
Lab

“Smart” valve positioner: *Questions 91 and 92, completed objectives due by the end of day 5*

Exam

Day 5 – 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
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Recommended daily schedule

Day 1

Theory session topic: Valve sizing and self-operated valves

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

Day 2

Theory session topic: Valve characterization

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

Day 3

Theory session topic: Valve problems

Questions 41 through 60; answer questions 41-50 in preparation for discussion (remainder for practice)

Day 4

Theory session topic: Guest-led workshop on smart valve positioner

Questions 61 through 80; all questions are for your practice only

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

Day 5

Exam

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.

General Values, Expectations, and Standards (continued)

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.

Program Outcomes for Instrumentation and Control Technology (BTC)

#1 Communication

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

#2 Time management

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

#3 Safety

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

#4 Analysis and Diagnosis

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

#5 Design and Commissioning

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

#6 System optimization

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

#7 Calibration

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

#8 Documentation

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

#9 Independent learning

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

#10 Job searching

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

file outcomes_program

INST 250 Course Outcomes

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]

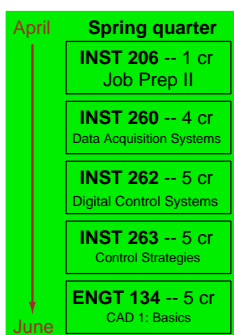
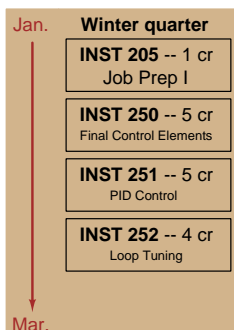
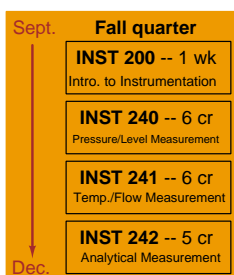
- Wire and program a VFD (Variable Frequency motor Drive) for variable-speed control of an AC induction motor, measuring motor line current with a clamp-on ammeter. [Ref: Program Learning Outcome #5]
- Diagnose random faults placed in other team's hand control systems by the instructor within a limited 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]

Sequence of second-year Instrumentation courses



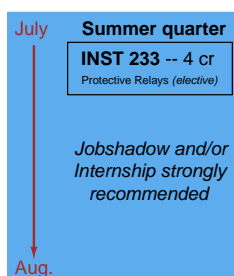
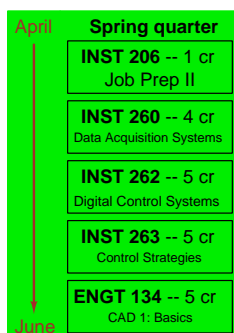
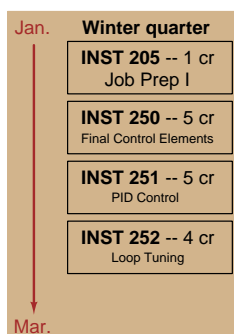
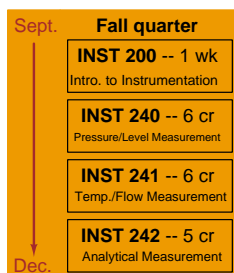
Some second-year courses are only offered in particular quarters with those quarters not having to be in sequence, while others are offered three out of the four quarters and must be taken in sequence. The following layout shows four typical course sequences for second-year Instrumentation students,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

Beginning in Summer



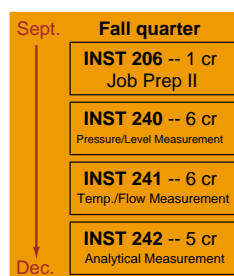
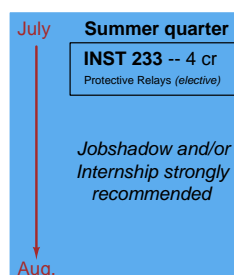
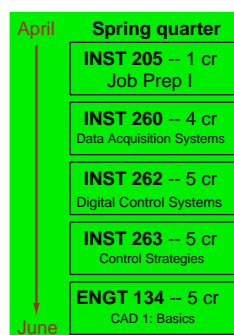
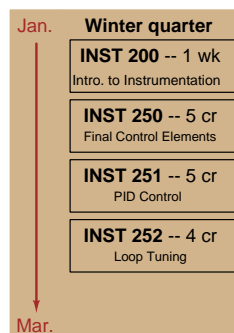
Graduation!

Beginning in Fall



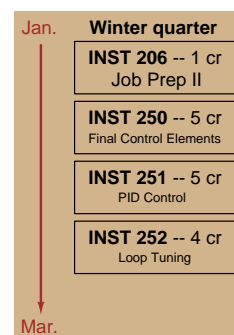
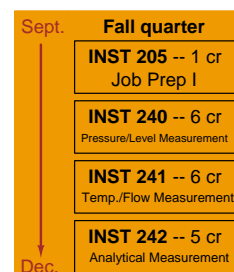
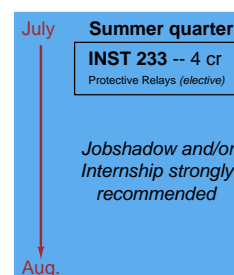
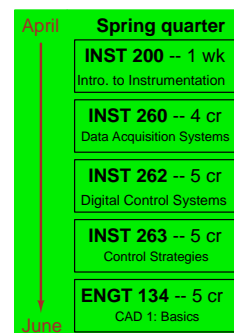
Graduation!

Beginning in Winter



Graduation!

Beginning in Spring



Graduation!

9

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.

Methods of instruction (continued)

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

Sample rubric for pre-assessments

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

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

Sample rubric for post-assessments

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

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

Methods of instruction (continued)

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

Methods of instruction (continued)

Lab sessions

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

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

Troubleshooting assessments must meet the following guidelines:

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

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.

Metric prefixes and conversion constants

- **Metric prefixes**

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



- **Conversion formulae for temperature**

- $^{\circ}\text{F} = (^{\circ}\text{C})(9/5) + 32$
- $^{\circ}\text{C} = (^{\circ}\text{F} - 32)(5/9)$
- $^{\circ}\text{R} = ^{\circ}\text{F} + 459.67$
- $\text{K} = ^{\circ}\text{C} + 273.15$

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 (in³) = 4 quarts (qt) = 8 pints (pt) = 128 fluid ounces (fl. oz.)
= 3.7854 liters (l)

1 milliliter (ml) = 1 cubic centimeter (cm³)

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 (ft²) = 4840 square yards (yd²) = 4046.86 square meters (m²)

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 10¹⁰
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/s²) = 32.1740 feet per second per second (ft/s²)

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-Kelvin⁴ ($\text{W}/\text{m}^2 \cdot \text{K}^4$)

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

Properties of Water

Freezing point at sea level = $32^\circ\text{F} = 0^\circ\text{C}$

Boiling point at sea level = $212^\circ\text{F} = 100^\circ\text{C}$

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

Specific heat of water at 14°C = $1.00002 \text{ calories}/\text{g} \cdot ^\circ\text{C} = 1 \text{ BTU}/\text{lb} \cdot ^\circ\text{F} = 4.1869 \text{ Joules}/\text{g} \cdot ^\circ\text{C}$

Specific heat of ice $\approx 0.5 \text{ calories}/\text{g} \cdot ^\circ\text{C}$

Specific heat of steam $\approx 0.48 \text{ calories}/\text{g} \cdot ^\circ\text{C}$

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

Surface tension of water (in contact with air) at 18°C = 73.05 dynes/cm

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

Properties of Dry Air at sea level

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

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

file conversion_constants

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!

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:

☒ 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.

☒ 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.

☒ 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.

☒ Specifically identify any **CONFUSING** points. The reason for doing this is to help diagnose misconceptions, as well as practice both metacognition and critical thinking.

☒ **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.

☒ 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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Questions

Question 1

Read and outline the “Flanged Pipe Fittings” subsection of the “Pipe and Pipe Fittings” section of the “Instrument Connections” chapter in your *Lessons In Industrial Instrumentation* textbook.

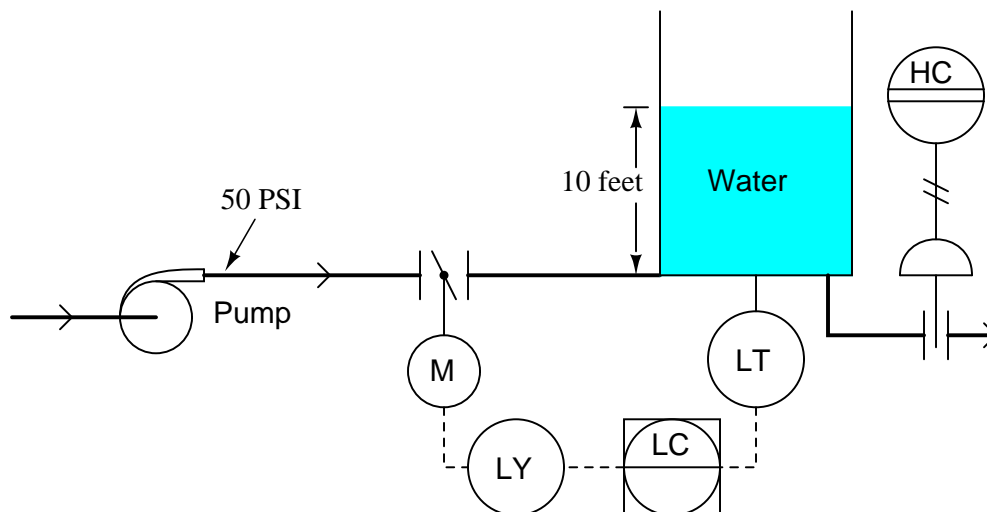
After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

- (1) Your written summary of all major points of the text, expressed as simply as possible in your own words.
- (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 i04232](#)

Question 2

A water control valve is supposed to pass a maximum flow rate of 300 GPM from the pump to the storage vessel, to hold the vessel's level constant at the setpoint shown:



The pump's outlet pressure is a constant 50 PSI, and we will assume the vessel's level remains constant at 10 feet. Given these conditions, calculate the flow capacity (C_v rating) for this control valve. Also, determine whether or not there is enough information given in this P&ID to indicate the control valve's action (either signal-to-open or signal-to-close).

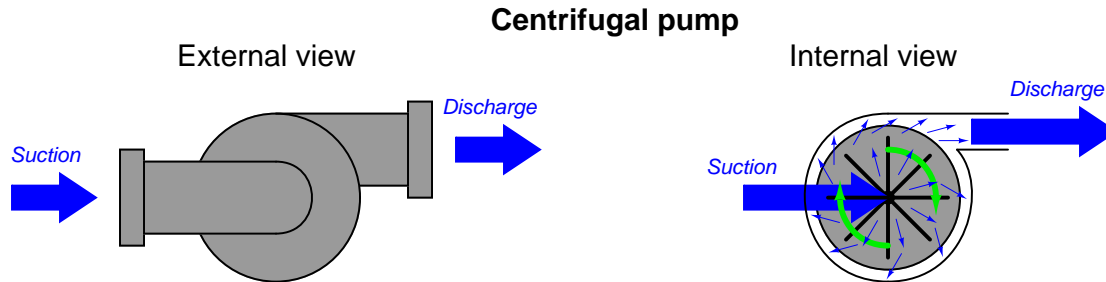
Suggestions for Socratic discussion

- Explain how you may use the known height of water in the vessel to calculate the valve's downstream pressure (P_2). There is more than one way to do this!
- What do the symbols and line types tell you about the individual instruments used in this level control system?
- Suppose operations personnel decided to raise the setpoint in this level control system from 10 feet to 15 feet. Would this operational change affect the required control valve size (assuming we still need 300 GPM maximum flow)? Why or why not?
- Suppose electricians installed a *VFD* ("variable-frequency drive") in the pump motor electrical system, allowing the AC induction motor to be run at less than 100% speed to conserve energy. Would a reduced pump speed affect the required control valve size (assuming we still need 300 GPM maximum flow)? Why or why not?
- Suppose the sliding-gate valve on the discharge line from this liquid storage vessel were replaced with one having a smaller pipe size. Would this hardware change affect the required control valve size (assuming we still need 300 GPM maximum flow)? Why or why not?

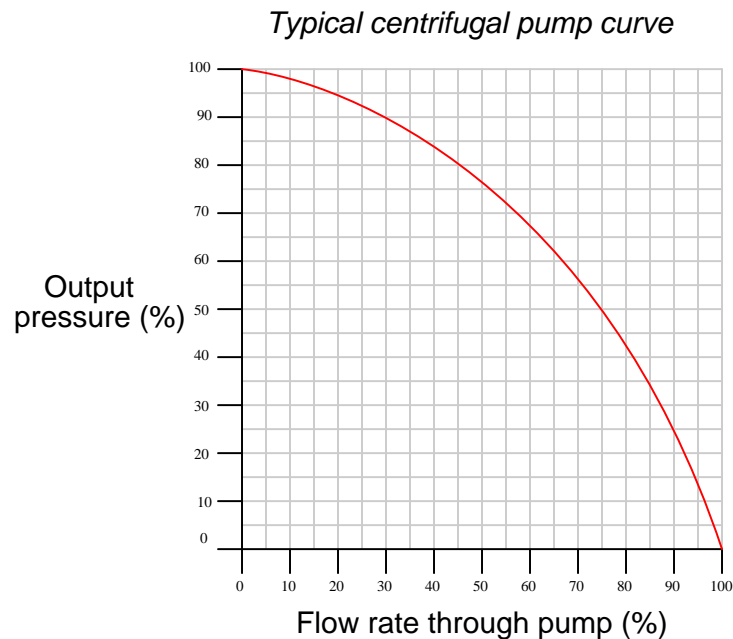
[file i01408](#)

Question 3

A *centrifugal pump* works by spinning a disk with radial vanes called an “impeller,” which flings fluid outward from the center of the disk to the edge of the disk. This kinetic energy imparted to the fluid translates to potential energy in the form of pressure when the fluid molecules strike the inner wall of the pump casing:



The performance of a centrifugal pump is often expressed in a special graph known as a *pump curve*. A typical centrifugal pump curve appears here, traced for one particular shaft speed:



Examine this pump curve, and explain in your own words what it tells us about the performance behavior of this pump when turned at a constant speed.

Suggestions for Socratic discussion

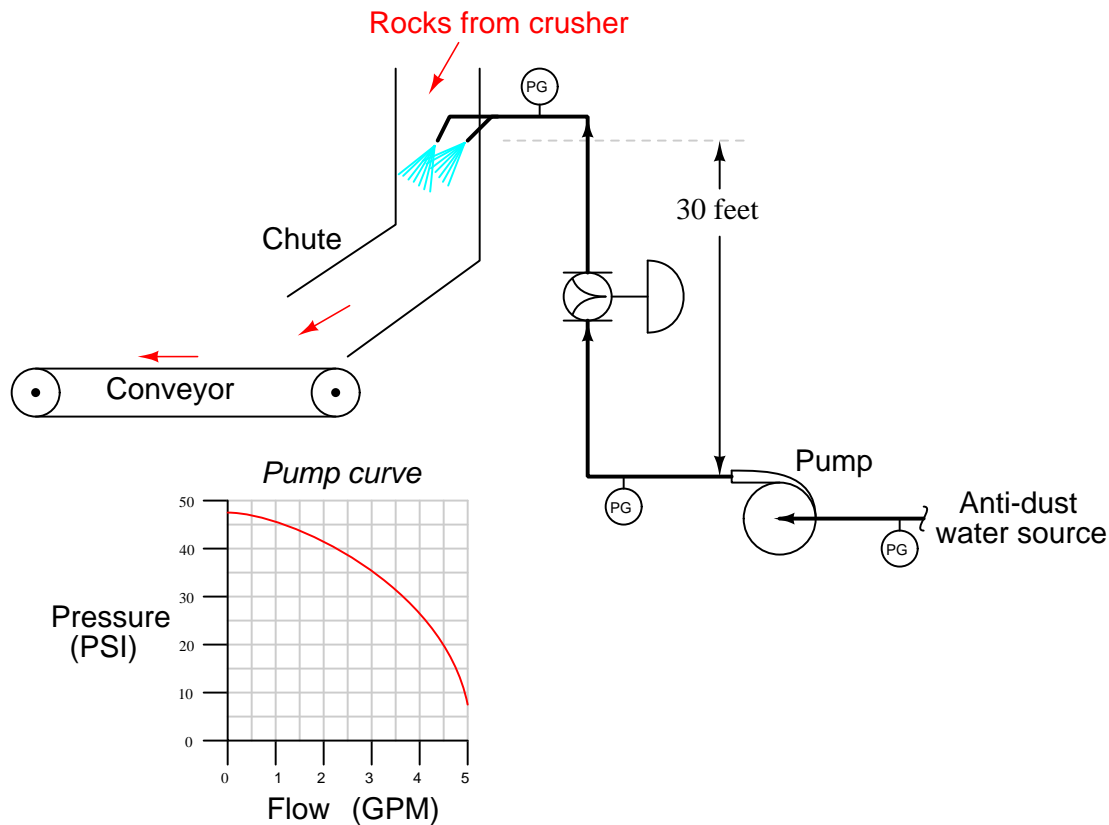
- One way to describe the operation of a centrifugal pump is to say it generates discharge pressure by converting kinetic energy into potential energy. Elaborate on this statement, explaining exactly where and how kinetic energy gets converted to potential energy. Hint: this might be easier to answer if you consider the “limiting case” of maximum discharge pressure described by the pump curve, where flow is zero and pressure is maximum.
- Appealing to the conversion of energy between kinetic and potential forms, explain *why* discharge pressure for a centrifugal pump falls off as flow rate increases.

