles per hour on level terrain, she intentionally shifts her car's transmission into neutral and times how long it takes to coast down to 65 miles per hour, after which she re-engages the transmission and speeds back up to regular highway velocity. Here is the data from her experiment, plus other data she knows about her car:

- **Time so slow down from 70 MPH to 65 MPH** = 4.4 seconds
- **Fuel tank level** = 75% full
- **Ambient air temperature** = 69 ^{o}F
- **Engine temperature** = 205 ^{o}F
- **Curb weight** = 3170 lbs
- **Engine speed at 70 MPH** = 2300 RPM
- **Music playing on the stereo** = *Autobahn* by Kraftwerk

Based on this data, calculate the approximate horsepower required to maintain Stephanie's car at a speed of 70 MPH. Stephanie will use this calculated value to help choose an appropriate motor size for her electric conversion.

file i04228

Question 83

Suppose two control valves are progressively split-ranged with the following calibrations:

Control signal	**Valve A**	**Valve B**
4 mA	Fully closed	Fully closed
8 mA	50% open	Fully closed
12 mA	100% open	Fully closed
16 mA	100% open	50% open
20 mA	100% open	100% open

Calculate the stem position of each control valve at a signal value of 6.34 mA:

Valve A = __________ Valve B = __________

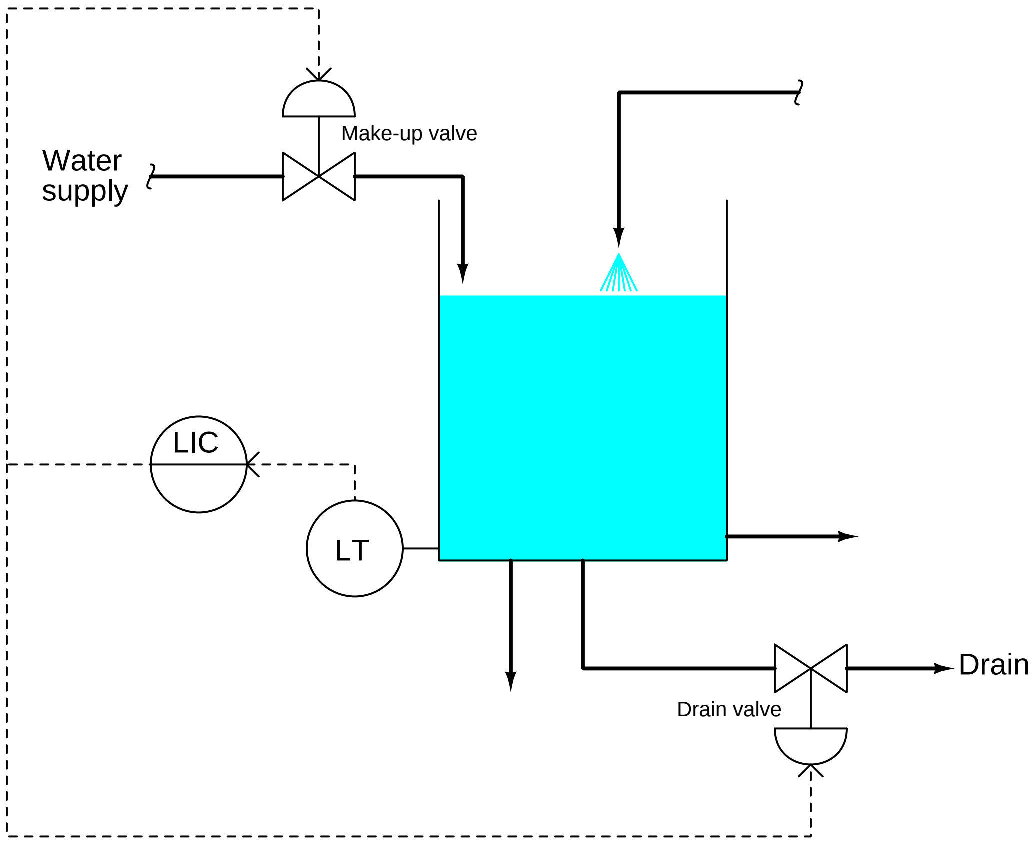
Now, calculate the stem position of each control valve at a signal value of 15.81 mA:

Valve A = __________ Valve B = __________

Be sure to show all your work in solving for these valve stem position percentages!
file i00063

Question 84

This water level control system controls the level of water in a vessel by either adding "make-up" water to the vessel or by draining excess water out of it (but never both at the same time!). The level transmitter outputs 4 mA with an empty tank and 20 mA with a full tank:



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

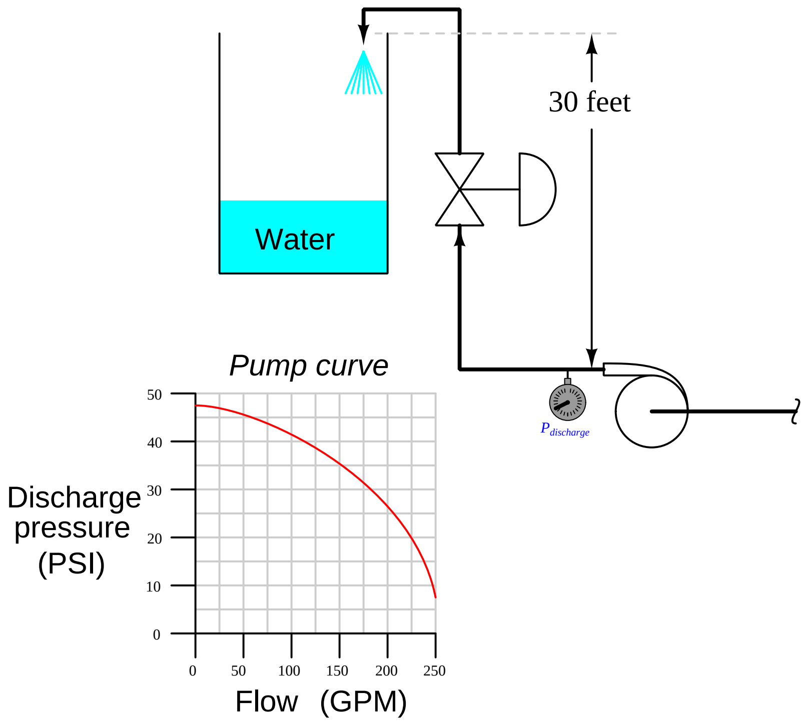
Drain valve position	Controller output signal
Fully shut (0%)	??? mA
Wide open (100%)	??? mA

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

file i03784

Question 85

Determine the required C_v rating for this control valve to provide a flow rate of 150 GPM. Note the *pump curve* describing the discharge pressure of the water pump for different flow rates (assuming a constant pump speed):

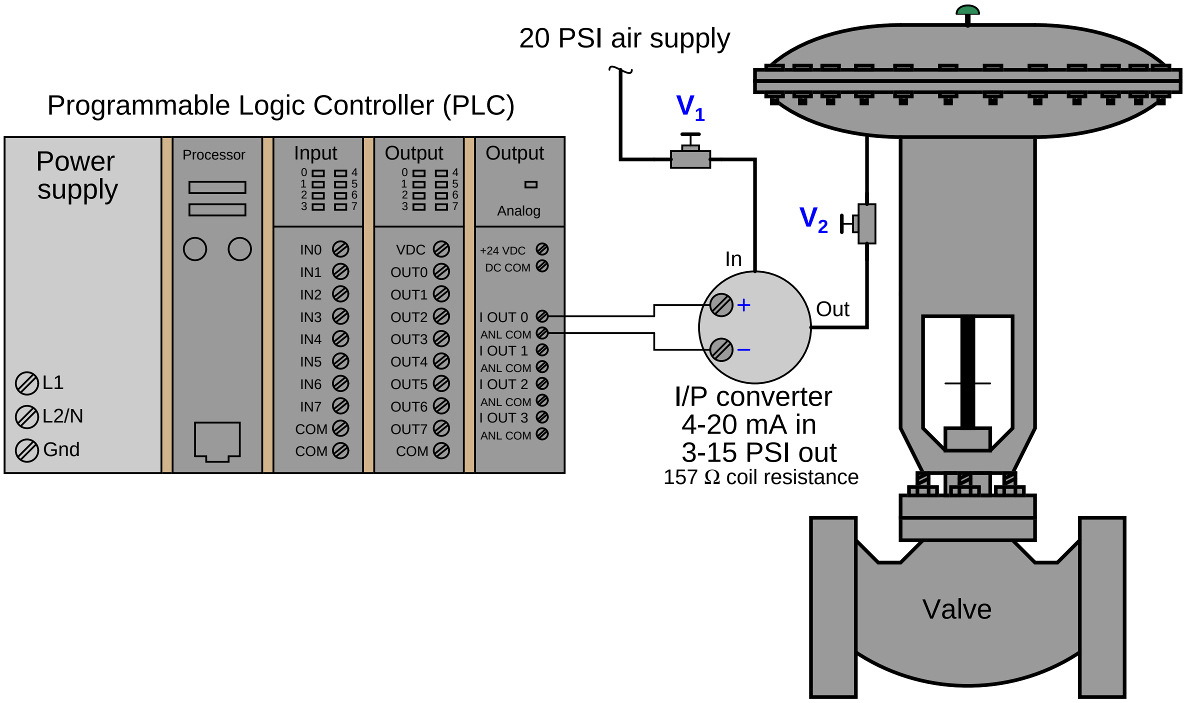


Also, calculate the approximate size of the valve (nominal pipe diameter, in inches) given a single-ported, ported plug globe valve ($C_d = 9.5$).

file i01406

Question 86

Suppose a 12-bit DAC (digital-to-analog converter) in a PLC analog output card has a digital range of 0 to 4095 counts (decimal) and an analog range of 0 to 20 milliamps:



Suppose the valve stem position is seen to be at 5% when the analog channel register value is 604 counts (hexadecimal). A technician measures the DC voltage appearing at the I/P converter terminals, and gets a measurement of 1.18 volts.

First, calculate the correct valve position corresponding to this register value. Next, 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.

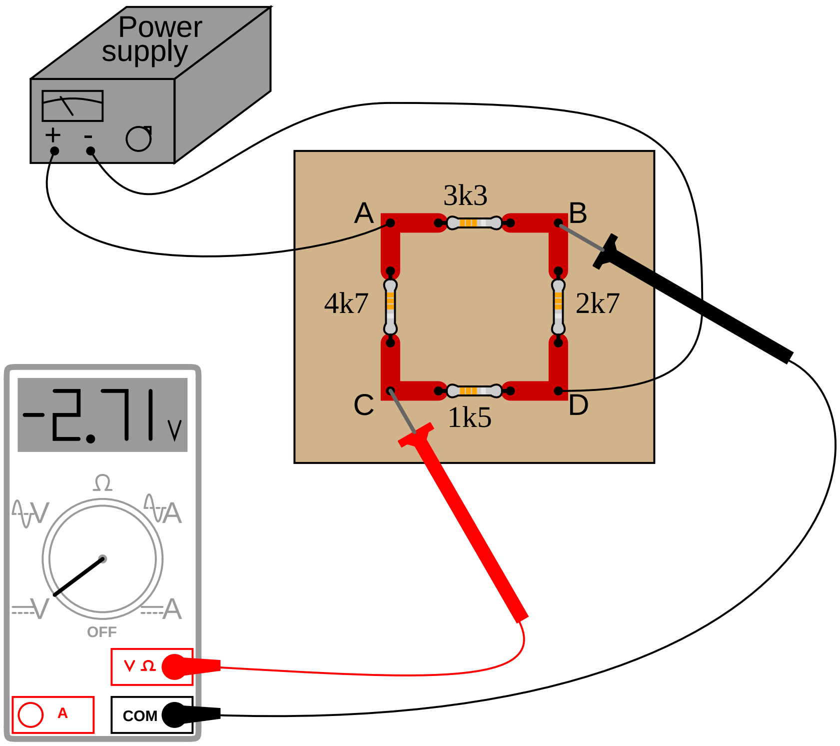
Fault	**Possible**	**Impossible**
Open wire between "I OUT 0" and "+" terminals		
Open wire between "ANL COM" and "−" terminals		
I/P mis-calibration		
Shorted cable between PLC and I/P		
Defective analog output card in PLC		
Valve V1 shut		
Valve V2 shut		
I/P restrictor plugged (completely or partially)		
I/P nozzle plugged (completely or partially)		

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

file i00737

Question 87

Calculate the amount of "excitation" voltage applied to this unbalanced bridge circuit by the DC power supply. Be sure to show all your work!

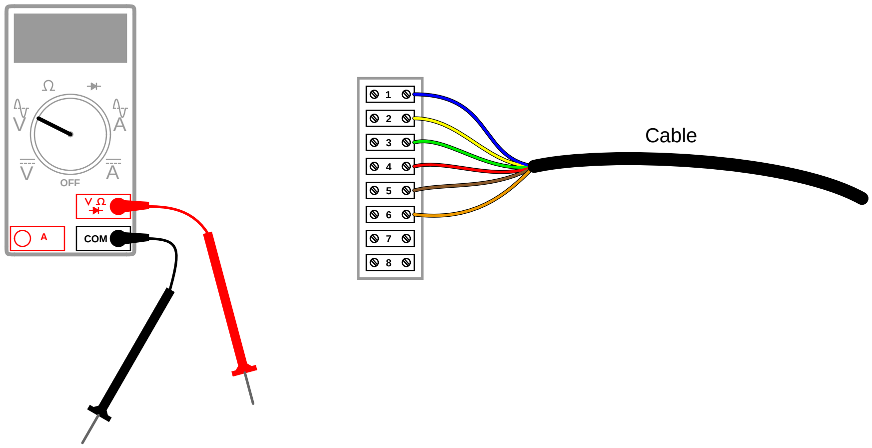


file i03151

Question 88

On a job you are asked to disconnect a six-conductor cable from a terminal strip in preparation for that cable's complete removal. Another technician tells you that the other end of that cable has already been completely disconnected, and therefore there can be no dangerous voltage present on the cable.

Your next step is to confirm the absence of dangerous voltage on the conductors before physically touching any of them. This confirmation, of course, is done with a voltmeter, and we all know that voltage is measured *between two points*. The question now is, how many different combinations of points must you measure between to ensure there is *no* hazardous voltage present?



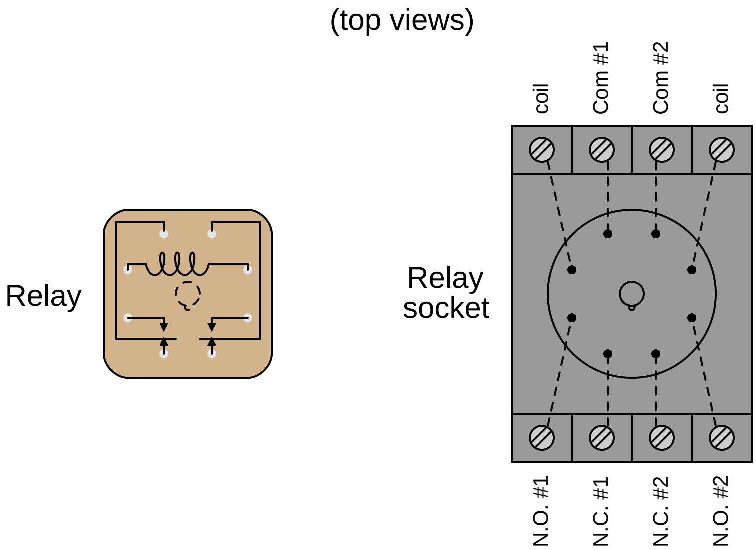
List all possible pairs of points you should test for voltage between, in order to ensure the conductors are safe for you to touch. Don't forget to include earth ground as one of those points!

Next, write a mathematical formula to calculate the number of point-pair combinations (i.e. the number of different voltage measurements that must be taken) given N number of connection points in the circuit.