- The pump curve shown assumes a constant rotational speed for the pump's impeller. How would the pump curve be modified if the pump were rotated at a slower speed?

file i01407

Question 4

A rock-crushing operation uses a set of water spray nozzles to “knock down” dust released by the rocks as they exit the crushing machine down a chute and onto a conveyor belt:



Determine the required C_v rating for this control valve to provide a flow rate of 3 GPM, assuming the nozzles drop approximately 4 PSI of water pressure at that flow rate and that the pump suction (inlet) pressure is 0 PSIG at all times.

Next, determine the readings of all three pressure gauges with the control valve wide-open.

Next, determine the readings of all three pressure gauges with the control valve fully shut.

Suggestions for Socratic discussion

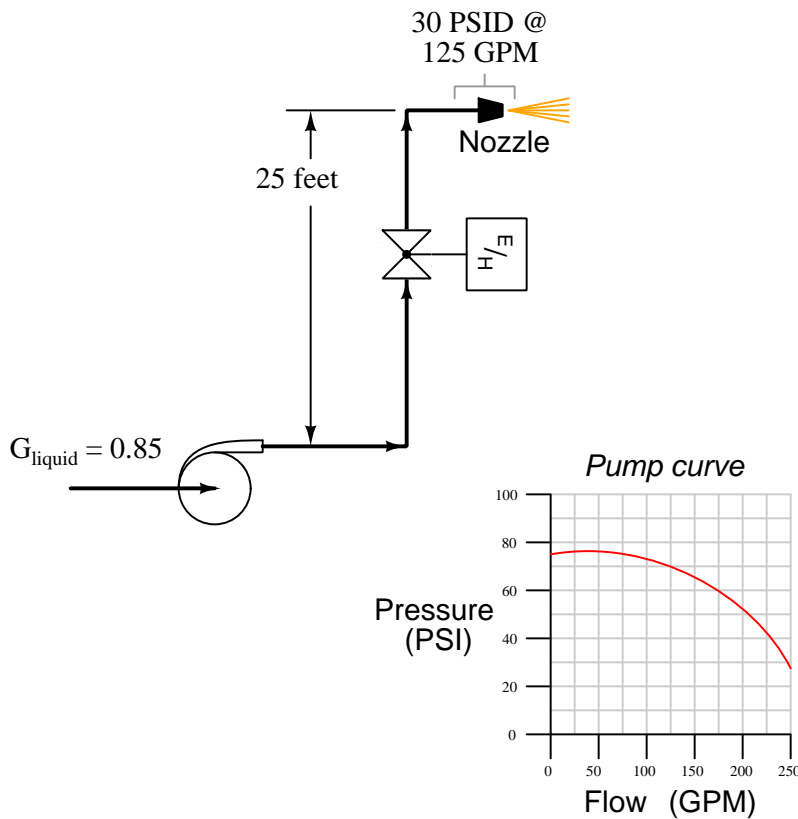
- A helpful problem-solving strategy for people familiar with basic electricity is to model the fluid system as a DC circuit: any source of constant pressure is represented by a voltage source (e.g. battery) while any restriction to flow is represented by a resistor. In such a model, what determines the polarity of each component's voltage as it relates to the direction of flow (current)?
- What type of control valve and actuator are used in this application?
- Calculate the pressure registered by each of the pressure gauges in this system in a condition where the control valve is wide-open.
- Calculate the pressure registered by each of the pressure gauges in this system in a condition where the control valve is fully shut.
- Does it matter where the control valve is installed in the vertical pipe section (e.g. at the top versus at the bottom versus in the middle)? Explain why or why not.

- How do you think the pump curve would be affected if the pump's speed were altered (e.g. the AC electric motor powered through a VFD)?

file i01409

Question 5

Calculate the required valve C_v rating to achieve a flow rate of 125 GPM, assuming that the nozzle at the end of the pipe drops a pressure of 30 PSID at that rate of flow. Assume a liquid with a specific gravity of 0.85, and a pump suction (inlet) pressure of 0 PSIG at all times:



Also, calculate the approximate size of the valve (nominal pipe diameter, in inches) given a double-ported, contoured plug globe valve ($C_d = 13$).

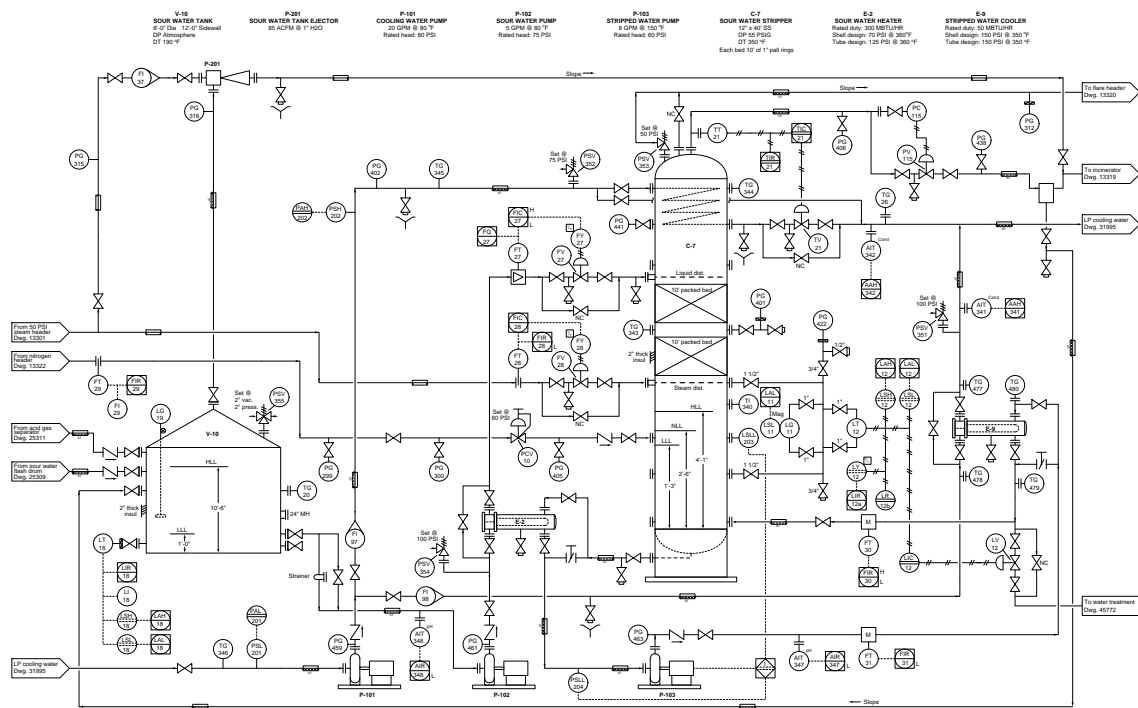
Suggestions for Socratic discussion

- A helpful problem-solving strategy for people familiar with basic electricity is to model the fluid system as a DC circuit: any source of constant pressure is represented by a voltage source (e.g. battery) while any restriction to flow is represented by a resistor. In such a model, what determines the polarity of each component's voltage as it relates to the direction of flow (current)?
- Suppose the pump were powered by an electric motor through a VFD (Variable Frequency Drive), allowing adjustment of pump speed. How would a *decrease* in pump speed alter the pump curve, if at all?
- What type of control valve and actuator are used in this application?
- Calculate the pressures at the upstream and downstream flanges of the control valve when that valve is wide-open, if possible.
- Calculate the pressures at the upstream and downstream flanges of the control valve when that valve is fully shut, if possible.
- Does it matter where the control valve is installed in the vertical pipe section (e.g. at the top versus at the bottom versus in the middle)? Explain why or why not.

[file i01410](#)

Question 6

Calculate a realistic C_v value for LV-12, given only the information shown on the following P&ID:



Also, calculate the approximate pipe size of control valve necessary to achieve this flow capacity, assuming the use of a double-ported globe valve with a contoured plug ($C_d = 13$).

Suggestions for Socratic discussion

- A problem-solving technique useful for getting started is to document all relevant information given to you. What bits of information are found in this given problem that might be relevant to the answer? Is the given information quite certain, or are there any ambiguities? Is there any necessary information missing from the problem – if so, what?
- Identify any assumptions you were forced to make in calculating this control valve's C_v rating. Then, identify how these assumptions would skew the necessary C_v rating if they were incorrect.
- Identify the principal advantage that a *double-ported* globe valve enjoys over a *single-ported* globe valve.
- Identify the equivalent cage-guided globe valve type (balanced or unbalanced) to a double-ported stem-guided globe valve.

[file i03216](#)

Question 7

Read and outline the “Gas 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 i04233

Question 8

Calculating gas flow rates through a control valve is a bit more complex than calculating liquid flow rates. One standard equation for gas flow through a valve, assuming the absence of choking (sonic, or *critical*, gas velocity in the valve), is as follows:

$$Q = 963 C_v \sqrt{\frac{\Delta P (P_1 + P_2)}{G_g T}}$$

Where,

Q = Gas flow rate, in units of Standard Cubic Feet per Hour (SCFH)

C_v = Valve capacity coefficient

ΔP = Pressure dropped across valve, pounds per square inch differential (PSID)

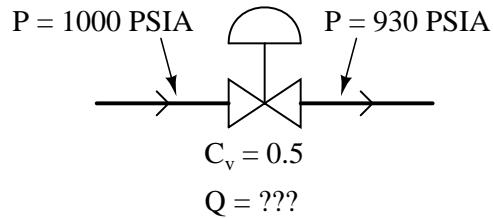
P_1 = Upstream valve pressure, pounds per square inch absolute (PSIA)

P_2 = Downstream valve pressure, pounds per square inch absolute (PSIA)

G_g = Specific gravity of gas (Air at standard temperature and pressure = 1.0)

T = Absolute temperature of gas in degrees Rankine ($^{\circ}\text{R}$)

Using this “subcritical” formula for gas flow through a valve, determine the amount of air flow through this valve when it is wide open:



Assume room temperature (70° F) for the air flowing through the valve.

Also, explain why it would be important to specify the proper *ANSI flange class* when ordering a control valve for this application.

Suggestions for Socratic discussion

- Explain why, when selecting the proper ANSI class for pipe flanges and valves, *temperature* is just as important a variable to consider as static *pressure*.

[file i01412](#)

Question 9

Read and outline the “Self-Operated Valves” subsection of the “Control Valve Actuators” 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 i04234](#)

Question 10

Read selected portions of the National Transportation Safety Board’s Pipeline Accident Report, *Pipeline Rupture and Subsequent Fire in Bellingham, Washington, June 10, 1999* (Document NTSB/PAR-02/02 ; PB2002-916502) and answer the following questions:

Pages 31-32 of the report describe the pressure relief system at the Bayview terminal. Identify the ANSI pressure class of the piping components at the Bayview terminal, and their maximum pressure rating at ambient temperature. Also discuss what a “piston stop” is and how it affects the operation of a control valve.

Pages 33-37 describe the pressure relief valve RV-1919, which was found to be malfunctioning at the time of the accident. Describe how this pressure relief valve is supposed to work, and what the accident investigators found when they examined the valve. Additional information on this valve is found on pages 45-46 and 69 of the report.

Explain the difference(s) between a *pressure relief valve* such as RV-1919 and a *pressure control valve* such as a Fisher E-body sliding-stem globe valve. What purpose does each valve serve in a process system? Can one be used in place of the other if necessary?

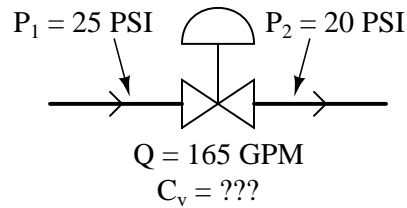
Suggestions for Socratic discussion
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- What role did instrument technicians play in this accident?
- Explain how the instrument technician could have done a better job than he did, possibly averting the disaster.
- Explain why the actual pressure rating of the 300# class pipes and components greatly exceeds 300 PSI. What, exactly, does the “300#” rating mean?
- Explain why you think the results obtained testing the relief valve pilot mechanisms differed from the “dynamic” (flowing) test results of the relief valves.
- Explain how and why *X-ray photography* was used as part of the forensic analysis following this accident.

[file i04240](#)

Question 11

Calculate the proper C_v value for this valve, given the flow rate and pressures shown for full-open condition. Assume the process liquid is ethanol (density = 49.3 lb/ft³):

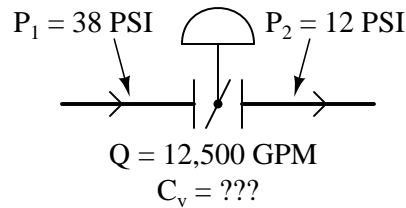


Also, calculate the approximate pipe size of control valve necessary to achieve this flow capacity, assuming the use of a double-ported globe valve with a ported plug ($C_d = 12.5$).

[file i03217](#)

Question 12

Calculate the proper C_v value for this valve, given the flow rate and pressures shown for full-open condition. Assume this valve is used to throttle the flow of sea water (density = 64.0 lb/ft³) into a desalinization facility, where salt water from the sea is converted into drinkable (potable) water:

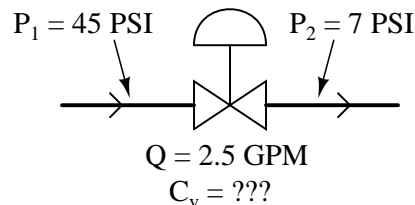


Also, calculate the approximate pipe size of control valve necessary to achieve this flow capacity, assuming the use of a 90° butterfly valve with an offset seat ($C_d = 29$).

[file i03218](#)

Question 13

Calculate the proper C_v value for this valve, given the flow rate and pressures shown for full-open condition. Assume the process liquid is acetic acid (specific gravity = 1.05):



[file i03219](#)

Question 14

What is the mathematical relationship between valve size (in inches) and maximum flow capacity (C_v)? For example, how does the flow capacity of an 8-inch valve compare with the flow capacity of a 4-inch valve, all other factors being equal?

[file i01372](#)

Question 15

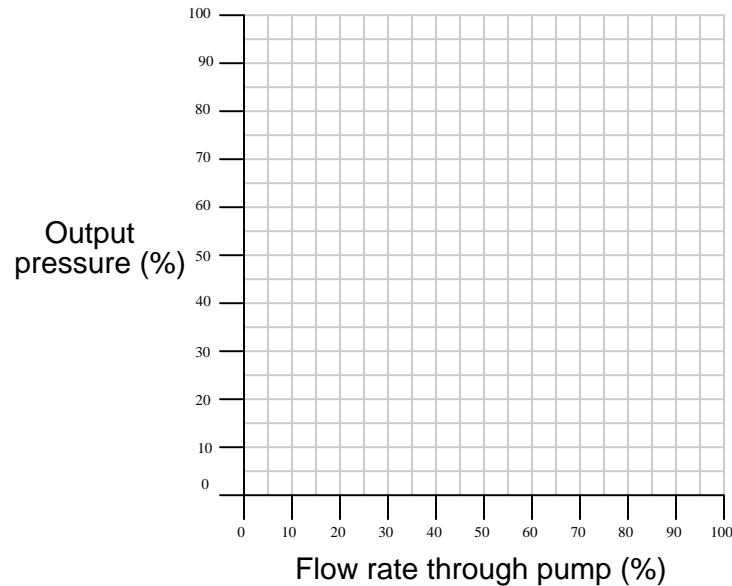
Suppose you are on the job site with an experienced technician, just about to remove a control valve from a piping system that has been taken out of service for you by operations personnel. You take your wrenches and proceed to loosen the nearest flange bolt, but your work partner stops you.

“Loosen the bolts on the *far* side of the pipe first!” the more experienced technician tells you. So, you lean over the pipe and work on loosening the bolts on the opposite side of the pipe first. Why is this a better idea than loosening the closest bolts (the bolts on your side of the pipe) first? Why should it matter which bolts are loosened, if all the bolts must come out anyway to disconnect the valve from the pipes?

[file i01881](#)

Question 16

Sketch the *pump curve* for a positive-displacement pump turned at a constant speed by an electric motor:



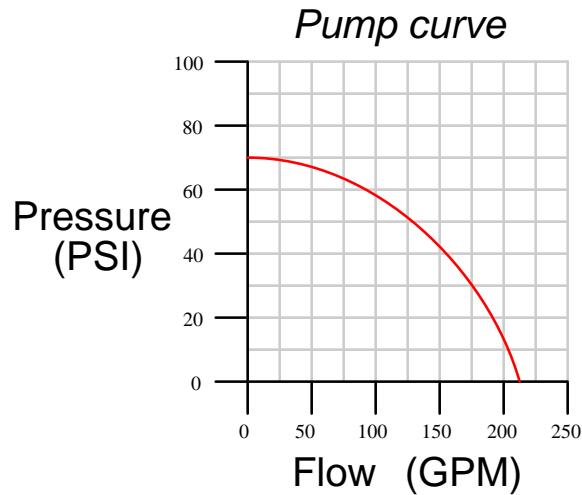
Suggestions for Socratic discussion
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- What will change about the pump curve graph if the driving motor’s speed changes?

[file i00743](#)

Question 17

Given the following pump curve for a water pump driven at a constant speed by an AC induction motor, determine the following:



- Flow rate at a discharge head of 70 feet = _____ GPM
- Discharge head at 112 GPM = _____ feet

[file i02833](#)

Question 18

Suppose two valves are used to control the amount of gas pressure in a vessel, one valve admitting gas into the vessel from a supply header with a constant pressure of 95 PSIG, and the other valve venting gas out of the vessel to atmosphere. The desired pressure in the vessel is 8 PSIG.

Assuming no other substantial flows of gas into or out of this vessel but these two control valves, and also assuming we wish these two valves to operate at approximately 50% open while maintaining the setpoint pressure of 8 PSIG, which of the two control valves should have the larger C_v rating? Explain your answer in detail.

[file i00696](#)

Question 19

Question 20

Question 21

Read and outline the “Inherent versus Installed Characteristics” subsection of the “Control Valve Characterization” 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.
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- (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 i04235](#)

Question 22

Read and outline the “Control Valve Performance with Constant Pressure” subsection of the “Control Valve Characterization” section of the “Control Valves” chapter in your *Lessons In Industrial Instrumentation* textbook.