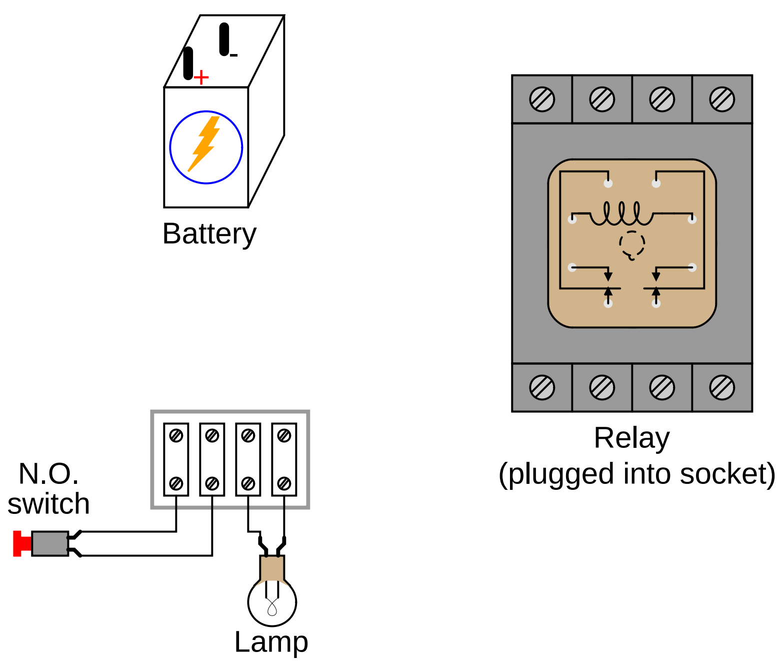
file i04261

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. Note the labels near terminals on the relay socket, showing the locations of the coil terminals and contact terminals:



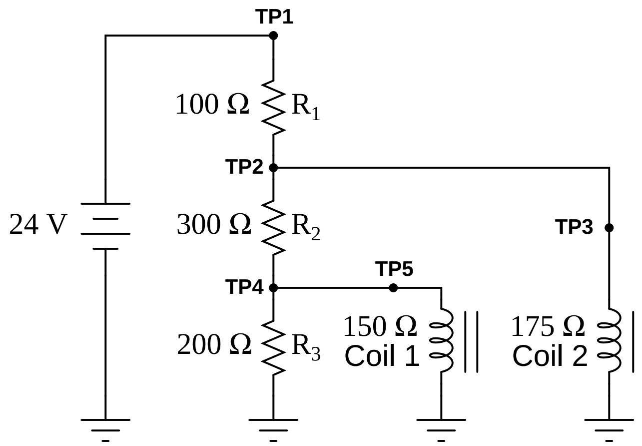
Draw the necessary connecting wires between terminals in this circuit, so that actuating the normally-open pushbutton switch sends power from the battery to the coil to energize the relay, with one of the relay's normally-open contacts closing to send current from the battery to the lamp. The pushbutton switch should not carry any lamp current, just enough current to energize the relay coil:



file i03211

Question 90

A piece of laboratory equipment uses a voltage divider to reduce voltage to two electromagnet coils from a higher-voltage source. Coil #1 is supposed to receive 2.91 volts and coil #2 is supposed to receive 13.11 volts:



One day, something goes wrong with this circuit. The magnetic field from coil #1 suddenly disappears, yet there is still a magnetic field coming from coil #2. The technician who looked at this problem before you took two voltage measurements and then gave up: 13.55 volts at test point TP3 and 5.42 volts at test point TP4. You left your multimeter back at the shop, which means you cannot take any more voltage measurements. However, since you are more determined than the former technician, you proceed to identify the following from the two measurements already taken:

- Two components or wires in the circuit that you know cannot be failed either open or shorted, besides the 24 volt source which is obviously operational.

- One component or wire in the circuit you think could possibly be bad, and the type of failure it would be (either open or shorted).

file i03166

Question 91

Lab Exercise – introduction

Your task is to install an electronic "smart" positioner on a control valve, and control the position of that valve from the output of a single "Hand Indicating Controller" (HIC) in its "manual" mode. Each instrument in the loop should be labeled with a proper tag name (e.g. "HV-78" for a hand-controlled valve), with all instruments in each loop sharing the same loop number. Write on pieces of masking tape to make simple labels for all the instruments and signal lines.

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

Objective completion table:

Performance objective	**Grading**	**1**	**2**	**3**	**4**	**Team**
Team meeting and prototype sketch (do *first!*)	mastery	–	–	–	–	
Circuit design challenge	mastery					– – – –
Final loop diagram and system inspection	mastery					– – – –
Alignment of positioner to valve	mastery	–	–	–	–	
Positioner calibration (with saturation)	mastery	–	–	–	–	
Demonstration of working system	mastery	–	–	–	–	
Troubleshooting	mastery					– – – –
Safety and professionalism	deduction					
Lab percentage score	proportional					– – – –
Decommission and lab clean-up	(ungraded)	–	–	–	–	

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

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. <u>Do not begin construction until your design has been analyzed and approved!</u> Note that multiple meetings may be required if the instructor's assistance is needed to select components influencing your design.

Circuit design challenge

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

Final loop diagram and system inspection

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

Alignment of positioner to valve

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

Positioner calibration

Calibrate the positioner to accurately drive the valve stem according to the 4-20 mA signal from the controller. The positioner should be fully "saturated" at 4 mA and at 20 mA to ensure full valve stem travel and seat loading.

Demonstration of working system

Show that the control valve may be operated over its full range using the controller's manual mode to set the 4-20 mA "manipulated variable" signal value.

Troubleshooting

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

Lab 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 – 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.

For example, if you intend to connect field devices to a PLC (Programmable Logic Controller), your prototype sketch must show how those devices will connect to typical input/output terminals on the PLC, where electrical power will be supplied, etc. Prototype sketches need not show all intermediary connections between components, such as terminal blocks in junction boxes between the field device and the controller.

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.

You team will need to install a digital electronic ("smart") positioner on the control valve you formerly "rebuilt". The Fisher DVC series of electronic valve positioners is highly recommended for this lab exercise.

Consult documentation from the manufacturer's website to identify how to properly wire, power, and calibrate the transmitter. Your instructor will check to see you have located and are familiar with the equipment manual(s).

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

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

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

Another important detail regarding positioner installation is properly aligning the linkage between the positioner and the control valve stem. Improper linkage alignment will result in non-linear valve travel (i.e. if 0% and 100% is accurate, 25%, 50% and/or 75% will not be). Again, consult the manufacturer's documentation for instructions on how to properly align the positioner-to-stem linkage.

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

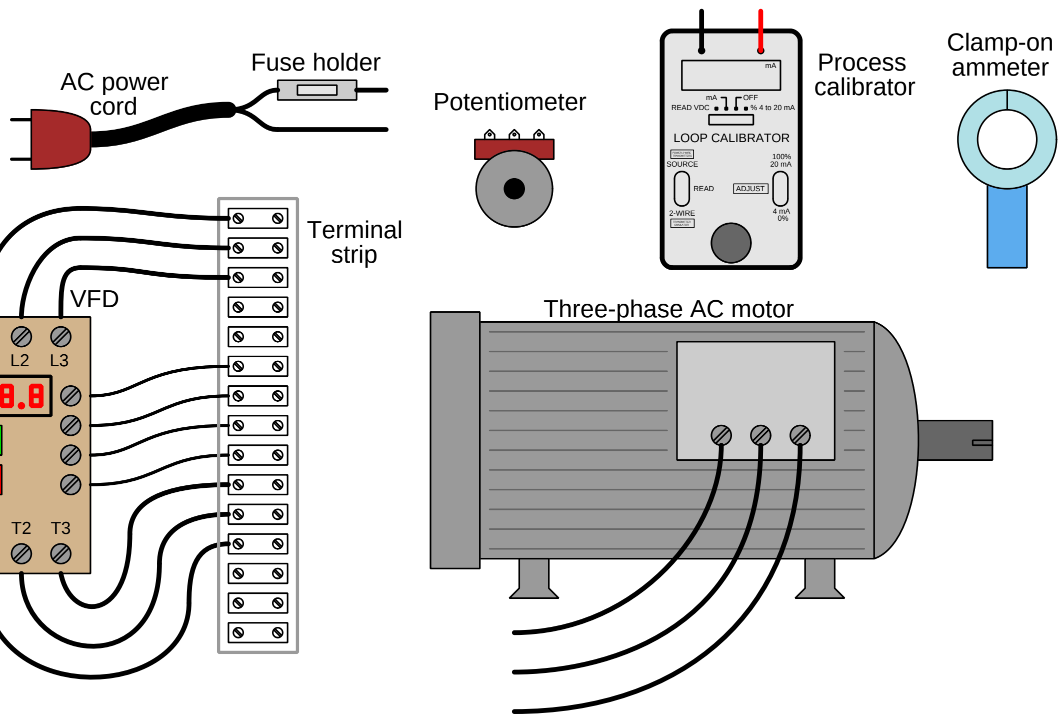
Common mistakes:

- Not checking valve stroke length for proper configuration before installing the positioner.
- Disturbing the valve body/actuator stem coupling by disassembling the coupling when the actuator spring pressure is still seating the plug.
- Incorrect installation and/or alignment of the linkage coupling the positioner to the valve stem: *consult the manual when installing your team's positioner to see exactly how it should attach!*
- Improper pipe/tube fitting installation (e.g. trying to thread tube fittings into pipe fittings and vice-versa).

Lab Exercise – circuit design challenge

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

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



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

Note that some VFDs require jumper wires installed in lieu of remote start/stop switches. The Allen-Bradley PowerFlex 4 VFD is an example of this, requiring a jumper wire between terminals 1 and 11 to take the place of an external "Stop" switch.