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- (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.).
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- (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 i04236](#)

Question 23

Read and outline the “Control Valve Performance with Varying Pressure” subsection of the “Control Valve Characterization” section of the “Control Valves” chapter in your *Lessons In Industrial Instrumentation* textbook.

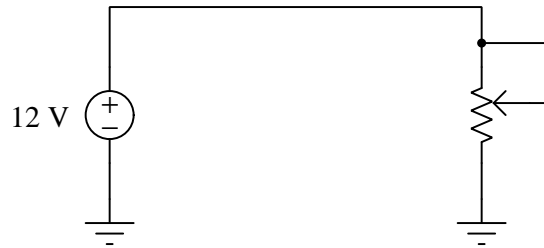
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- (2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author’s problem-solving strategies, etc.).
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- (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 i04237

Question 24

Calculate the amount of current in this simple DC circuit given a potentiometer setting of 1 k Ω :

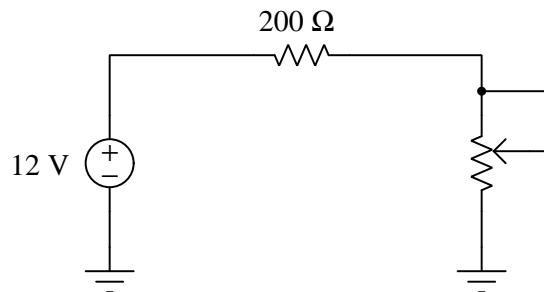


$$I = \text{_____ mA}$$

Next, calculate the necessary potentiometer resistance to *double* this amount of current:

$$R = \text{_____ } \Omega$$

Consider a minor modification to this circuit, whereby we install a fixed resistor in series. Re-calculate current in this circuit given a potentiometer setting of 1 k Ω :



$$I = \text{_____ mA}$$

Next, calculate the necessary potentiometer resistance to *double* this amount of current:

$$R = \text{_____ } \Omega$$

Compare the calculated potentiometer settings for each circuit against the original 1 k Ω values. Did one circuit require a different setting than the other in order to double the current? Relate this to the phenomenon of control valve “distortion” in a fluid system.

Suggestions for Socratic discussion
--

- Which electrical parameter is analogous to *flow rate* (e.g. gallons per minute) in a fluid system?
- Which electrical parameter is analogous to *pressure drop* (e.g. pounds per square inch) in a fluid system?
- When energy is dissipated by an electrical resistor, it takes the form of heat. What form does energy take when dissipated by a throttling valve?
- Could the potentiometer be modified somehow to provide a more linear response? If so, describe that modification.

file i01197

Question 25

Read and outline the “Characterized Valve Trim” subsection of the “Control Valve Characterization” 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.).
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- (6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

[file i04238](#)

Question 26

Suppose a control valve with an equal-percentage trim characteristic has a maximum (wide-open) C_v value of 38.5, and a C_v value of 1.9 at 25% open. Complete the following table relating stem position values to C_v values for this valve:

Stem position	C_v
0%	
25%	1.9
50%	
60%	
70%	
80%	
90%	
100%	38.5

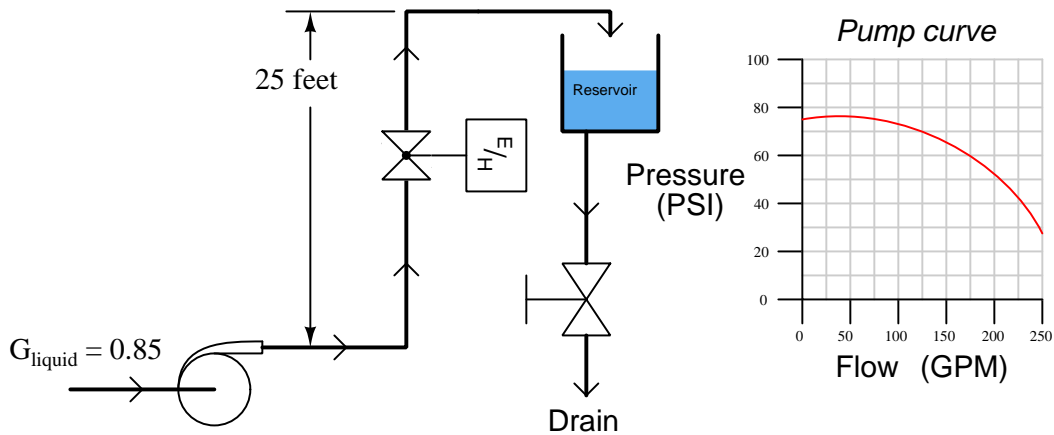
Suggestions for Socratic discussion

- There is more than one way to algebraically manipulate the equal-percentage C_v formula to solve for the rangeability coefficient R . One method makes use of powers, while another uses logarithms. Demonstrate both methods of algebraic manipulation.
- Set up a computer spreadsheet to graph the C_v of this control valve for a range of stem positions encompassing the positions specified in the table.
- is your calculated C_v value for a fully closed valve (stem position = 0%) realistic? Explain why or why not.

[file i01896](#)

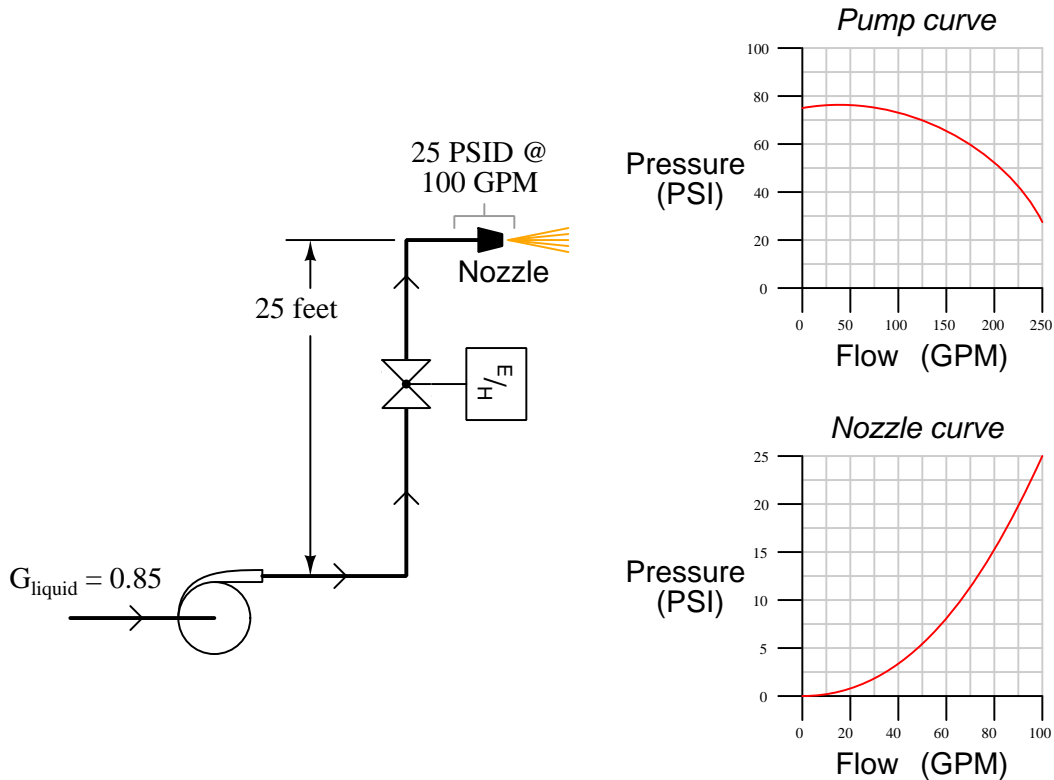
Question 27

Suppose a control valve is used to throttle liquid into a reservoir which then gravity-drains to a process. A level-control system (not shown) commands the control valve as needed to maintain a constant liquid level in the reservoir, over a typical flow range of 0 to 100 gallons per minute:



Based on the information shown in the simple PFD and pump curve, determine whether a control valve with linear characteristics will actually behave in a linear manner (i.e. have linear *installed* characteristics) in this process. Explain your reasoning in detail.

Next, determine the same for the following process, where the control valve throttles liquid through a spray nozzle over the same typical flow range of 0 to 100 GPM:



Suggestions for Socratic discussion

- A helpful problem-solving strategy for people familiar with basic electricity is to model the fluid system as a DC circuit: any source of constant pressure is represented by a voltage source (e.g. battery) while any restriction to flow is represented by a resistor. In such a model, what determines the polarity of each component's voltage as it relates to the direction of flow (current)?
- Explain in a general sense where and why we may need a “characterized” control valve to achieve linear flow control in any given process.
- Will control valves of the same C_v rating work equally well in both scenarios? Explain why or why not. If different C_v ratings are necessary, which scenario demands a control valve with a larger C_v ?
- It is generally bad practice to “dead-head” a centrifugal pump (i.e. to completely block its discharge line while running, as this control valve will do when shut). Identify multiple ways to address this problem, so that the pump can never “dead-head” no matter what position the control valve is placed in.

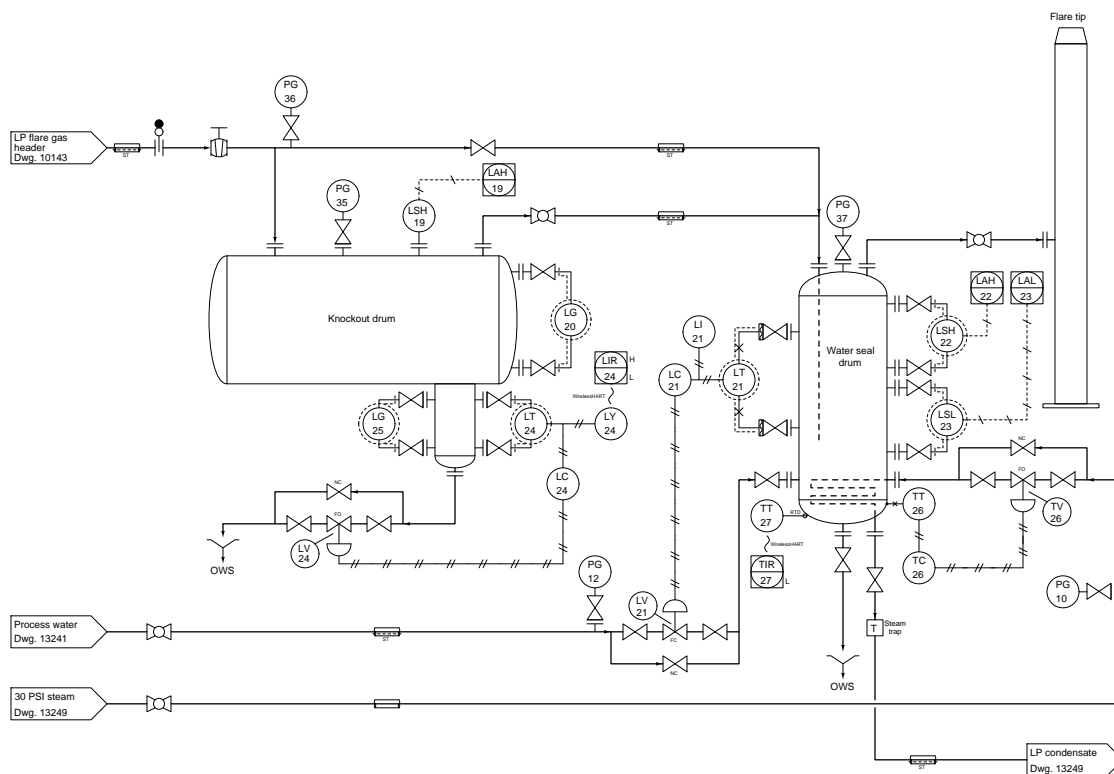
file i01180

Question 28

The “flare” at an oil refinery functions as a safe way to quickly dispose of pressurized hydrocarbon compounds, by burning them far away from anything else that might be flammable. In this system, as with most flare systems, a “knockout drum” exists to separate vapors from liquid, so that only vapors are sent to the flare tip to be burned. Any captured liquid is drained to the Oily Water Sewer (OWS) system.

Another vessel called the “water seal drum” maintains a column of water through which all flare gases must bubble through before passing on to the flare to be burned. The purpose of the water seal drum is to prevent fire from possibly traveling backward through the process piping if ever a combustible mixture of fuel and oxygen were to exist in the flare system piping. Water inside the seal drum is prevented from freezing in cold weather by a temperature control system located on that vessel:

Inspect this P&ID closely to first identify all automatically-controlled valves, and then to predict whether a control valve with a linear inherent characteristic should behave linearly when installed (i.e. have a linear *installed* characteristic as well):



Assume the following parameters in this system:

- Flare gas temperature varies widely (from below ambient to hundreds of degrees Fahrenheit) depending on which units are discharging to the flare gas header at any time
- PG-37 always registers atmospheric pressure (0 PSIG)
- PG-36 varies from atmospheric (0 PSIG) to 35 PSIG, depending on how many units are discharging to that header pipe at any given time
- PG-35 always registers the same as PG-36
- PG-12 varies between 85 PSIG and 25 PSIG depending on how fast water is being drawn to fill up the water seal drum
- PG-10 reads nearly constant at 27 PSI all the time

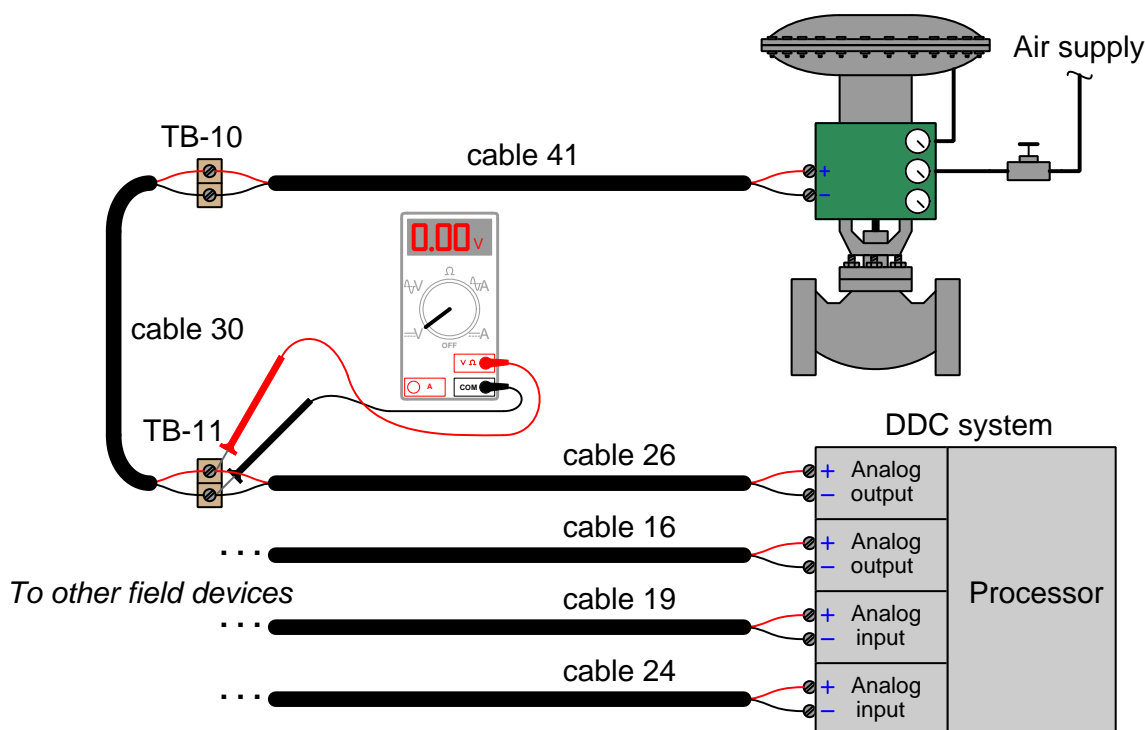
Suggestions for Socratic discussion
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- What is/are the decisive criteria for determining linear control valve behavior?
- For any control valve in this process experiencing “distortion”, what would you recommend we do to improve the control loop response?

file i01379

Question 29

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



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

For the next diagnostic test, the technician disconnects the red wire of cable 30 where it attaches to the screw terminal on TB-11, and re-measures voltage at TB-11. After disconnecting the wire, the new voltage measurement at TB-11 reads 25.3 volts. Determine what this result tells us about the nature and location of the fault.

Suggestions for Socratic discussion

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

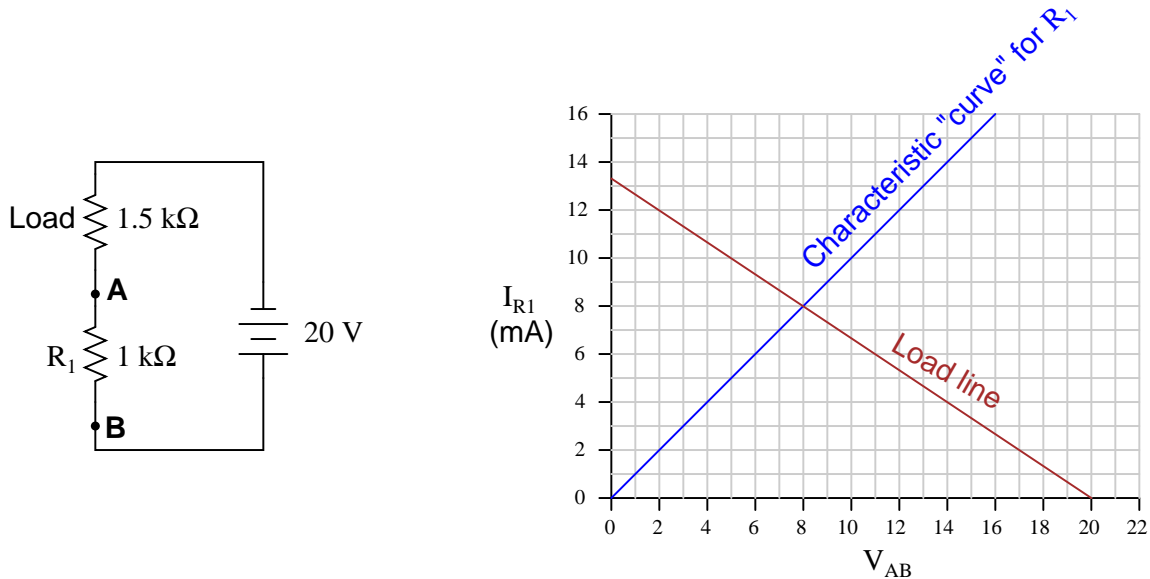
[file i04239](#)

Question 30

Load lines are useful tools for analyzing transistor amplifier circuits, but they may be hard to understand at first. To help you understand what “load lines” are useful for and how they are determined, we will explore their application to a simple two-resistor circuit.

A load line plot has multiple functions graphed on the same axes, current through one component of interest in the circuit versus voltage across that same component. One of those functions represents the characteristics of the component of interest, while the other represents the characteristics of the load component(s).

Examine this load line plot, and explain how the two graphed lines represent each of the components in this simple circuit. In this particular circuit the component of interest is the $1\text{ k}\Omega$ resistor R_1 while the load is the $1.5\text{ k}\Omega$ resistor in series with R_1 :



At what value of current (I_{R1}) do the two lines intersect? Explain what is significant about this value of current.

Suggestions for Socratic discussion

- Explain how to mathematically predict the behavior of this circuit *without* using load lines.

[file i03222](#)

Question 31

Load lines are useful tools for analyzing transistor amplifier circuits, but they may be applied to other types of circuits as well. Here, we will explore the application of load lines to a simple diode-resistor circuit.

The diode's characteristic curve is already plotted on the following graph, based on Shockley's diode equation shown below:

$$I_D = I_S(e^{\frac{qV_D}{NkT}} - 1)$$

Where,

I_D = Current through the PN junction, in amps

I_S = PN junction saturation current, in amps (typically 1 picoamp)

e = Euler's number ≈ 2.718281828

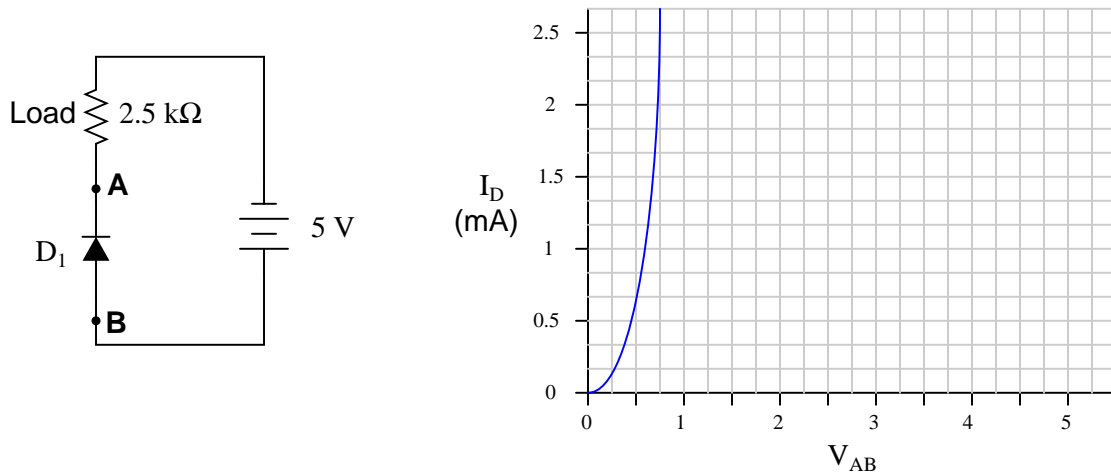
q = Electron unit charge, 1.6×10^{-19} coulombs

V_D = Voltage across the PN junction, in volts

N = Nonideality coefficient, or emission coefficient (typically between 1 and 2)

k = Boltzmann's constant, 1.38×10^{-23} joules per kelvin

T = Junction temperature, in degrees kelvin



Your task is to plot the load line for the circuit on the same graph, explaining the significance of the two plots' intersection.

Suggestions for Socratic discussion

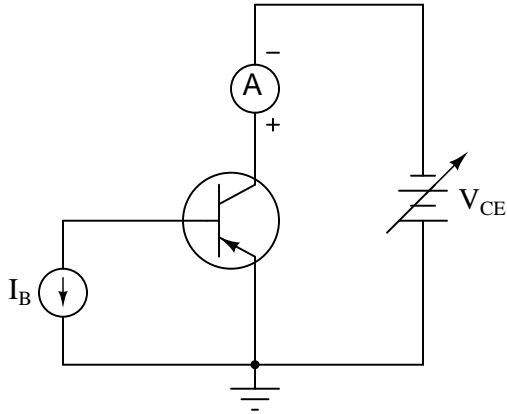
- Explain why the use of a load line greatly simplifies the determination of circuit current in such a diode-resistor circuit.
- Suppose the resistor value were increased from 2.5 kΩ to 10 kΩ. What difference would this make in the load line plot, and in the intersection point between the two plots?

[file i03223](#)

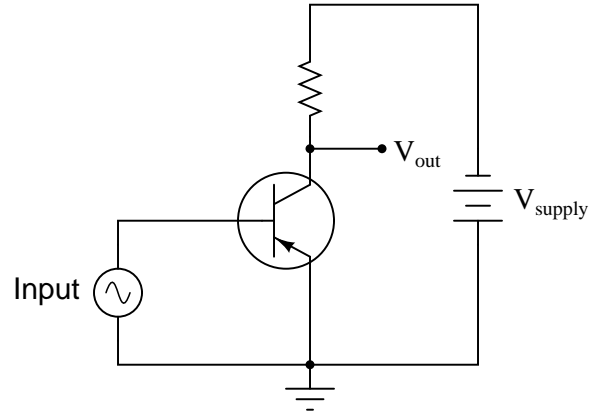
Question 32

The issue of *inherent characteristic* versus *installed characteristic* for process control valves has an interesting parallel in the world of semiconductor electronics: the behavior of transistors under ideal (constant supply voltage) versus realistic (loaded) conditions:

"Laboratory circuit" used only for collecting characteristic data



A more practical circuit for real-life applications



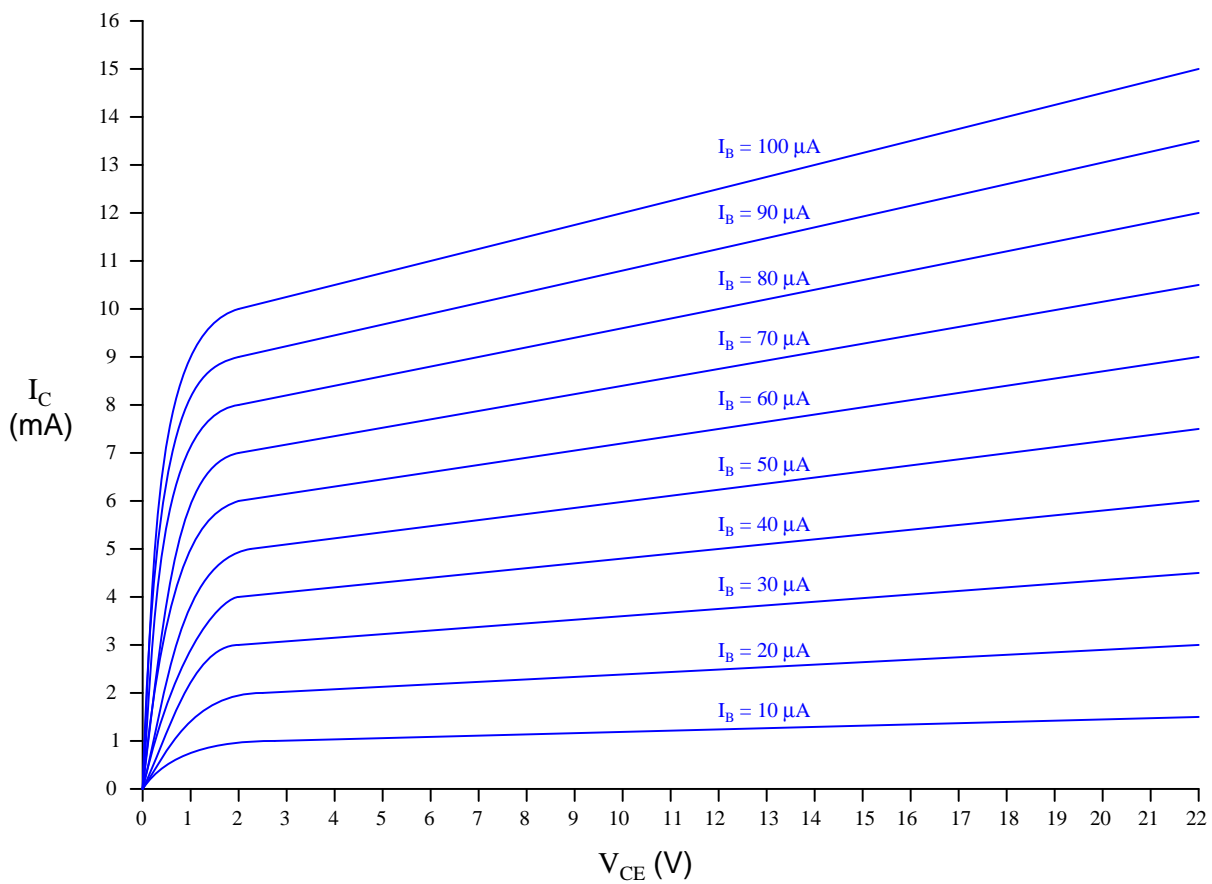
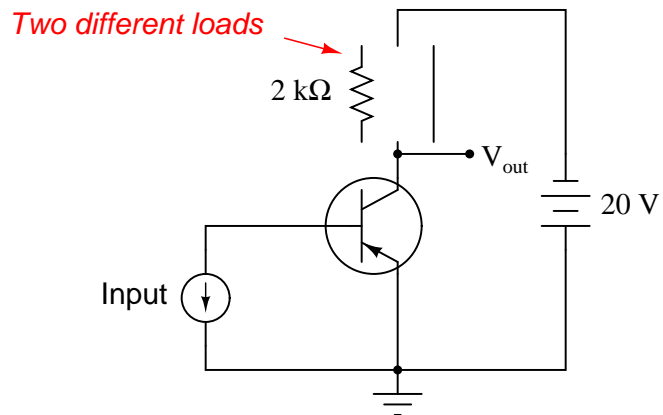
In order to understand how the ideal behavior of a transistor maps to the real (“installed”) world of an amplifier circuit, we can sketch something called a *load line* on the same graph where we draw the transistor’s characteristic curves.

Explain what a “load line” is and what it means for a transistor circuit.

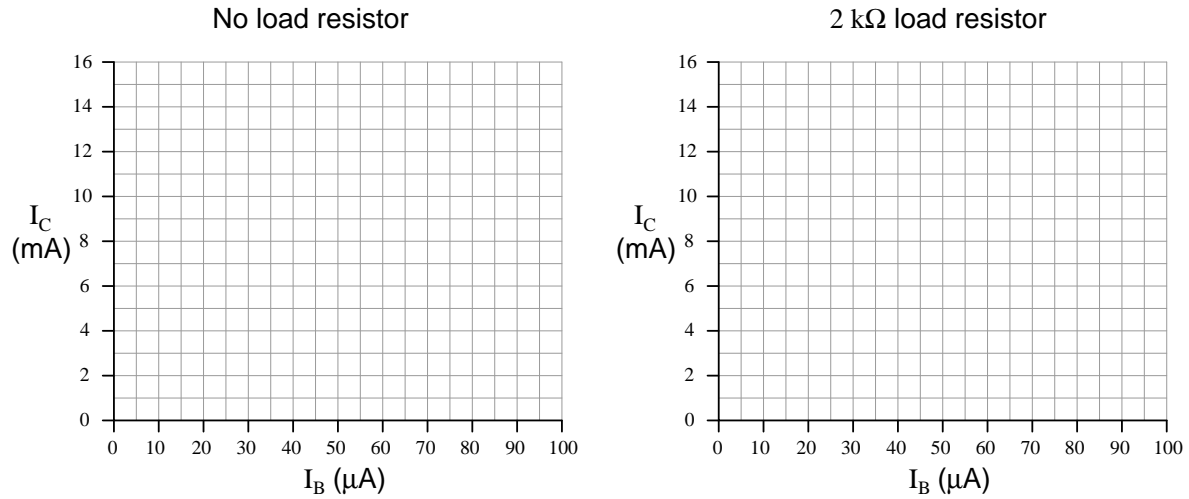
[file i01387](#)

Question 33

Calculate and superimpose two different *load lines* on top of the transistor's characteristic curves, one load line assuming a $2\text{ k}\Omega$ collector (load) resistor, and another assuming no collector resistor at all (i.e. a constant 20 volts between collector and emitter at all times):



Now, plot two graphs showing the relationship between base current (I_B) and collector current (I_C), one graph for each load condition (no load resistor versus a $2\text{ k}\Omega$ load resistor). In which case is the relationship between base and collector current more linear? Explain why.



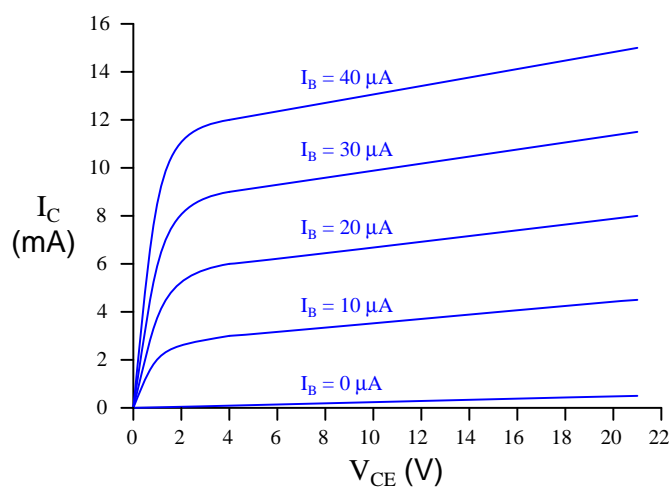
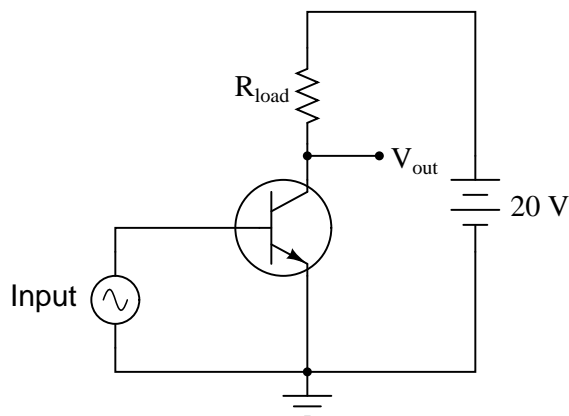
Also, explain how this electronic circuit's behavior relates to the installed versus inherent characteristics of control valves. Identify what each of these parameters in the transistor circuit is analogous to in a control valve scenario:

- Base current
- Collector current
- Collector-emitter voltage
- Collector resistor (load) value

[file i01386](#)

Question 34

Calculate and superimpose two *load lines* for this circuit on top of the transistor's characteristic curves, one load line for $R_{load} = 2\text{ k}\Omega$ and another one for $R_{load} = 0\text{ k}\Omega$ (a shorted load resistor):



Next, calculate the amount of collector current in the two different circuits (with different R_{load} values) at the following base current values:

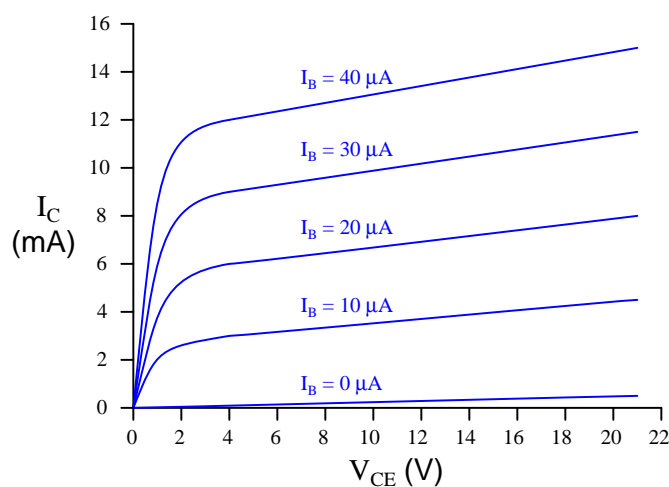
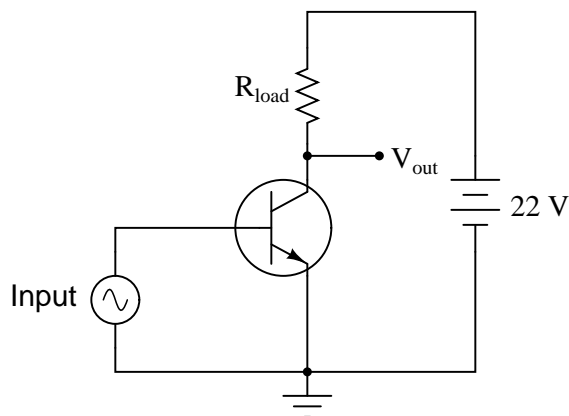
Base current (I_B)	Collector current (I_C) $R_{load} = 2\text{ k}\Omega$	Collector current (I_C) $R_{load} = 0\text{ k}\Omega$
$0\text{ }\mu\text{A}$		
$10\text{ }\mu\text{A}$		
$20\text{ }\mu\text{A}$		
$30\text{ }\mu\text{A}$		
$40\text{ }\mu\text{A}$		

Looking at the relationship between I_B and I_C now, which of these two circuits yields the more *linear* response? In other words, for which load resistor value does the transistor exhibit the most proportional response to increases in base current? Explain why.