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

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

Speed control options (instructor chooses):

____ 4-20 mA analog signal
____ 0-10 V analog signal
____ Potentiometer (CW = faster)
____ Potentiometer (CCW = faster)
____ VFD front panel buttons/knob

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

Maximum motor speed (instructor chooses): __________ RPM

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

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

Base motor parameters (from nameplate):

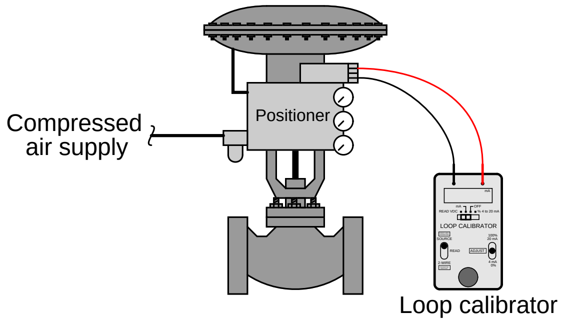
V_{line} = __________ Volts
I_{line} = __________ Amps @ full load
Speed = __________ RPM @ 60 Hz

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

Study reference: the "Variable-Speed Motor Controls" chapter of *Lessons In Industrial Instrumentation*, particularly the sections on AC Motor Speed Control and AC Motor Braking. The manual for the VFD will be absolutely necessary to reference!

Lab Exercise – calibrating the positioner

When finished installing the positioner, you should test it prior to building the rest of the loop system. Simply simulate the output signal of a loop controller by using a 4-20 mA loop calibrator in "source" mode, driving a signal to the I/P (or to the positioner directly, depending on the model) to stroke the valve.



One of the criteria for a successful positioner calibration is that the positioner must "saturate" its output pressure(s) when the valve reaches full stroke. For example, on a simple air-to-open valve calibration (i.e. 4 mA = valve at 0% position ; 20 mA = valve at 100% position), the positioner should saturate at beyond bench-set pressure at full signal (20 mA) and saturate at 0 PSI at minimum signal (4 mA) to ensure full seat loading. This requirement is in addition to accurate positioning at all points between 0% and 100%.

When finished calibrating your team's positioner, be sure to place a calibration tag on it showing the date it was calibrated. A set of calibration tags are given here, which you may tape to the positioner:

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

CALIBRATED	**CALIBRATED**	**CALIBRATED**	**CALIBRATED**
By: _____ Date: _____	By: _____ Date: _____	By: _____ Date: _____	By: _____ Date: _____
Range:____________	Range:____________	Range:____________	Range:____________

Valve positioners add an element of danger to control valves, because they are capable of sourcing greater flow rates of air to the actuator than most I/P transducers. This means the control valve will be capable of moving much more rapidly than when powered directly by an I/P. You should keep all body parts clear of the actuator when testing a positioner-equipped valve.

Similarly, you should never make adjustments to the feedback mechanism of a valve positioner when it is "powered" by compressed air! Any adjustments made to this mechanism will cause the positioner to immediately respond, "thinking" the valve has moved out of position and must be corrected, the result being rapid motion of the valve stem.

Common mistakes:

- Incorrect supply pressure given to positioner
- Failing to re-check stroke length and bench set on the valve before attempting to calibrate the positioner.

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

Lab Exercise – building the system

The Instrumentation lab is set up to facilitate the construction of working instrument "loops," with over a dozen junction boxes, pre-pulled signal cables, and "racks" set up with 2-inch vertical pipes for mounting instruments. 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 the positioner-equipped valve system. This will consist of a loop controller placed into "manual" mode to allow direct control over the position of your team's valve.

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

Select a specific loop controller to act as a display indicator 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. The controller itself should be labeled "HC-" or "HIC-" because it is a "hand" controller, allowing a human operator manual control over the valve's position.

Finally, your hand valve system needs to have a loop number, so all instruments may be properly labeled. This loop number needs to be unique, so that another team does not label their instruments and cables the same as yours.

Common mistakes:

- 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 system from one working control valve should take no more than one full lab session (3 hours) if all components are readily available and the team is working efficiently!

Lab Exercise – loop diagram and system inspection

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

Construction Standards

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

Documentation Standards

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

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

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

Common mistakes:

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

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

Lab Exercise – troubleshooting

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

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

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

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

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

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

Common mistakes:

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

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

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

Lab Exercise – decommissioning and clean-up

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

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

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

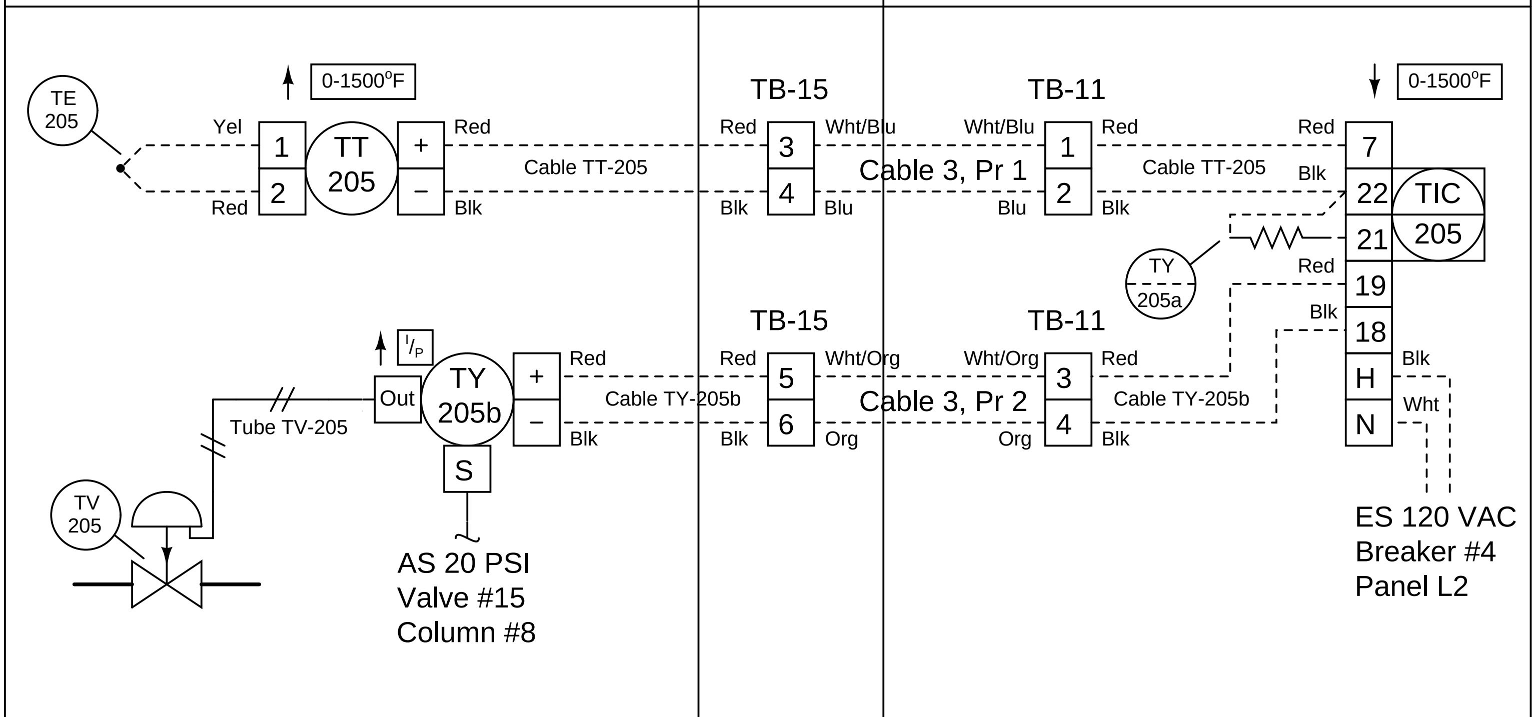
Return the following components to their proper storage locations:

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

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

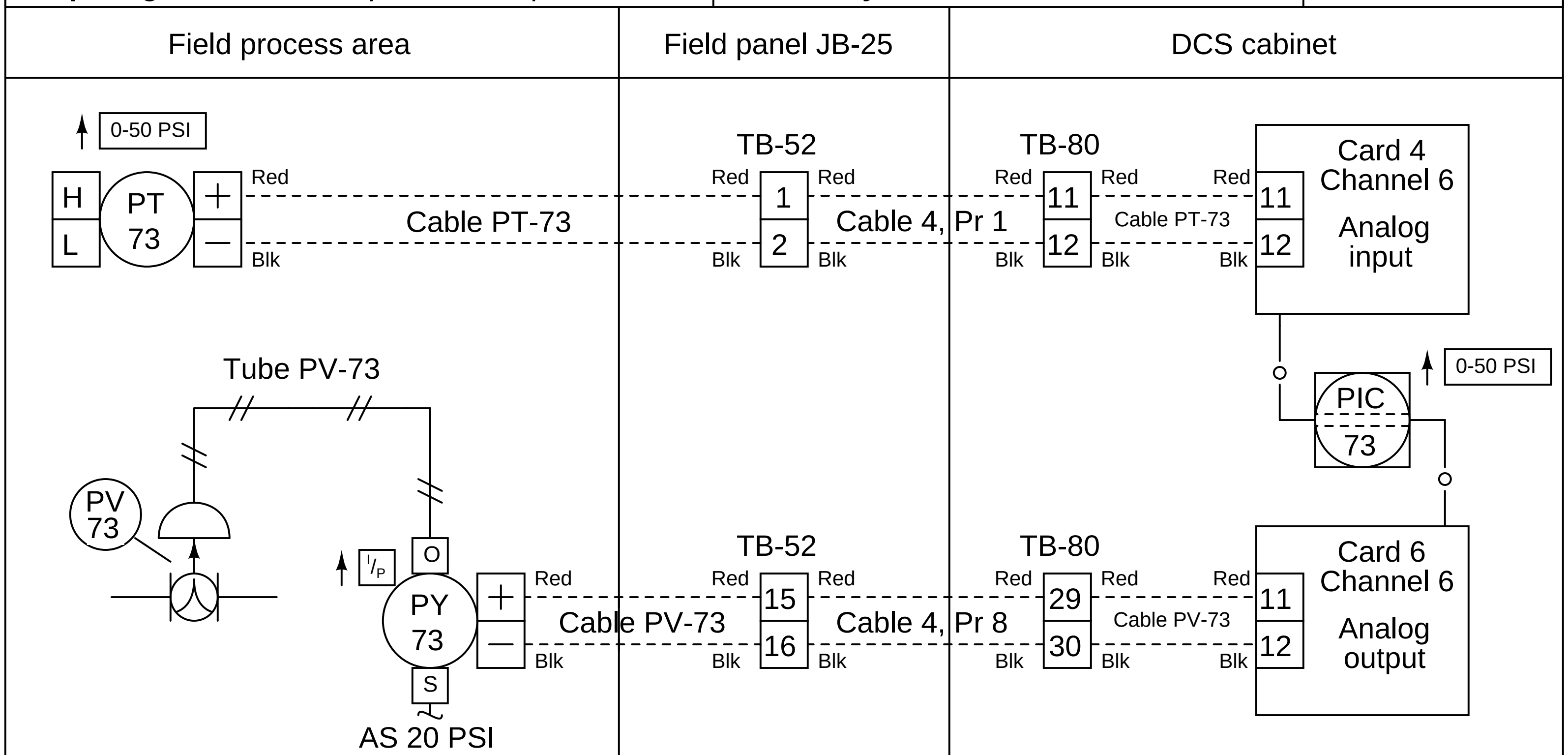
file i02590

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

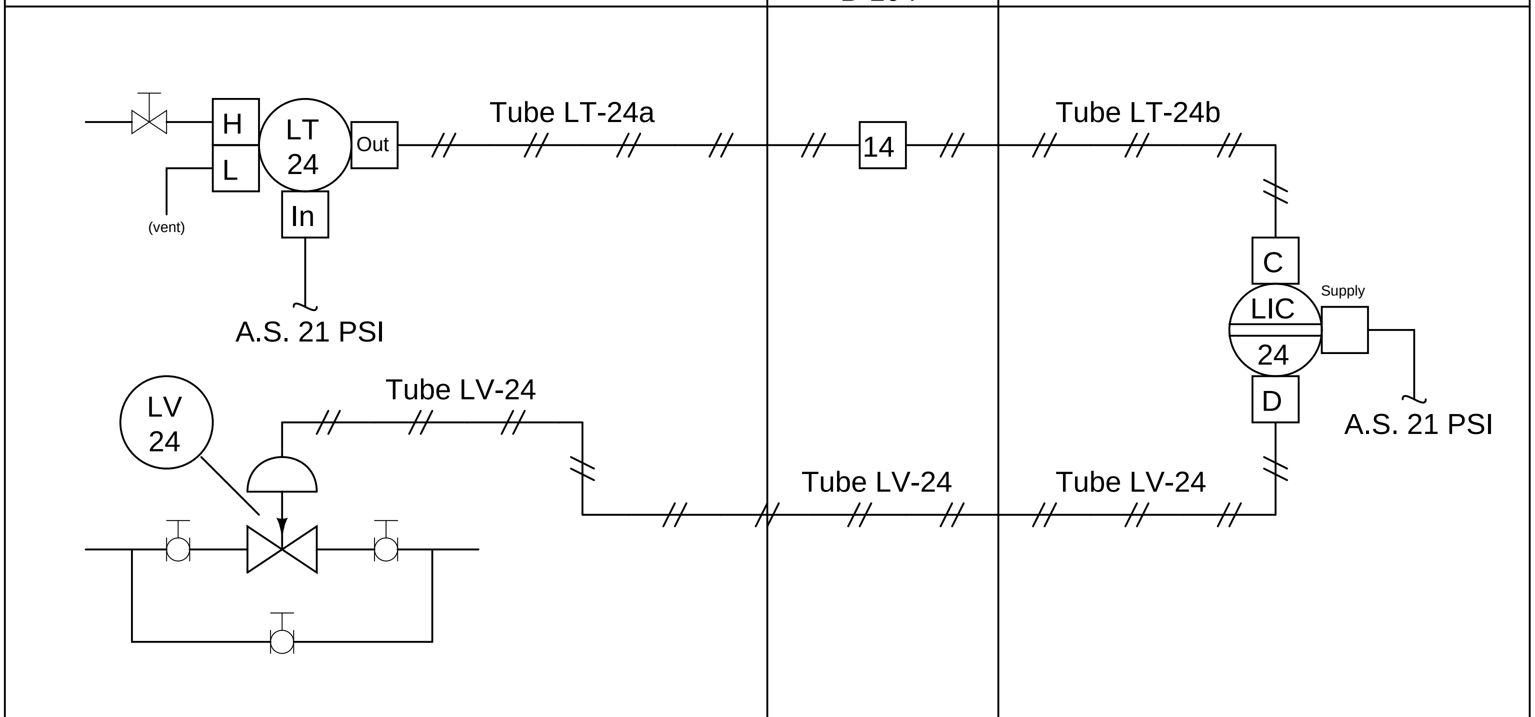
Loop Diagram: Blue team pressure loop	**Revised by:** Duncan D.V.	**Date:** April 1, 2009



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

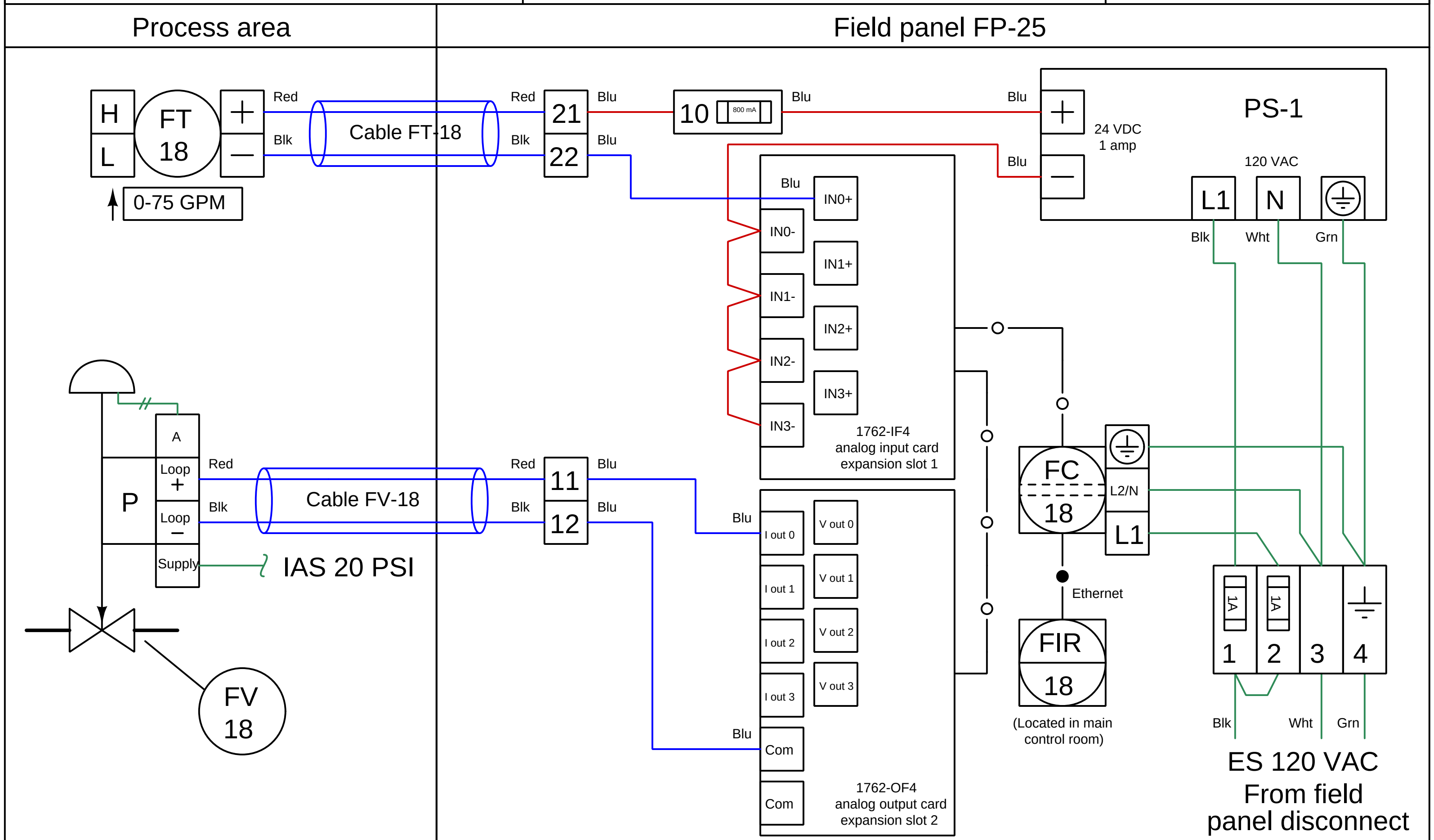
Loop Diagram: Sludge tank level control	**Revised by:** I. Leaky	**Date:** April 1, 2008