[file i03225](#)

Question 35

Calculate and superimpose two *load lines* for this circuit on top of the transistor's characteristic curves, one load line for $R_{load} = 2\text{ k}\Omega$ and another one for $R_{load} = 4\text{ k}\Omega$:



Next, calculate the amount of collector current in the two different circuits (with different R_{load} values) at the following base current values:

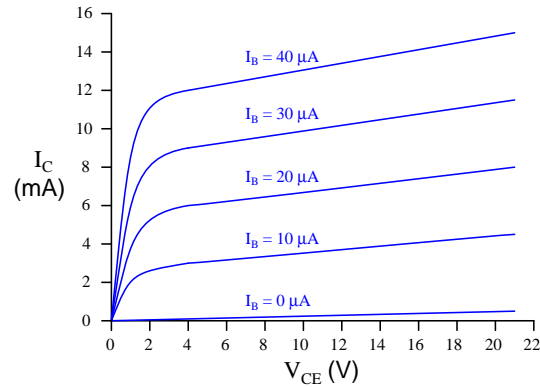
Base current (I_B)	Collector current (I_C) $R_{load} = 2\text{ k}\Omega$	Collector current (I_C) $R_{load} = 4\text{ k}\Omega$
$0\text{ }\mu\text{A}$		
$10\text{ }\mu\text{A}$		
$20\text{ }\mu\text{A}$		
$30\text{ }\mu\text{A}$		
$40\text{ }\mu\text{A}$		

Looking at the relationship between I_B and I_C now, which of these two circuits yields the more *linear* response? In other words, for which load resistor value does the transistor exhibit the most proportional response to increases in base current? Explain why.

[file i03224](#)

Question 36

In electronics, we often plot the *characteristic curve set* for a transistor to show how it regulates current across a range of supply voltages. This set of graphs proves useful in determining how the transistor will function in a real circuit:

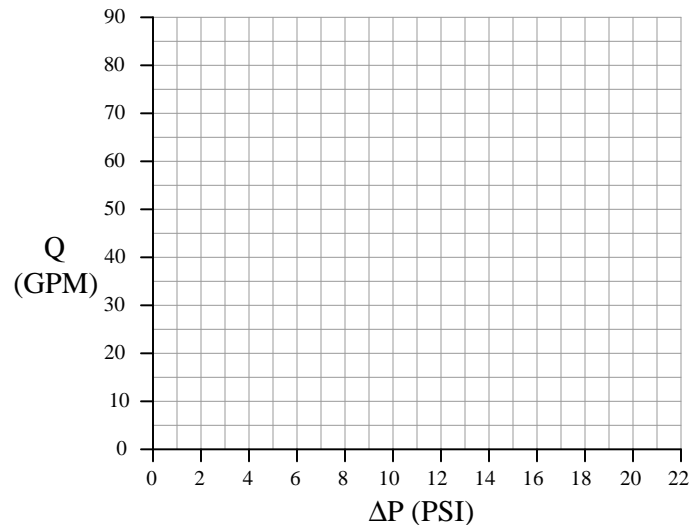


We may do the same thing for a control valve, plotting a set of “characteristic curves” showing how it will restrict fluid flow across a range of pressure drops. As with the transistor, this set of graphs proves useful in determining how the control valve will function in a real fluid system.

The following table shows this relationship for a linear control valve with a (maximum) C_v of 18:

Opening	C_v
0%	0
25%	4.5
50%	9
75%	13.5
100%	18

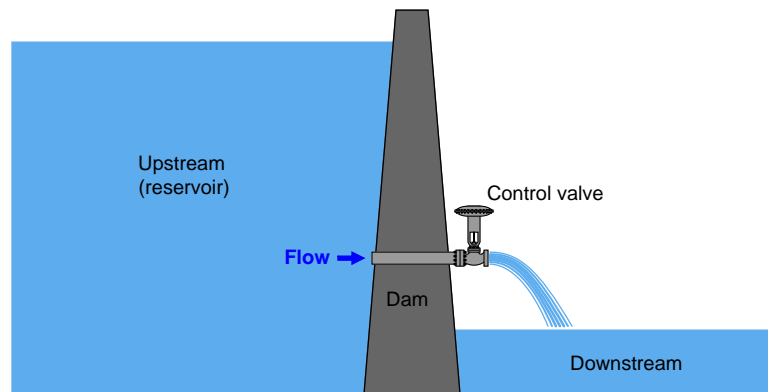
Use this valve’s C_v data, along with the equation relating flow (Q), pressure drop (ΔP), specific gravity (G_f), and C_v to plot a set of characteristic curves, one curve for each C_v value shown in the table. Assume that the fluid in question is water ($G_f = 1$):



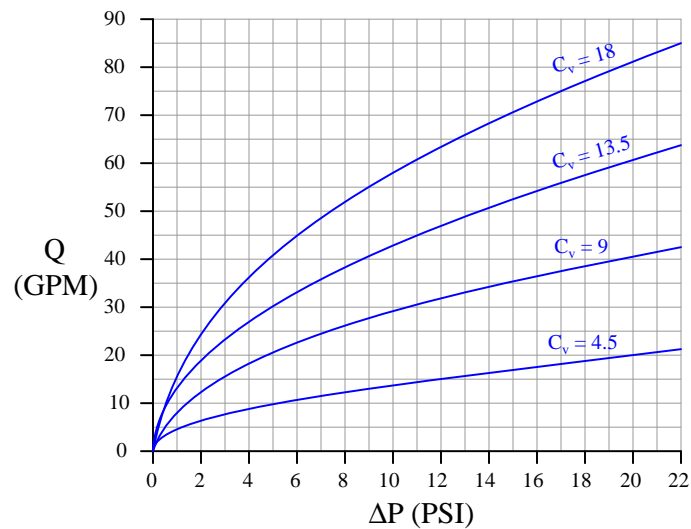
file i03226

Question 37

Suppose a control valve with a linear inherent characteristic and a maximum flow capacity of 18 ($C_v = 18$) is installed at the base of a dam, where it experiences a constant upstream pressure of 20 PSI and a constant downstream pressure of 0 PSI (atmospheric):



Superimpose the “load line” for this control valve on its characteristic curve set, and then use the intersection points between the load line and the curves to determine the actual water flow rates at 0% open, 25% open, 50% open, 75% open, and 100% (full) open:

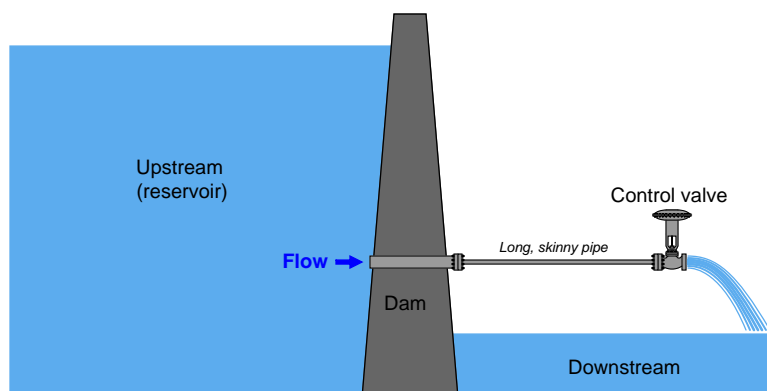


Opening (%)	C_v	Flow rate (GPM)
0	0	
25	4.5	
50	9	
75	13.5	
100	18	

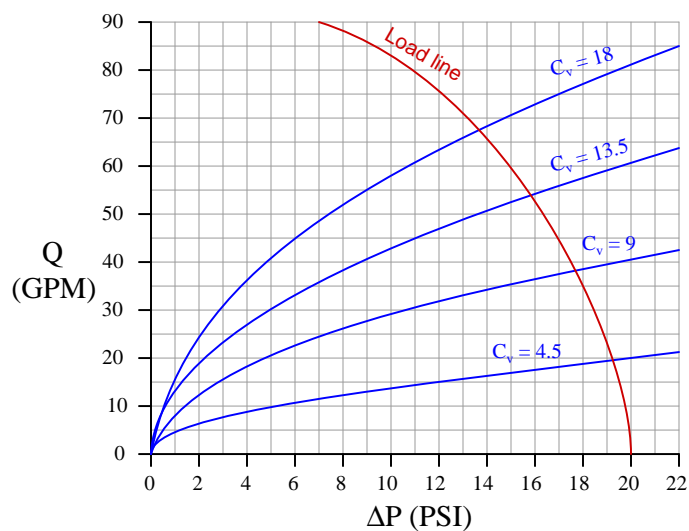
file i03227

Question 38

Suppose a control valve with a linear inherent characteristic and a maximum flow capacity of 18 ($C_v = 18$) is installed at the base of a dam, where it experiences a constant downstream pressure of 0 PSI (atmospheric) and an upstream pressure that varies with flow rate (owing to the pressure losses along the skinny pipe):



A “load line” for this piping system has been superimposed on the control valve’s characteristic curve set. Use this graph to determine the water flow rates at 0% open, 25% open, 50% open, 75% open, and 100% (full) open:



Opening (%)	C_v	Flow rate (GPM)
0	0	
25	4.5	
50	9	
75	13.5	
100	18	

[file i03228](#)

Question 39

One solution to the problem of installed control valve characterization is to eliminate the control valve entirely, using a variable-speed pump to control liquid flow rather than a constant-speed pump and a throttling valve. The most popular means of controlling the speed of an electric pump is to use a variable-frequency drive (VFD) to adjust the AC frequency of power sent to the driving motor. VFDs provide the option of analog signal control, with analog input terminals that you may connect to the analog output terminals of a controller, so that the controller can command the pump motor to spin at different speeds just like it could command a throttling valve to go to different stem positions.

Read the appropriate section(s) of the Allen-Bradley “PowerFlex 4 Adjustable Frequency AC Drive user manual” (document FRN 5.xx) in order to determine how to connect one of these VFDs to the 4-20 mA analog output of a loop controller. Sketch a simple diagram showing how to connect a PowerFlex 4 VFD to the output of one of these controller outputs (you choose the controller!):

Controller options

- Siemens 352P single-loop
- Siemens 353 four-loop
- Siemens 353R multi-loop with IO-8AO 8-channel analog output module
- Foxboro 762CNA dual-loop
- Foxboro 716C single-loop temperature
- Foxboro 718TC single-loop temperature
- Moore Industries 535 single-loop
- Emerson ROC800 SCADA/RTU with AO analog output module
- Emerson DeltaV DCS with M-series 2 AO 8-channel 4-20 mA output module

Suggestions for Socratic discussion

- Which parameter(s) in the PowerFlex 4 VFD must be configured to allow 4-20 mA control? Hint: this is typically referred to as the “Speed Reference” parameter for a VFD.
- What other options are available for the “Speed Reference” of this VFD?

[file i01384](#)

Question 40

Question 41

Read and outline the “Valve Seat Leakage” 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.

Further exploration . . . (optional)

For more insight on this topic, consider this passage written in scientific terms as it might appear in a “whitepaper” document:

An important parameter in the mitigation of seat leakage is that of *seat load*. This is typically expressed as the quotient of seating force between the plug and the seat versus the mean seat joint circumference, usually in the range of 20 to 1000 pounds per linear inch. Sufficient seat load causes the plug and seat to yield at their mating surfaces, forming a leak-tight interface. Insufficient seat load fails to produce the requisite deformation for tight sealing, while excessive seat load may stress said components beyond their elastic limits.

Try interpreting and re-expressing the meaning of this passage in simpler terms. What is it trying to say, and how does it relate to the assigned reading on valve seat leakage in your textbook?

[file i04241](#)

Question 42

Read and outline the “Mechanical Friction” subsection of the “Control Valve Problems” 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 i04242](#)

Question 43

Read and outline the “Flashing” subsection of the “Control Valve Problems” 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 i04243](#)

Question 44

Read and outline the “Cavitation” subsection of the “Control Valve Problems” 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.

Further exploration . . . (optional)

For more insight on this topic, watch the video “Challenge At Glen Canyon Dam” chronicling the diagnosis and rectification of a major cavitation problem in one of the spillway tubes at a hydroelectric dam. This was an example of cavitation on a massive scale! The video may be downloaded from the *Socratic Instrumentation* website, located in the “Video Resources” section.

[file i04244](#)

Question 45

Read and outline the “Choked Flow” and “Noise” subsections of the “Control Valve Problems” 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 i04245](#)

Question 46

Read and outline the “Erosion” and “Chemical Attack” subsections of the “Control Valve Problems” 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 i04247](#)

Question 47

Read the Fisher “Design CAV4 Control Valve” product flier (document 51.2:CAV4, April 2007), and answer the following questions:

Explain how the unique construction of this sliding-stem valve trim helps prevent cavitation in liquid service. In particular, note how the design differs from some other anti-cavitation valve designs.

This particular control valve has been designed for extremely high pressure drops. Just how great are the pressure drops (in units of PSID) this valve is designed to handle, and why is this parameter relevant to the subject of cavitation?

This valve design intentionally separates the *throttling* and *seating* portions of the valve trim. Explain why it has been designed this way, and what might happen to the valve over time if it were designed more conventionally (with throttling and seating performed by the same portion of the trim).

This bulletin provides a formula on page 6 useful for selecting the particular cavitation-control valve design to use for different process applications ($A_r = \frac{\Delta P}{P_1 - P_v}$). Identify whether a *low* value for *application ratio* A_r or a *high* value for A_r is “better” with regard to minimal cavitation.

Read the Fisher “Vee-Ball Design V150, V200, and V300 Noise Attenuator” product flier (document 51.3:Vee-Ball(S2), July 2006), and answer the following questions:

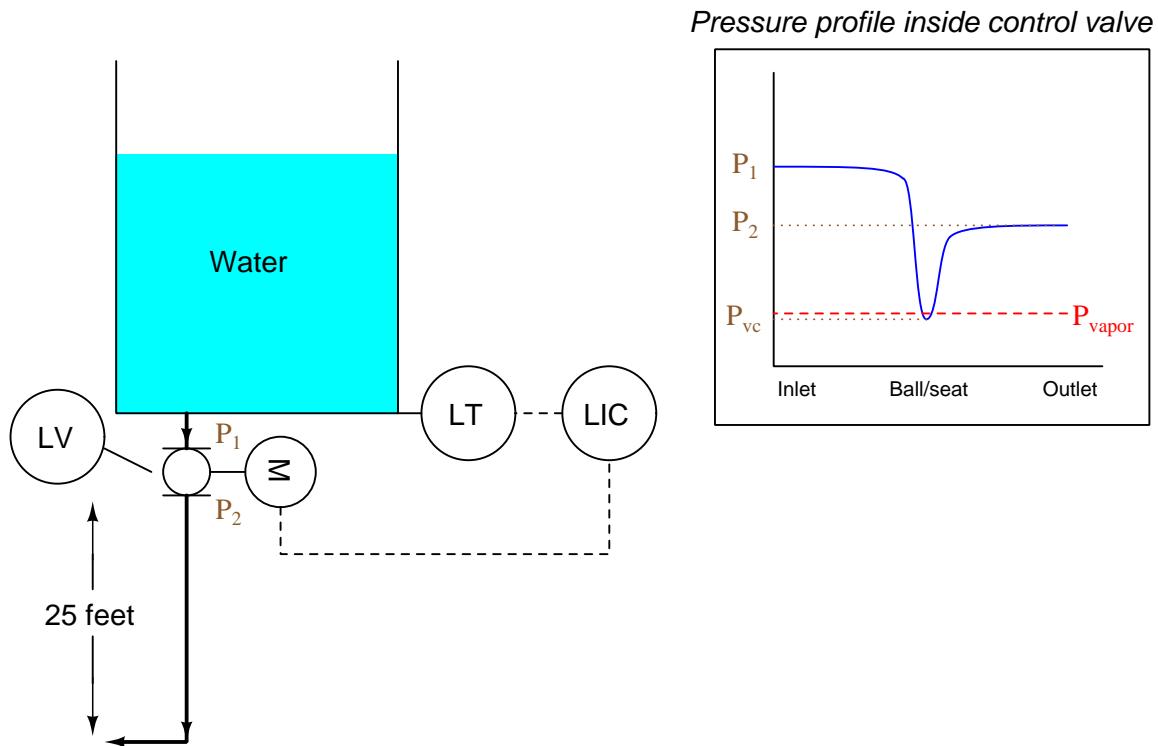
Explain how the unique construction of this ball valve trim helps prevent cavitation in liquid service.

Based on the valve characteristics graph shown in figure 4 (page 6), is this trim *quick-opening*, *linear*, or *equal-percentage*?

file i04248

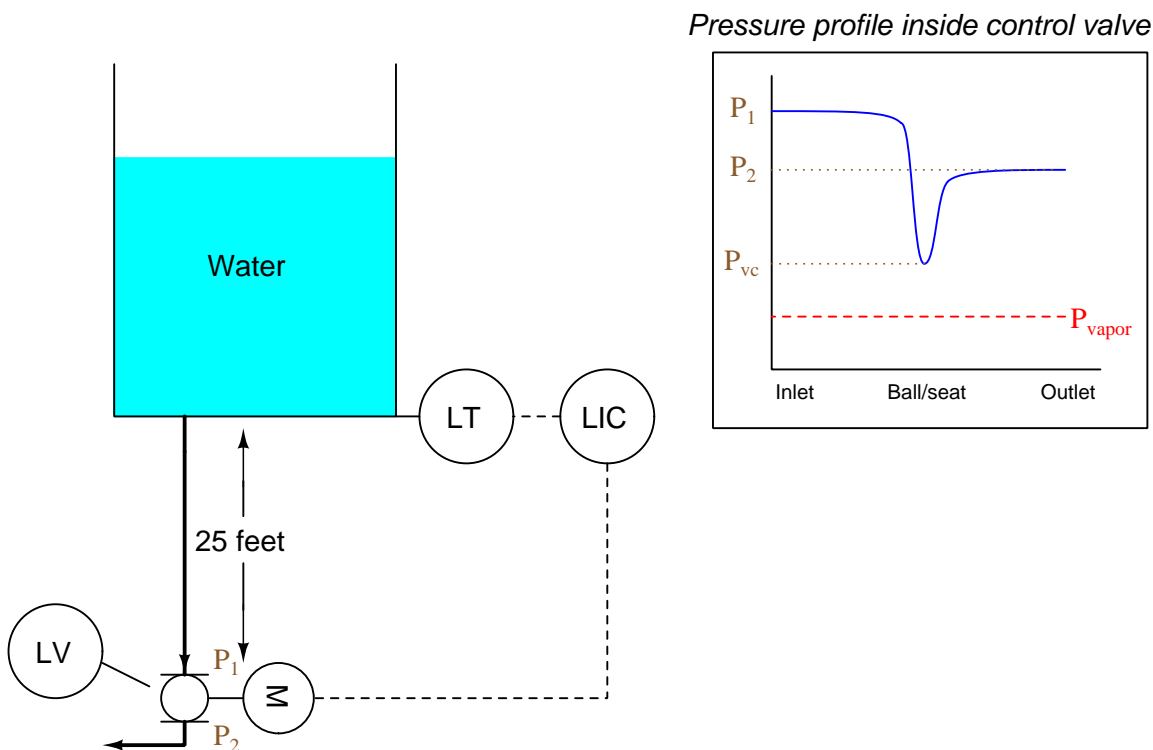
Question 48

This level control valve cavitates when water flows through it. A pressure profile graph shows the valve's inlet pressure (P_1), outlet pressure (P_2), and vena contracta pressure (P_{vc}) superimposed on a dashed line showing the vapor pressure of the water:



Explain why this valve cavitates, being sure to include data from the valve's pressure profile in your explanation.

Later, a process engineer decides to re-locate this same control valve to a lower position on the pipe. Now, even with the exact same flow rate going through the valve (Q) and the same pressure drop ($P_1 - P_2$), the valve no longer cavitates! A new pressure profile graph shows how all pressures at all points inside the control valve have changed as a result of the re-location:



Explain why the engineer's solution worked, being sure to include data from the valve's altered pressure profile in your explanation. Also, identify at least one *other* change that could have been made to this process to reduce or eliminate cavitation other than re-locating the valve.

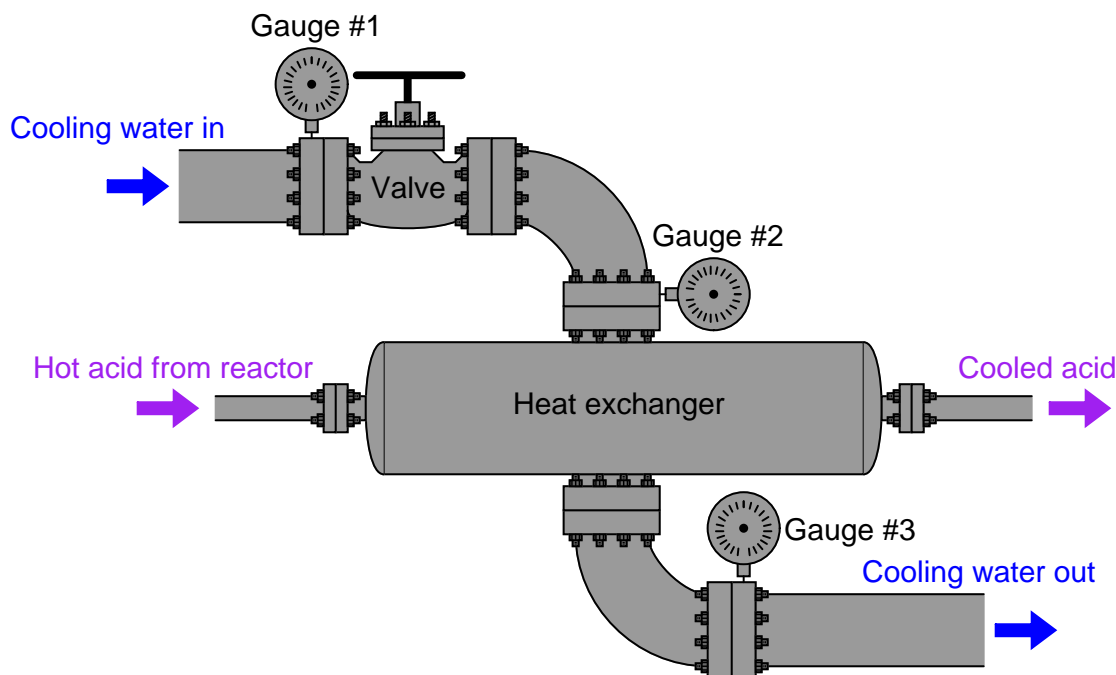
Suggestions for Socratic discussion

- Explain what the term "vapor pressure" means for a substance
- Would the engineer's solution have worked if water had been flowing the *other* direction through the valve (i.e. *up* into the vessel rather than *down* out of the vessel)? Why or why not?
- What type of control valve and actuator are used in this application?

[file i01419](#)

Question 49

A heat exchanger is used to lower the temperature of sulfuric acid (H_2SO_4) exiting an exothermic reactor in an acid manufacturing process, using water as the coolant. An automatic control valve will eventually be installed in the water line, but for now a hand (manual) valve performs the role of coolant throttling over a range of 0 to 25 GPM (gallons per minute):



An experienced instrument technician is summoned to test this heat exchanger system and determine what kind of valve characterization (quick-opening, linear, equal-percent) is best for throttling the water flow. The technician proceeds to set the manual valve to different positions while recording the three pressure gauge readings and the flow rate (measured by a flowmeter not shown in this illustration). The results are shown in this table:

Water flow	Gauge #1	Gauge #2	Gauge #3
0 GPM	48 PSI	0 PSI	0 PSI
15 GPM	23 PSI	2.3 PSI	0.8 PSI
25 GPM	6 PSI	5 PSI	1.5 PSI

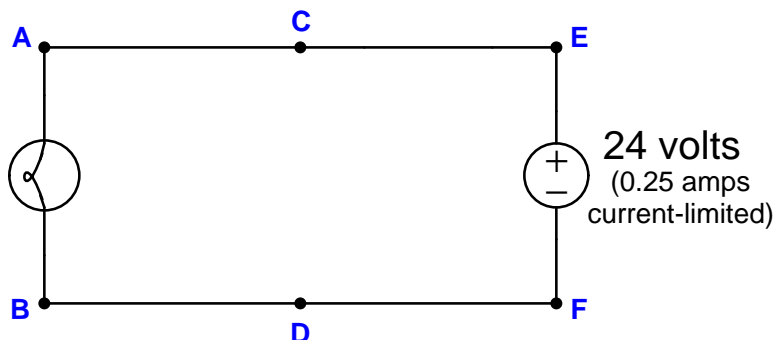
After examining these results, the technician declares “We’ll definitely need equal-percentage trim on this valve. No way will a linear control valve give us good results.”

Explain the rationale behind the technician’s decision. What is it exactly about the pressure readings that suggest a linear-characteristic valve will not give good results over the flow range of 0 to 25 GPM? Conversely, what sort of pressure measurements *would* suggest a linear-characteristic control valve would suffice?

file i00741

Question 50

Suppose the lamp refuses to light up. A voltmeter registers 24 volts between test points **C** and **D**:



First, list all the possible (single) faults that could account for all measurements and symptoms in this circuit, including failed wires as well as failed components:

Now, determine the diagnostic value of each of the following tests, based on the faults you listed above. If a proposed test could provide new information to help you identify the location and/or nature of the one fault, mark “yes.” Otherwise, if a proposed test would not reveal anything relevant to identifying the fault (already discernible from the measurements and symptoms given so far), mark “no.”

Diagnostic test	Yes	No
Measure V_{CF}		
Measure V_{ED}		
Measure V_{AB}		
Measure V_{AD}		
Measure V_{CB}		
Measure V_{EF}		
Measure current through wire connecting A and C		
Jumper A and C together		
Jumper B and D together		
Jumper A and B together		

Finally, develop a rule you may use when assessing the value of each proposed test, based on a comprehensive list of possible faults.

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.
- Suppose the fault were intermittent: sometimes the lamp lights up, and other times it goes out. Explain how you could use a digital multimeter (DMM) set to *record* voltage as a troubleshooting tool to determine where the fault is located in the circuit over a span of time too long for you to personally observe the circuit.

[file i01746](#)

Question 51

What does the term *rangeability* mean, with regard to control valves? Why is this parameter important to us?

Which valve opening characteristic exhibits the greatest rangeability: *quick opening*, *linear*, or *equal percentage*? Explain your answer.

file i01423

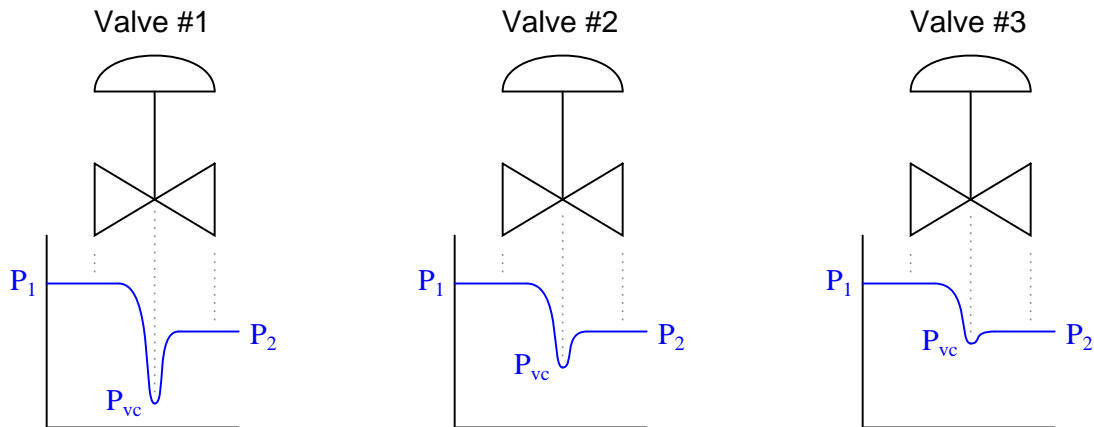
Question 52

Explain what *choked flow* refers to for a control valve, and what accounts for “choking” in liquid flow control applications and in gas flow control applications. Also, identify which type of control valve is most susceptible to choked flow: one with a high F_L (pressure recovery factor) or one with a low F_L .

file i01716

Question 53

Examine the following graphs, plotting pressures along the fluid flow path within three different control valves:



As you can see from the graphs, the inlet pressures (P_1) and outlet pressures (P_2) are the same for each valve. That is, each of the three valves exhibits the same amount of permanent pressure drop. However, what happens inside each valve is quite different, as indicated by the different *vena contracta* pressures (P_{vc}).

When fluid enters a constricted portion of the valve, its velocity increases. A greater fluid velocity means the fluid molecules possess greater kinetic energy than before. In accordance with the Law of Energy Conservation, this increase in kinetic energy must be balanced by a corresponding loss in potential energy (fluid pressure) through the constriction. This is what accounts for the sudden decrease in pressure at the vena contracta point (the point of maximum constriction inside the valve).

After passing through the constriction, the fluid enters a wider portion of the valve and slows down. Molecular kinetic energy decreases while potential energy (pressure) increases. This is why pressure “recovers” downstream of the vena contracta. The difference between upstream and downstream pressures ($P_1 - P_2$) represents fluid energy lost in the throttling action of the valve.

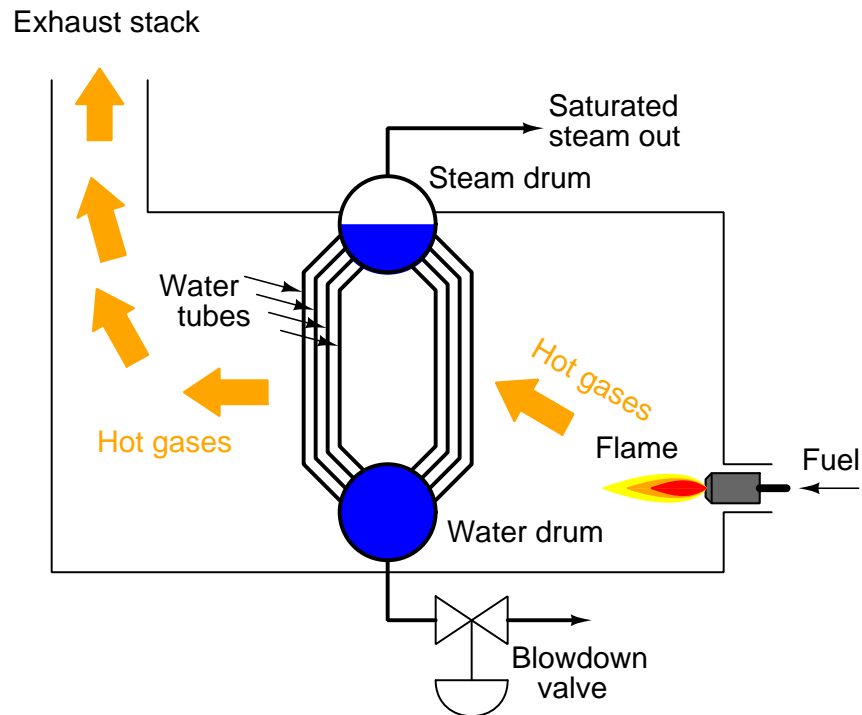
Determine which of the three valves has the greatest *pressure recovery*, and which of the three valves has the greatest *pressure recovery factor* (sometimes referred to as *pressure recovery coefficient*). Then, determine which of the three valves is more prone to cavitation in liquid service, all other factors being equal.

Finally, identify control valve types characterized by extremes of pressure recovery and pressure recovery factor.

[file i01418](#)

Question 54

A valve is located on the water drum (sometimes called the “mud” drum) of a boiler, for the purpose of “blowing down” the boiler system to remove sediment and excess mineral content from the otherwise ultra-pure water:



The engineer who specified this valve was relatively inexperienced, and that inexperience shows in the valve’s performance. Although the valve’s C_v has been sized appropriately for the pressure drop across it and the density of the hot water flowing through it, it is found that the valve flows *much* less water through it than what was expected. When fully open, the blowdown valve only releases a small fraction of the intended flow rate of water, even when the downstream side is vented to the atmosphere, and the full pressure of the boiler is dropped across the valve.

What is wrong here? What is preventing the blowdown valve from flowing enough water when wide-open?

[file i01421](#)

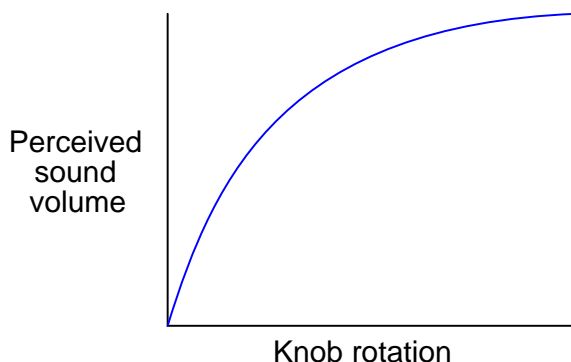
Question 55

Human hearing is nonlinear in nature: in order for a sound to be perceived as being twice as loud, *ten* times the power output is required from the sound source. This is why sound pressure is measured in units of *decibels*: a nonlinear scale.

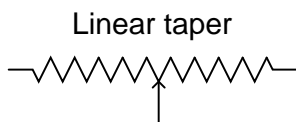
Perception (Base level)	dB	Power (Base level)
2 ×	10	10 ×
4 ×	20	100 ×
8 ×	30	1000 ×
16 ×	40	10000 ×
32 ×	50	100000 ×

This is something of a problem if we try to design a variable-volume sound amplifier, such as a power amplifier for a public-address (PA) system or a music reproduction (Hi-Fi) system. We want the action of the volume control knob to “feel” natural in that there will be a proportionate increase in perceived sound volume for each rotary motion increment of the knob throughout its range.

An audio amplifier circuit designed with a linear potentiometer to control volume will not deliver the desired “feel.” Instead, the knob rotation-versus-sound function will look something like this when plotted on a graph:

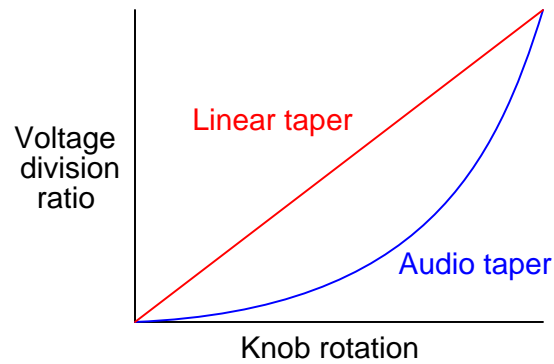


To combat this trend and “linearize” the knob rotation-versus-sound function, amplifier designers typically use *audio-taper potentiometers* for the volume control elements in their circuits. Audio-taper potentiometers are built with nonlinear resistive strips inside, so that their voltage division purposely does not track in a linear fashion with shaft position:



This is not a real schematic symbol, but it graphically represents how an audio taper potentiometer is constructed.