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



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

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



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

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file i00654

Answer 1

Answer 2

Answer 3

Feel free to bring a Fisher model 3582 positioner to class for hands-on learning!

Answer 4

A good diagnostic test here would be to pull the flapper away from the nozzle with your finger to see if the valve actuator returns to the "closed" (0%) position.

Answer 5

A good diagnostic test here would be to push the flapper toward the nozzle with your finger to see if the valve actuator tries to open.

Answer 6

Answer 7

Partial answer:

- Is this an air-to-open valve, or an air-to-close valve? *It is air-to-open. We know this from the positive slope of the traces: more air pressure is required to move the valve stem further open.*

- What principle of physics makes the plots (approximately) linear throughout the bulk of the travel range? *Hooke's Law describes the linear relationship between force applied to a spring and that spring's displacement:* $F = kx$

- What phenomenon accounts for the separation between the two traces? *Packing friction!*

Answer 8

The "hump" indicates a sudden change in frictional force from about 58% to 68% valve stem travel, but normal friction throughout the rest of the travel.

Answer 9

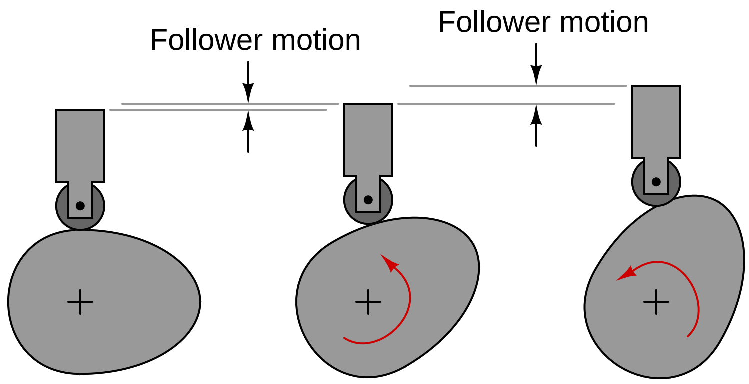
The glaring mistake in the technician's test is that he connected an ammeter in *parallel* when he should have connected it in *series*.

Answer 10

The Hall Effect sensor will output zero voltage when it is perfectly centered in the magnet assembly's length of travel (as shown in the illustration).

Answer 11

A *cam* is a rotating object with an irregular radius, which may be shaped in any way desired to produce a specific relationship between angular displacement and linear displacement:



Answer 12

- Gauge readings at 0% (3 PSI) signal to the positioner: *left-hand gauge saturated high (full pressure), right-hand gauge saturated low (0 PSI)*
- Gauge readings at 50% (9 PSI) signal to the positioner: *too little information to given to tell. We would have to know the valve's bench set pressure range as well as any other forces acting on the stem such as packing friction*
- Gauge readings at 100% (15 PSI) signal to the positioner: *left-hand gauge saturated low (0 PSI), right-hand gauge saturated high (full pressure)*

Answer 13

Answer 14

Answer 15

Answer 16

Answer 17

Answer 18

Answer 19

Answer 20

Answer 21

Answer 22

Hint: we will need more than a single SPST switch to control this motor!

Answer 23

When closing a gate valve, you want the gate to wedge firmly against the valve seat for tight shutoff. However, it does not matter as much whether or not the gate is fully withdrawn when the valve is wide open.

Answer 24

Answer 25

Answer 26

Note: the *Service Factor* (SF) on an electric motor's nameplate specifies the degree to which the motor may be overloaded on an intermittent basis. For this particular motor, the service factor is equal to 1.15, which means it will be able to output 1.15 times its nameplate horsepower (300 HP $\times$ 1.15 = 345 HP). Under this amount of overload, it will draw 477 Amperes of current rather than its 100% rating of 427 Amperes. The fact that the *Service Factor Amps* rating does not equal 1.15 times the full-load *Amps* rating tells us this motor's power factor is not constant between these two operating conditions.

Answer 27

Hint: here are *some* of the parameters you will need to configure in the VFD – `P031`, `P034`, and `P036`.

Answer 28

$\tau = 7.26$ lb-ft

Answer 29

Partial answer:

- If the first gear's shaft exerts a torque of 600 lb-ft on the gear (the "input" torque), how much torque will be exerted on the second gear's shaft (the "output" torque)? τ_{output} = *3,400 lb-ft*
- If the small gear has 24 teeth, how many teeth will the large gear have? *136 teeth*

Answer 30

Partial answer:

$\tau_{motor} = 8.8472$ lb-ft

Motor output = 2.897 horsepower

Answer 31

The normally-closed contacts are referred to as *interlock* contacts, and they prevent simultaneous *forward* and *reverse* actuation of the motor.

Answer 32

The mechanic's work is 1432 Newton-meters, or 1432 Joules. The mechanic's average power output during the 6 seconds is 238.7 watts.

Answer 33

$F = 1636.36$ lb

To solve for force, we simply need to manipulate the torque equation so that force (F) is by itself on one side of the equality sign:

$$\vec{\tau} = \vec{r} \times \vec{F}$$

$$\vec{F} = \frac{\vec{\tau}}{\vec{r}}$$

Since we happen to know in this problem that all three vectors are orthogonal (perpendicular) to each other, we may re-write the equation in simpler terms of scalar quantities instead of vector quantities:

$$F = \frac{\tau}{r}$$

Before we may insert the given values for torque and moment arm length, we need to convert units of length for the moment arm:

(11 inches)(1 foot / 12 inches) = 0.916667 feet

Now, solving for force:

$$F = \frac{1500 \text{ lb-ft}}{0.916667 \text{ ft}}$$

$$F = 1636.36 \text{ lb}$$

Answer 34

One way to measure worm screw thrust force is with a *load cell*. Another way is to spring-load the screw shaft and use an LVDT or other motion-sensing device to measure displacement.

Answer 35

The motor drive input in the 1-5 volt signal system "sees" more noise voltage than the motor drive input in the 4-20 mA signal system.

Follow-up question: what bad effects do you think noise superimposed on the DC signal cable would have on motor speed control?

Challenge question: why do you suppose the 1-5 volt signal system requires a much greater input impedance (1 MΩ) than the 4-20 mA signal system? What might happen to the voltage signal received at the motor drive's input terminals if the input resistance were much less?