If we were to graph the voltage division ratio against knob rotation for both potentiometers, we would see the following results:



When installed as the volume control in an audio amplifier, the nonlinear nature of the audio potentiometer “cancels out” the natural power-versus-loudness nonlinearity inherent to human hearing, resulting in a much more linear “feel” to the knob’s control over volume.

At this point, you’re probably wondering, “*What has this to do with control valves?*” The analogy is as follows: the nonlinear nature of human hearing is like the tendency of process piping restrictions to “distort” the characteristic of an installed control valve, and the audio-taper potentiometer behaves like an equal-percentage control valve. Explain how equal-percentage control valves work to “linearize” the shaft position-versus-flow function in a process.

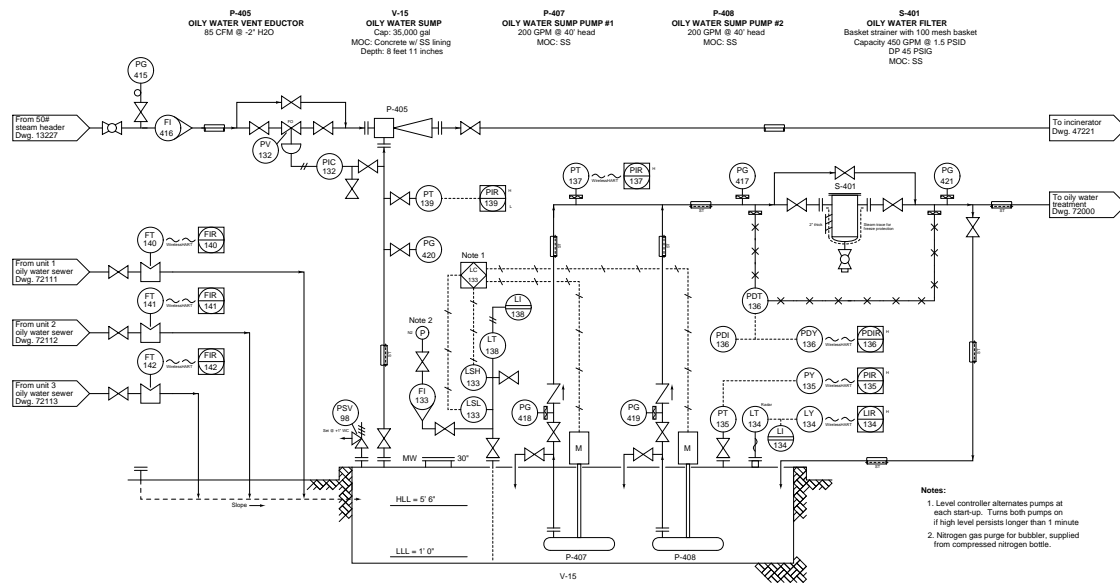
Suggestions for Socratic discussion

- Sketch how an audio signal source and an audio load (e.g. amplifier input) would connect to the audio-taper potentiometer symbol shown with the “compressed” scale. In other words, determine which end of the pot’s fixed contacts will be common with both audio source and audio load.

[file i01381](#)

Question 56

A *steam eductor* is a device used to create a vacuum, by passing steam through a “venturi” tube. In this process, a steam eductor is used to apply a constant venting suction to an oily water sump (underground storage vessel for collecting liquid):



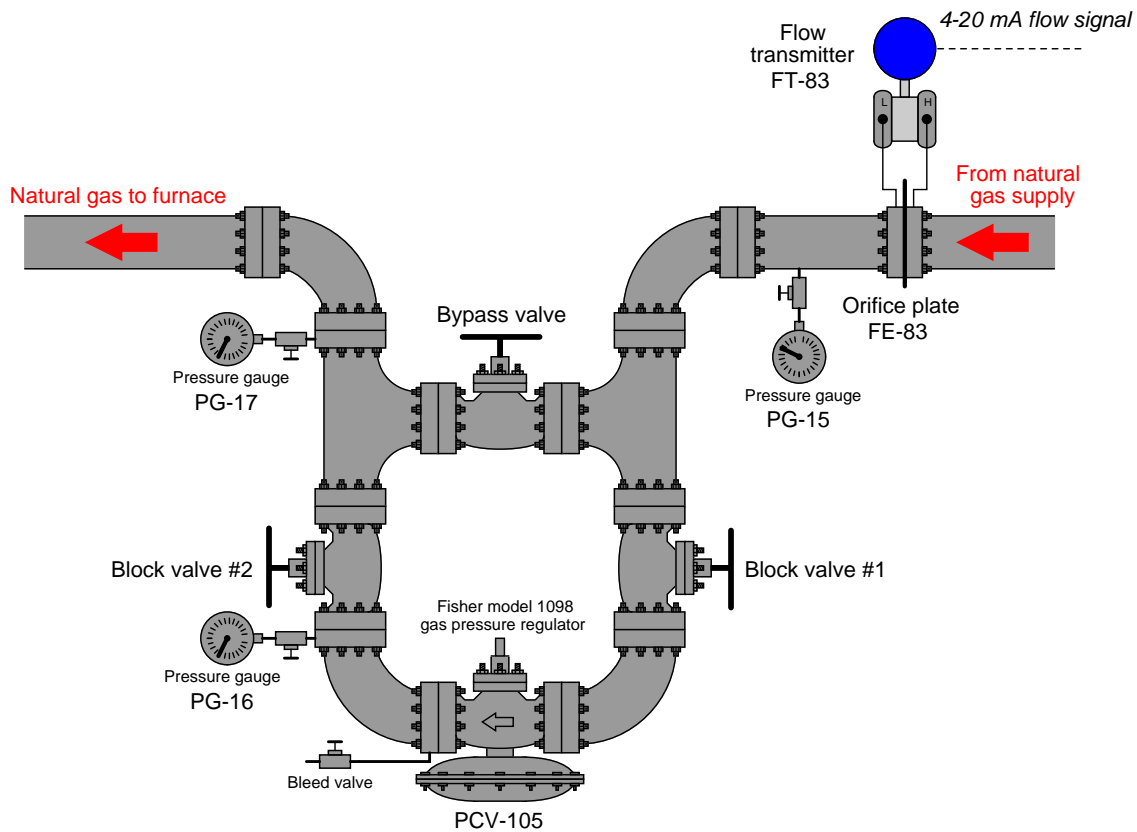
Calculate the amount of force applied to the “manway” cover on the sump when the educator is operating at its rated capacity, and also the direction of this force.

Will the applied vacuum from the educator help or hinder the two pumps’ ability to move liquid out of the sump and to water treatment? Will the effect be minimal or substantial?

[file i03465](#)

Question 57

A large natural-gas fired furnace receives its fuel gas supply through a pressure regulator which drops the natural gas pressure from 30 PSI to approximately 10 inches of water column:



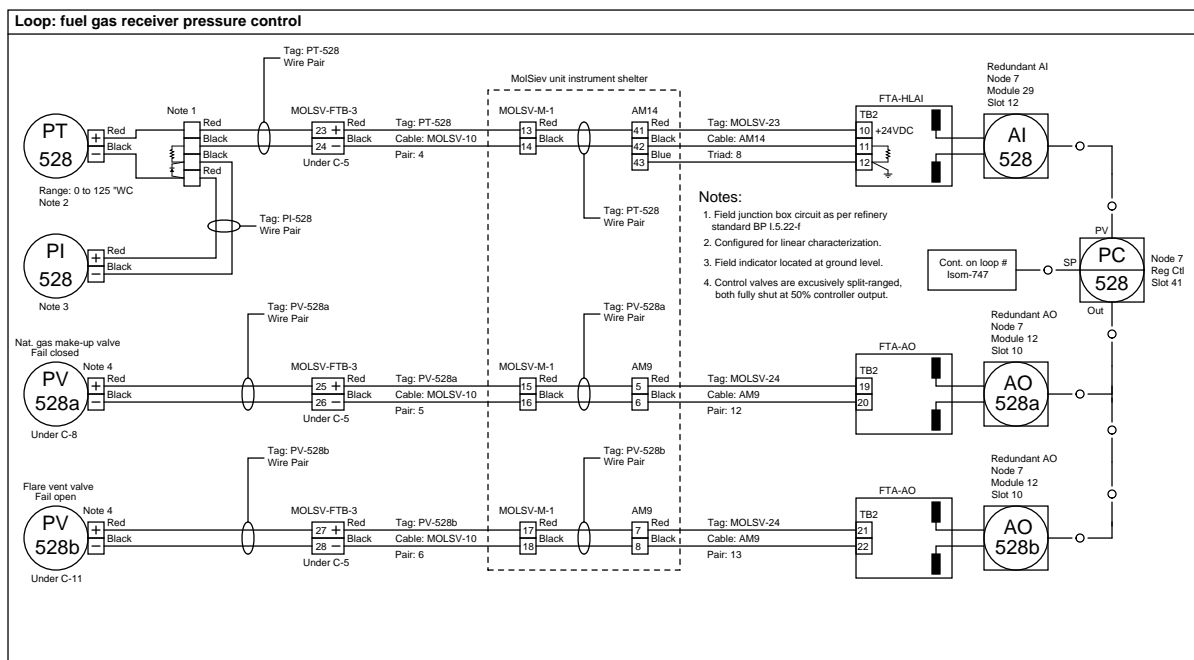
Devise a step-by-step procedure by which you may remove the pressure regulator (PCV-105) from service in order to rebuild it in the shop. Your procedure needs to ensure that the gas pressure delivered to the furnace does not ever exceed the allowable high limit (15 "WC) or fall below the allowable low limit (8 "WC):

-
-
-
-
-

file i02058

Question 58

A pair of split-ranged control valves work together to regulate natural gas pressure inside of a “receiver” vessel. One valve admits natural gas into the receiver vessel to raise its pressure, while the other valve vents excess natural gas from the receiver vessel to a flare to relieve pressure:



Based on the information shown in this loop sheet, sketch a P&ID of the receiver vessel and its pressure-control instrumentation. Then, identify potential faults in this system which could result in that receiver vessel’s gas pressure rising above setpoint.

[file i02147](#)

Question 59

Describe how a *positioner* may be used to change the inherent characteristic of a control valve, as an alternative to changing out the valve’s trim.

Also, explain why using a positioner to do this might not yield the best results.

Suggestions for Socratic discussion

- Describe a realistic scenario where someone might wish to alter the characteristic of a control valve, and how they would know this is the right thing to do.

[file i01385](#)

Question 60

Question 61

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

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

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

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

file i00999

Question 62

Convert between the following units of pressure. Remember that any pressure unit not explicitly specified as either absolute (A) or differential (D) is to be considered *gauge*. Also, remember those units which *always* represent absolute pressure, and have no need for a letter “A” suffix!

- 25 PSIA = ??? atm
- 340 "W.C. = ??? PSIA
- 0.73 bar (gauge) = ??? "Hg
- 5.5 atm = ??? torr
- 2,300 cm Hg = ??? "W.C.A
- 500 m torr = ??? PSIA
- 91.2 cm W.C. = ??? kPa
- 110 kPa = ??? "W.C.
- 620 mm HgA = ??? torr
- 77 Pa = ??? PSIA
- 1 atm = ??? "W.C.A
- 270 PSIA = ??? atm

There is a technique for converting between different units of measurement called “unity fractions” which is imperative for students of Instrumentation to master. For more information on the “unity fraction” method of unit conversion, refer to the “Unity Fractions” subsection of the “Unit Conversions and Physical Constants” section of the “Physics” chapter in your *Lessons In Industrial Instrumentation* textbook.

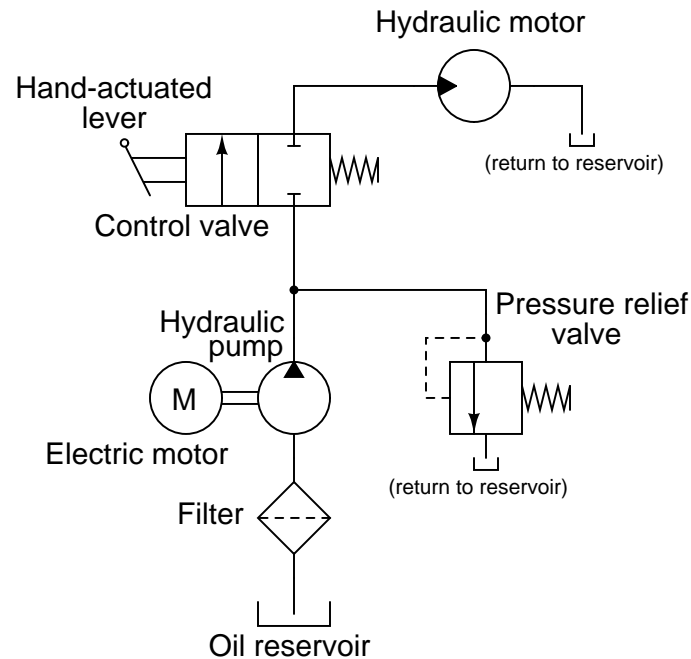
Suggestions for Socratic discussion

- Which of these conversions require an additive or subtractive offset, and which of these may be performed using multiplication and division alone?
- Demonstrate how to *estimate* numerical answers for these conversion problems without using a calculator.
- Suppose a novice tries to convert 3.5 atmospheres into PSIG, and arrives at a result of 51.45 PSIG. Identify the mistake made here, and also the proper conversion to go from units of atmospheres to PSIG.

file i00157

Question 63

A pressure-relief valve installed in a hydraulic system acts sort of like a *shunt voltage regulator* circuit: it limits pressure by bypassing (shunting) fluid back to the reservoir.



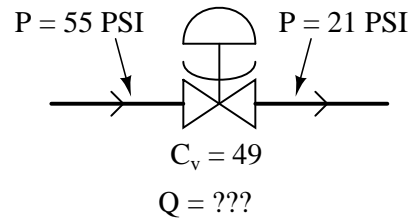
Qualitatively determine what will happen to the pressure-relief valve's return flow rate (back to the reservoir) for each of the following conditions, and be prepared to explain *why* for each case. Consider each condition as an independent event, without reference to previous conditions:

- Hand lever is moved from the “stop” position to the “run” position ; return flow (*increases, decreases, or stays the same*)?
- Hand lever is moved from the “run” position to the “stop” position ; return flow (*increases, decreases, or stays the same*)?
- While running, the hydraulic motor encounters a heavier mechanical load ; return flow (*increases, decreases, or stays the same*)?
- With the hydraulic motor stopped, the pump speed is decreased ; return flow (*increases, decreases, or stays the same*)?

file i00759

Question 64

How much liquid (density = 50 lb/ft³) will flow through this valve when wide open?



Suggestions for Socratic discussion

- What type of control valve and actuator are used in this application?

[file i01411](#)

Question 65

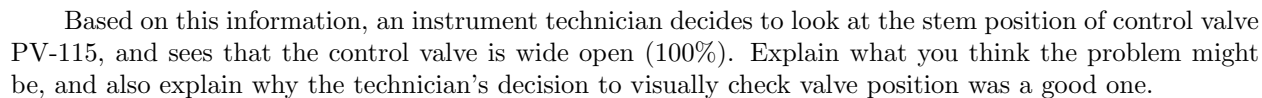
A gas flow control valve needs to be sized to pass 50,000 SCFH under these full-open conditions:

- Temperature = 280° R
- Upstream pressure = 3000 PSIG
- Downstream pressure = 100 PSIG
- Specific gravity = 1.1

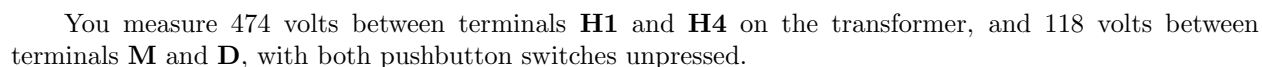
Calculate the necessary C_v factor for this valve.

[file i01415](#)

An operator reports a problem with the pressure control in this sour water stripping tower unit (where sulfide-laden water is “stripped” of sulfur compounds by the addition of hot steam). Pressure controller PC-115 has a setpoint of 6 PSI, but pressure gauge PG-441 registers significantly more (18 PSI) while pressure gauge PG-438 registers only 1 PSI:



Suppose this solenoid-controlled valve remains open all the time no matter which switch is pressed:



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. Also, identify one more possible fault not listed in the table.

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 i01425

Question 68

The `grades_template` spreadsheet provided for you on the Y: network drive allows you to calculate your grade for any course (by entering exam scores, attendance data, etc.) as well as project to the future for courses you have not yet taken. Download the spreadsheet file (if you have not done so yet) and enter all the data you can for grade calculation at this point in the quarter.

Also, locate the pages in your course worksheet entitled “Sequence of Second-Year Instrumentation Courses” to identify which courses you will need to register for next quarter.

If this is Fall, Winter, or Spring quarter, plan a time to complete your *Capstone Assessment*. This is a timed exercise where you must commission a feedback control system for a working process. It is permissible to do this during a scheduled lab period, but of course you should confer with your lab teammates before reserving a time to do this. Otherwise, you may check with your instructor to find a suitable date and time to reserve for completing this mandatory exercise.

Details about the Capstone Assessment are found in the very last question of this worksheet. Pay close attention to the objectives specific to this quarter’s study, and to any previous quarters you have completed. Capstone Assessments are *cumulative*, meaning the objectives accumulate for each quarter of study you have completed. Concepts you must know well to successfully complete a Capstone Assessment include: *4-20 mA loop circuit function, correctly identifying voltage polarities and current directions for DC sources and loads, setting loop controller parameters (e.g. controller action, PV scaling), and how to access equipment manuals within the electronic Instrumentation Reference*. Take time between now and your first Capstone attempt to master these things!

Lastly, prepare to comment on your job-search process to date. Where have you applied for jobs so far? Which industries most interest you, and why? Which employers have you researched, and what have you discovered so far? Which areas of the world are you interested in living and working? Which resources are you using to identify open positions (e.g. job search websites, classified advertisements, cold-calling specific employers)? Are there any places you would like to intern at in order to gain specific experience prior to employment?