Answer 36

The torque (τ) in this case is obviously 550 lb-ft, since the 550 pound weight is acting on a moment arm 1 foot long (the drum's radius). All we need to do is translate the vertical velocity of 1 foot per second into drum rotation in units of RPM, and we'll have the data we need to calculate k:

$$\text{Circumference of drum } = \pi D = 2\pi r = 6.283 \text{ ft}$$

This is the amount of cable that travels in one revolution of the drum (1 rev = 6.283 ft), and this equality constitutes a conversion factor which we may use to convert the linear velocity of 1 ft/s into a rotational velocity:

$$\left(\frac{1 \text{ ft}}{\text{sec}}\right)\left(\frac{1 \text{ rev}}{6.283 \text{ ft}}\right)\left(\frac{60 \text{ sec}}{1 \text{ min}}\right) = 9.5493 \text{ RPM}$$

Therefore,

$$P = k\tau S$$

$$1 \text{ hp} = (k)(550 \text{ ft-lb})(9.5493 \text{ RPM})$$

$$k = 0.0001904$$

$$P = 0.0001904\tau S$$

. . . or . . .

$$P = \frac{\tau S}{5252}$$

Where,
P = Shaft power in horsepower
τ = Shaft torque in lb-ft
S = Shaft speed in revolutions per minute (RPM)

By coincidence, the factor of 5252 happens to be close to the number of feet in a mile (5280 feet = 1 mile). This might come in handy as an approximation!

Answer 37

Work done in lifting the bucket manually: 5174.15 ft-lb, or 7015.24 J. Laborer "A" does the exact same amount of work as laborer "B," but their *power* output is not the same.

Time required for electric hoist to lift the 20 gallon bucket = 6.269 seconds.
Time required for electric pump to lift 20 gallons of water to the roof = 6.269 seconds.

Answer to challenge question: 44.54 ft/s (down)

Answer 38

Contrary to intuition, *no work has been done*. Lifting the 40 pounds of books 5 feet up constitutes 200 ft-lb of work done on the books (i.e. potential energy invested in the books), but returning those books back to floor level constitutes 200 ft-lb of energy *released* (negative work done). Thus, in physics terms, there was no net work performed.

The person tasked with this pointless exercise, however, may beg to differ.

This same principle of storing and releasing energy is employed in electric vehicles to recover braking energy. Instead of converting electrical energy into mechanical potential and vice-versa as happens with the elevator, electric vehicles convert electrical energy into kinetic form (vehicle motion) and vice-versa. Thus, accelerating an electric car from a full stop to some speed and then regeneratively decelerating it back to full stop is another example of zero (net) work. This energy-recovering capability is what makes electric vehicles so attractive for stop-and-go travel.

Answer 39

Partial answer:

Potential faults causing the valve not to open:

- C1 contact 5-6 failed open; C1 contact 3-4 failed open; C1 contact 1-2 failed open
- C1 coil failed open
- TRIAC output on circuit board to coil C1 failed open (terminal FL9)

Answer 40

Answer 41

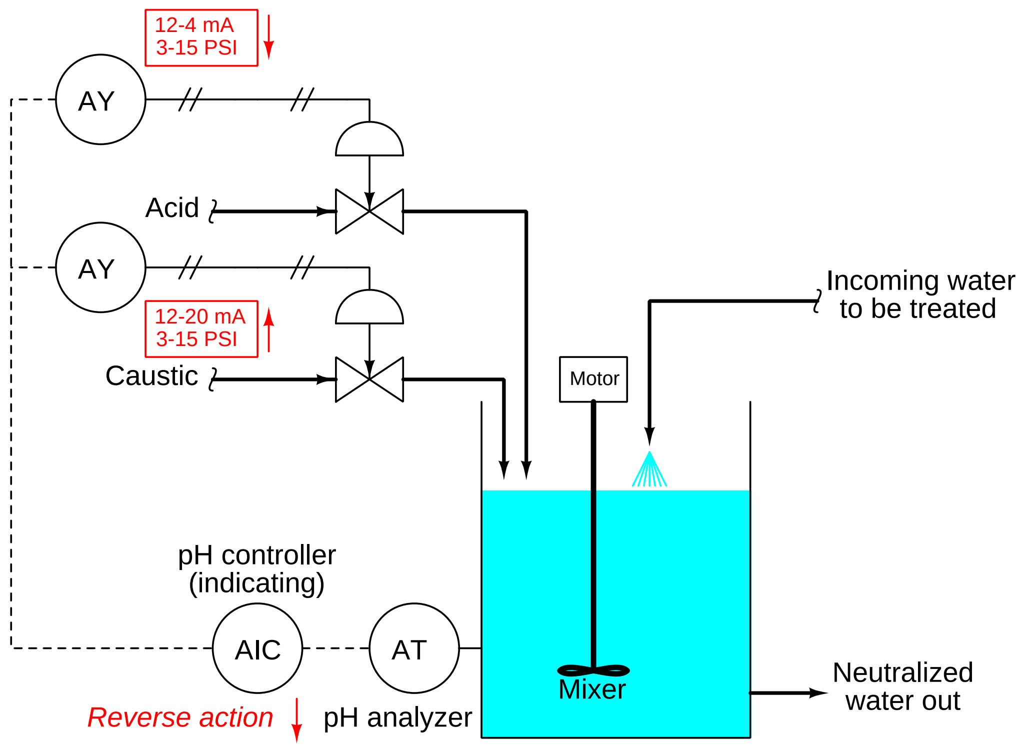
Answer 42

Answer 43

Answer 44

Answer 45

This is one way to connect the valves together as a split-ranged pair:



Answer 46

Partial answer:

- What will happen in the event that cable 3 becomes completely severed? **The hot water valve will completely shut and the cold water valve will completely open.**

- How much voltage will the controller have to output between terminals 19 and 18 when the output signal is at 100% of range? Assume a coil resistance of 176 ohms for each of the model 546 I/P transducers. **7.04 volts DC**

Answer 47

Forced draft damper position	Controller output signal
Fully shut (0%)	4 mA
Wide open (100%)	20 mA

Induced draft damper position	Controller output signal
Fully shut (0%)	20 mA
Wide open (100%)	4 mA

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

Answer 48

These two control valves are *progressively* split-ranged. PV-33a is the first to open as the control signal pressure falls below 15 PSI, sending more cooling water to the overhead condenser E-8 (more cooling causes the vapors to condense at a faster rate, reducing pressure in the fractionation tower). If a wide-open PV-33a is not enough to bring the tower pressure down to setpoint, valve PV-33b begins to open, venting vapor to the low-pressure flare where it may be safely burned off.

Answer 49

The failure mode of this valve due to loss of supply air pressure to the positioner will not be the same as the failure mode due to loss of air pressure from the I/P or due to loss of DC current to the I/P.

Answer 50

Base valve position	Controller output signal
Fully shut (0%)	20 mA
Wide open (100%)	4 mA

Pigment valve position	Controller output signal
Fully shut (0%)	4 mA
Wide open (100%)	20 mA

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

Answer 51

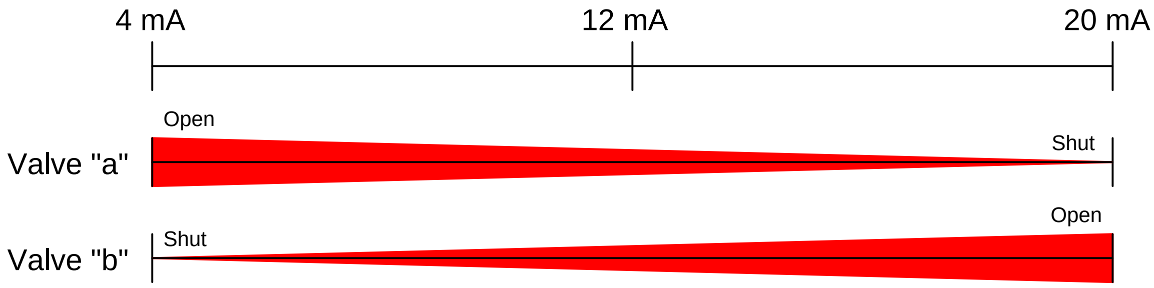
Small valve position	Controller output signal
Fully shut (0%)	20 mA
Wide open (100%)	12 mA

Large valve position	Controller output signal
Fully shut (0%)	12 mA
Wide open (100%)	4 mA

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

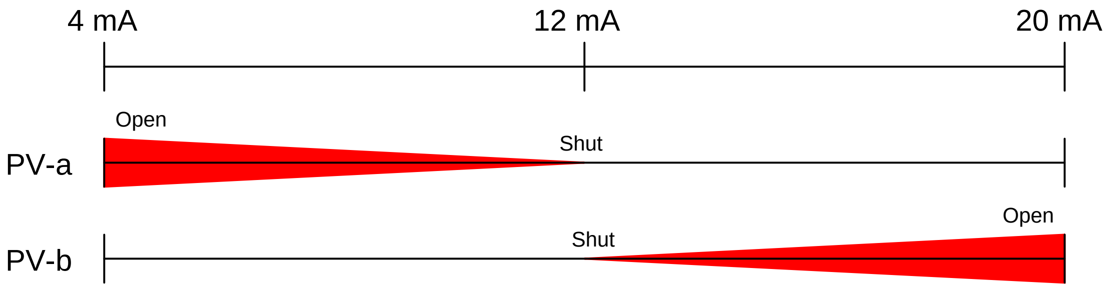
Answer 52

This application requires *complementary* split-ranging:



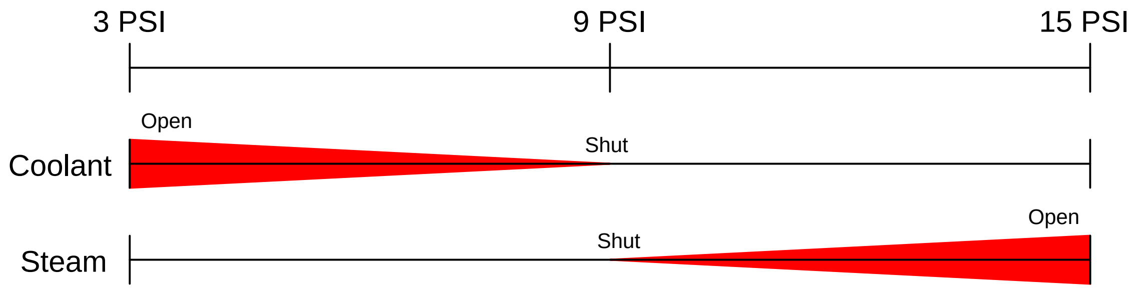
Answer 53

This application requires *exclusive* split-ranging:



Answer 54

This requires an *exclusive* split range sequencing:



With a 100% controller output signal (20 mA, or 15 PSI) driving the steam valve open and the coolant valve closed, the steam valve needs to be air-to-open, and the coolant valve needs to be air-to-close.

In order to avoid having both valves open at the same time, we can "split" the ranges so that one valve operates on the top half of the controller's output signal range (12-20 mA, 9-15 PSI), and the other valve on the bottom half of the controller's output range (4-12 mA, 3-9 PSI).

Since we desire to temperature controller to give a decreasing output (toward 0% for full-cooling mode) for an increasing process variable signal (increasing process temperature), it needs to be reverse-acting.

Answer 55

Current	FV-14a position	FV-14b position
4 mA	0%	0%
7.5 mA	43.75%	0%
13 mA	100%	12.5%
18.5 mA	100%	81.25%

These two control valves are *progressively* split-ranged.

Answer 56

Current	TV-99a position	TV-99b position
4 mA	0%	100%
9 mA	31.25%	68.75%
14.2 mA	63.75%	36.25%
19 mA	93.75%	6.25%

These two control valves are *complementarily* split-ranged.

Answer 57

Current	LV-50a position	LV-50b position
4 mA	100%	0%
8.6 mA	42.5%	0%
15.1 mA	0%	38.75%
20 mA	0%	100%

These two control valves are *exclusively* split-ranged.

Answer 58

Answer 59

Answer 60

Answer 61

Answer 62

Answer 63

Answer 64

If you calculated a necessary C_v value of 45.69, you're just plugging numbers into equations without thinking carefully enough about what those numbers represent. The correct C_v is nearly five times larger than this (incorrect) value.

Answer 65

Answer 66

- Segmented ball valve, 4 inch pipe size; C_v = **400**
- Single-port, cage-guided globe valve, 6 inch pipe size; C_v = **540**
- Double-port, ported-plug globe valve, 2 inch pipe size; C_v = **50**
- 90^o butterfly valve with offset seat, 20 inch pipe size; C_v = **11,600**

Note: the C_v values obtained using relative flow coefficients (C_d) are *approximate only!* This calculation technique should only be used to *estimate* the valve size needed for a particular application.

Answer 67

Partial answer:

$C_v = 21.1$

Answer 68

Fault	Possible	Impossible
LT calibration error		$\surd$
LY calibration error	?	
Controller failed	$\surd$	
Low air supply pressure	$\surd$	
Excessive resistance in LT circuit		$\surd$
Excessive resistance in LY circuit		$\surd$
Feedwater pump worn	$\surd$	
Controller in manual mode	?	

An LY calibration error is possible only if the error is quite significant. Otherwise, the controller will compensate for any modest valve errors through feedback.

The "excessive resistance" faults are not possible if we assume the extra resistance to be insufficient to cause the controller or transmitter to saturate. Ideally, both current sources (LT and LIC) will fight as hard as they must to maintain proper current in each circuit, even with extra resistance. However, if the extra resistance is very large, it would be possible for that resistance to force either current value to be less than it should be.

A controller in manual usually does not allow changes in setpoint due to the standard "setpoint tracking" feature. If this feature is turned off, however, changes in setpoint are possible in manual mode.

A good "next test" is to inspect the controller's output indication to see what it is trying to do to remedy the low process variable. The output should be saturated at 100% (wide-open valve) if the controller is doing its job. If not, the controller has a problem (e.g. left in manual mode, poor tuning). If the output is saturated as we would expect it to be, then the next logical place to check is the control valve to see whether or not the valve is actually making it to the full-open position.

Answer 69

$Q = 55.902$ gallons per minute

Answer 70

$P_1 = 61.8$ PSI

Answer 71

$Q = 52.46$ GPM at $C_v = 8$

$Q = 26.23$ GPM at $C_v = 4$

Answer 72

Liquid density = 73.879 pounds per cubic foot

Answer 73

- Work done by Sam in lifting his textbook = 1040 ft-lb
- Kinetic energy of Sam's textbook just before it hits the ground = 1040 ft-lb
- Velocity of Sam's textbook just before it hits the ground = 91.2 ft/s

- Work done by Tony in lifting his textbook = 650 ft-lb
- Kinetic energy of Tony's textbook just before it hits the ground = 650 ft-lb
- Velocity of Tony's textbook just before it hits the ground = 91.2 ft/s

Knowing that kinetic energy just before the book hits the ground should be equal to potential energy when released (assuming zero energy loss due to air friction), we may solve for v quite easily:

$$E_k = \frac{1}{2}mv^2 \qquad\qquad E_p = mgh$$

$$\frac{1}{2}mv^2 = mgh$$

$$\frac{1}{2}v^2 = gh$$

$$v^2 = 2gh$$

$$v = \sqrt{2gh}$$

Answer 74

5.1 meters (measured vertically) at an initial velocity of 10 m/s. At 20 m/s, the truck would have gained *four times* as much altitude (20.4 meters)!

Knowing that potential energy when the truck reaches its stopping point on the hill should be equal to kinetic energy when the clutch fails (assuming zero energy loss due to friction), we may solve for h quite easily:

$$E_p = mgh \qquad\qquad E_k = \frac{1}{2}mv^2$$

$$mgh = \frac{1}{2}mv^2$$

$$gh = \frac{1}{2}v^2$$

$$h = \frac{\frac{1}{2}v^2}{g}$$

$$h = \frac{v^2}{2g}$$

Note that the slope of the hill is unspecified, because it is irrelevant to the answer of how much vertical height the truck gains by coasting. What *would* the slope of the hill affect, though?

Answer 75

A measurement of 0 volts *may* imply electrical continuity, but it may not. There are other reasons why one might obtain a 0 volt measurement, such as an open fault isolating the measurement points from power. If some *other* part of the AC line is open (e.g. the contactor being de-energized), even an open fuse will drop 0 volts because it is not the only open in the circuit.

Answer 76

τ_{net} = 11.2 lb-ft, clockwise

$$M_A = \frac{F_{out}}{F_{in}} = \frac{3.2 \text{ lb}}{4 \text{ lb}} = 0.8$$

Answer 77

Maximum pulling force = 5236.36 pounds

$$W = Fx = (5236.36 \text{ lb})(300 \text{ ft}) = 1570909.1 \text{ ft-lb}$$

1 horsepower is 550 ft-lb of work done per second. If Roy's tractor did 1,570,909.1 ft-lb of work in 60 seconds, it is equivalent to 26,181.8 ft-lb/s of power, which is 47.6 horsepower.

As the tractor mechanism exerts torque on the wheels, and the weight of the load opposes the wheels' turning, the tractor experiences this torque about the axis of rotation: the axles. As the wheels *try* to rotate in a forward direction, but are impeded by the resistance of the load, the reaction torque *tries to rotate the tractor backward about the same axis*. This manifests itself in the form of the front tires of the tractor lifting off the ground.

Answer 78

When closing a gate valve, you want the gate to wedge firmly against the valve seat for tight shutoff. However, it does not matter as much whether or not the gate is fully withdrawn when the valve is wide open.

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.