If an employer were to interview you today, how would you describe your knowledge and skill set? What do you have listed on your resume that *demonstrates* (and not just claims) your work ethic and expertise?

Suggestions for Socratic discussion

- If you do not yet have enough data to calculate a final grade for a course (using the spreadsheet), experiment with plugging scores into the spreadsheet to obtain the grade you would like to earn. How might this be a useful strategy for you in the future?
- Why do you suppose this spreadsheet is provided to you, rather than the instructor simply posting your grades or notifying you of your progress in the program courses?
- Identify any courses that are *elective* rather than required for your 2-year AAS degree.

file i02659

Question 69

A hydraulic system has two cylinders linked together with high-pressure tubing. The piston diameter of cylinder #1 is 3 inches, while the piston diameter of cylinder #2 is 4.5 inches. How much force will cylinder #1's piston exert if cylinder #2's piston is pushed with 200 pounds of force? How much fluid pressure will be within the hydraulic tube with 200 pounds of force applied to the piston of cylinder #2?

Also, determine which of the two pistons will travel furthest, and explain why this is so.

Suggestions for Socratic discussion

- 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 i00151](#)

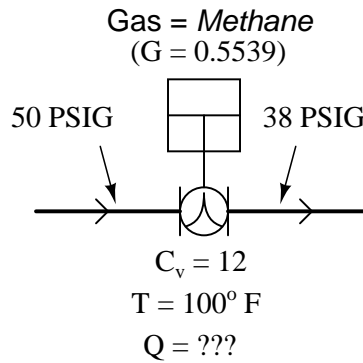
Question 70

Describe what a *metering pump* is and what one might be used for.

[file i01427](#)

Question 71

How much volumetric flow can we expect through this valve, in units of SCFH?

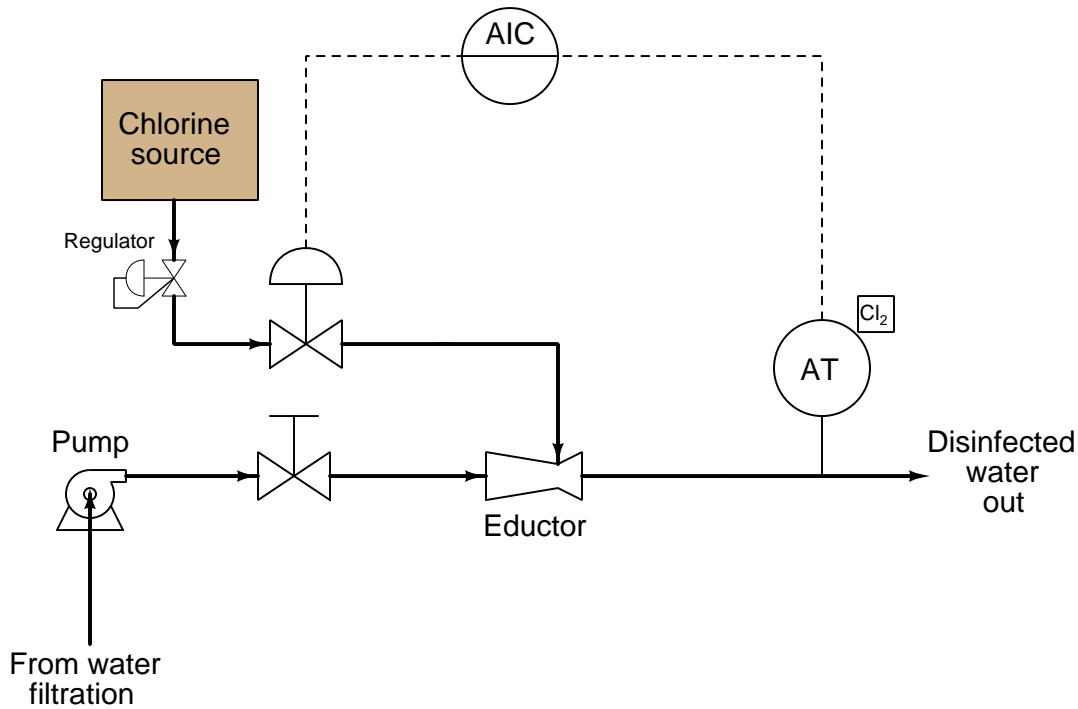
**Suggestions for Socratic discussion**

- What type of control valve and actuator are used in this application?

[file i01413](#)

Question 72

Calculate the necessary size (C_v , and also pipe size in inches) control valve to pass a maximum of 2.1 SCFM of chlorine gas (specific gravity = 2.47) in this wastewater disinfection system, where enough chlorine (Cl_2) is continuously mixed with the wastewater to kill most harmful micro-organisms:



A pressure regulator connected to the chlorine source regulates the control valve's upstream pressure at a constant -30 inches water column, while a venturi-shaped *eductor* uses the flow of wastewater to create a vacuum to pull chlorine gas into the water with a pressure of -120 inches water column. Assume a temperature of 50°F , a single-port ported-plug control valve, and negligible friction in the chlorine gas piping.

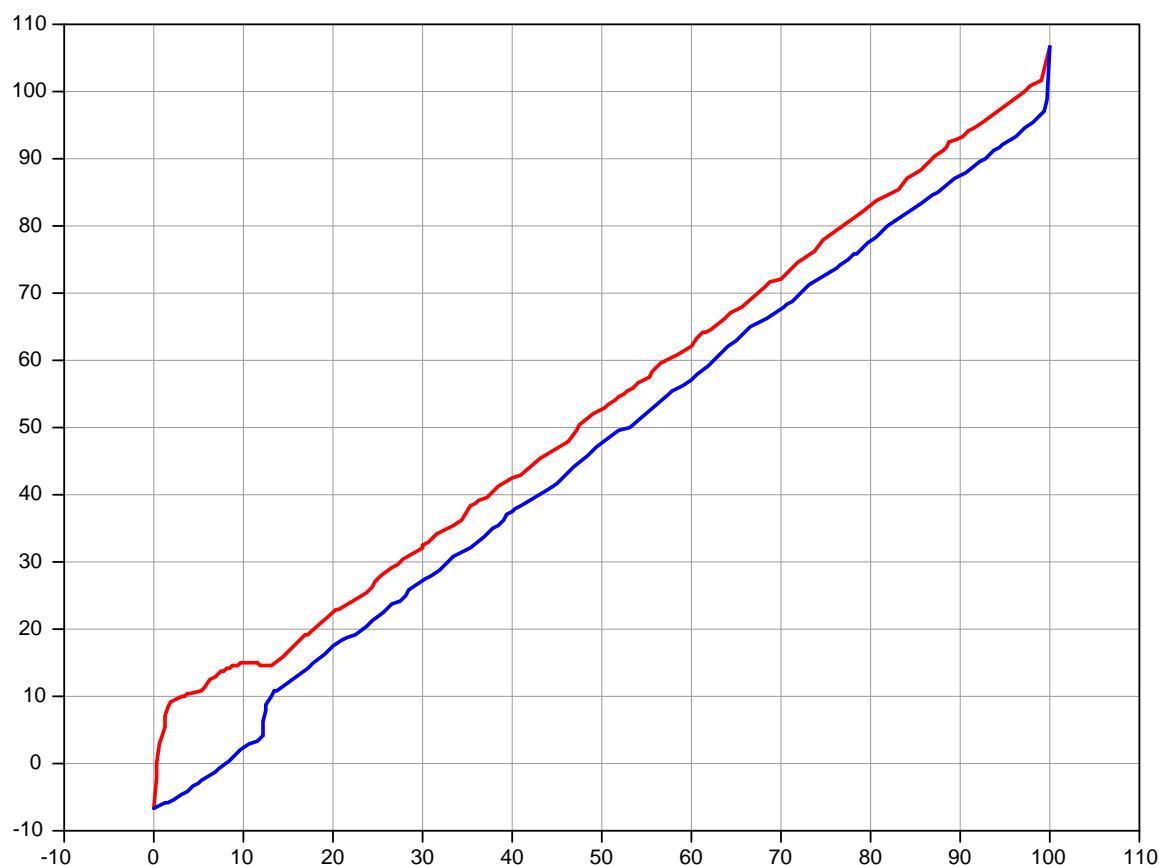
$C_v =$ _____

Nominal pipe size = _____ inches

file i04362

Question 73

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



What is your diagnosis of this valve signature? 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.

[file i01424](#)

Question 74

Question 75

Question 76

Question 77

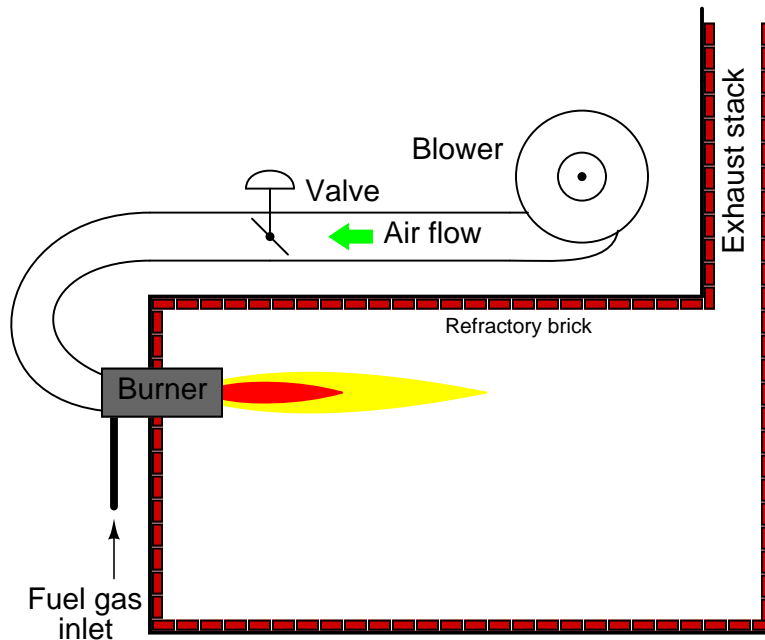
Question 78

Question 79

Question 80

Question 81

A butterfly-style control valve will be used to throttle combustion air flow to a large natural gas burner on an industrial furnace:



The pressure dropped across the burner is 8 ounces per square inch (8 oz/in²). At “high fire” (full air flow and full burner heat output) the blower outputs a static pressure of 35 ”W.C. at a flow rate of 2,000 standard cubic feet per minute (2,000 SCFM). The furnace pressure is controlled to equal atmospheric pressure at all times.

Given these conditions, what must the combustion air control valve’s C_v be at full-open in order to pass 2,000 SCFM to the burner? Assume an ambient temperature of 45° F. Also, calculate the approximate size of the valve (nominal pipe diameter, in inches) needed if the style is a 90-degree butterfly valve with an offset seat ($C_d = 29$).

Use the following valve capacity equation for your calculations:

$$Q = 963 C_v \sqrt{\frac{\Delta P (P_1 + P_2)}{G_g T}}$$

Where,

Q = Gas flow rate, in units of Standard Cubic Feet per Hour (SCFH)

C_v = Valve capacity coefficient

ΔP = Pressure dropped across valve, pounds per square inch differential (PSID)

P_1 = Upstream valve pressure, pounds per square inch absolute (PSIA)

P_2 = Downstream valve pressure, pounds per square inch absolute (PSIA)

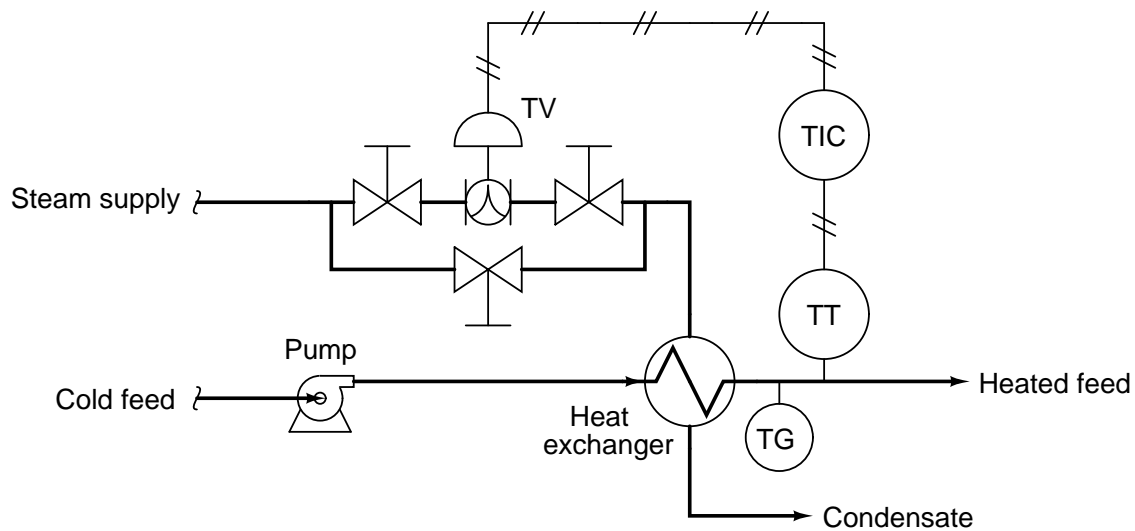
G_g = Specific gravity of gas (Air at standard temperature and pressure = 1.0)

T = Absolute temperature of gas in degrees Rankine (°R)

[file i01414](#)

Question 82

This temperature control system uses a pneumatic transmitter and controller to maintain constant temperature at the outlet of the heat exchanger:



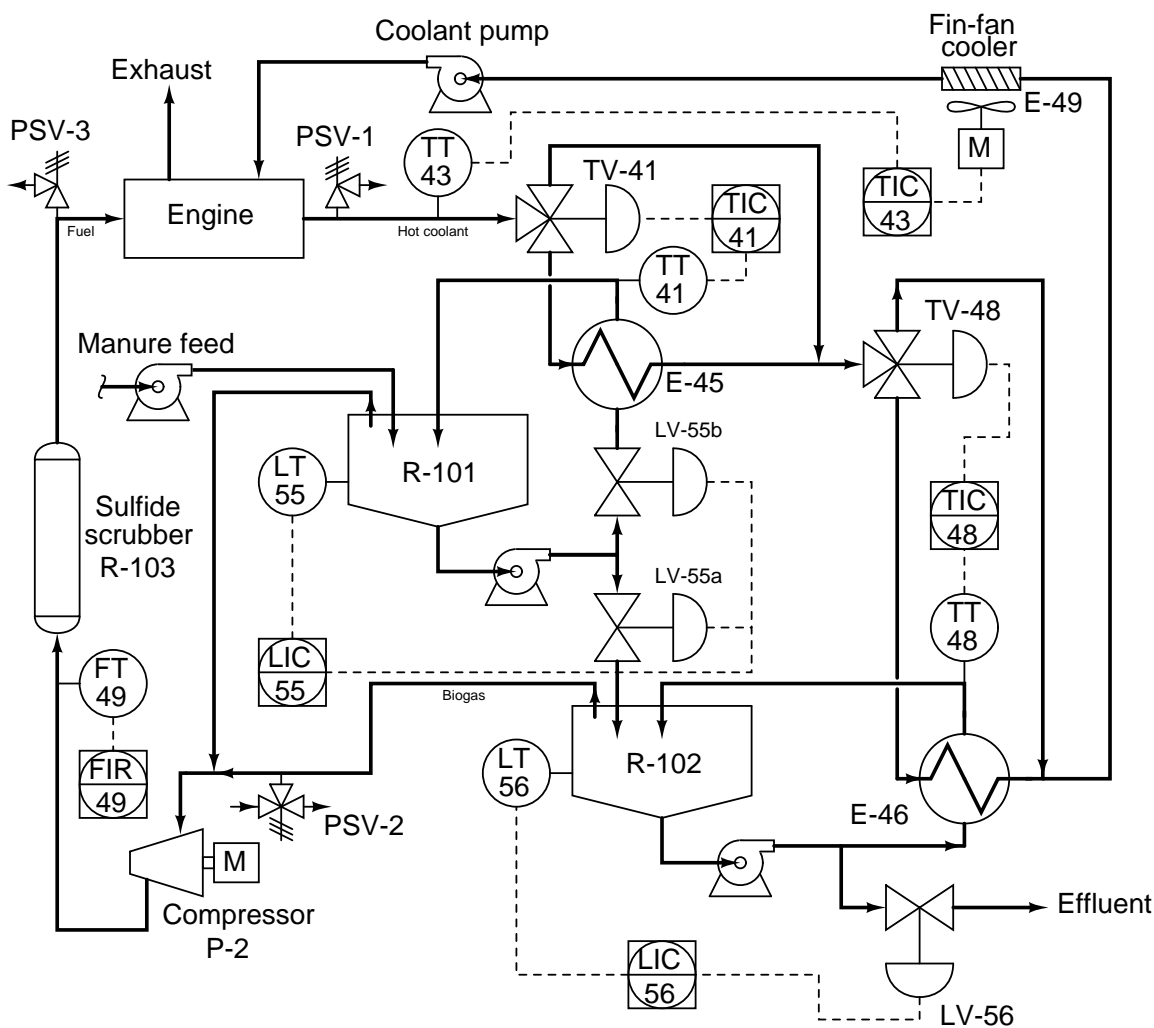
A routine maintenance task you are assigned is to “stroke-test” the control valve to verify that its travel is not impeded or its calibration too far off. The only problem is, this must be done while the process is “live” (feed flow being heated) and the pneumatic controller has no manual mode.

Outline a plan to follow allowing you to stroke-test this control valve with minimal interruption to the process. Points to address include:

- How to maintain feed temperature at setpoint while valve is being stroked
- How to stroke the valve from 0% to 100% of range with no manual mode in the controller

Question 83

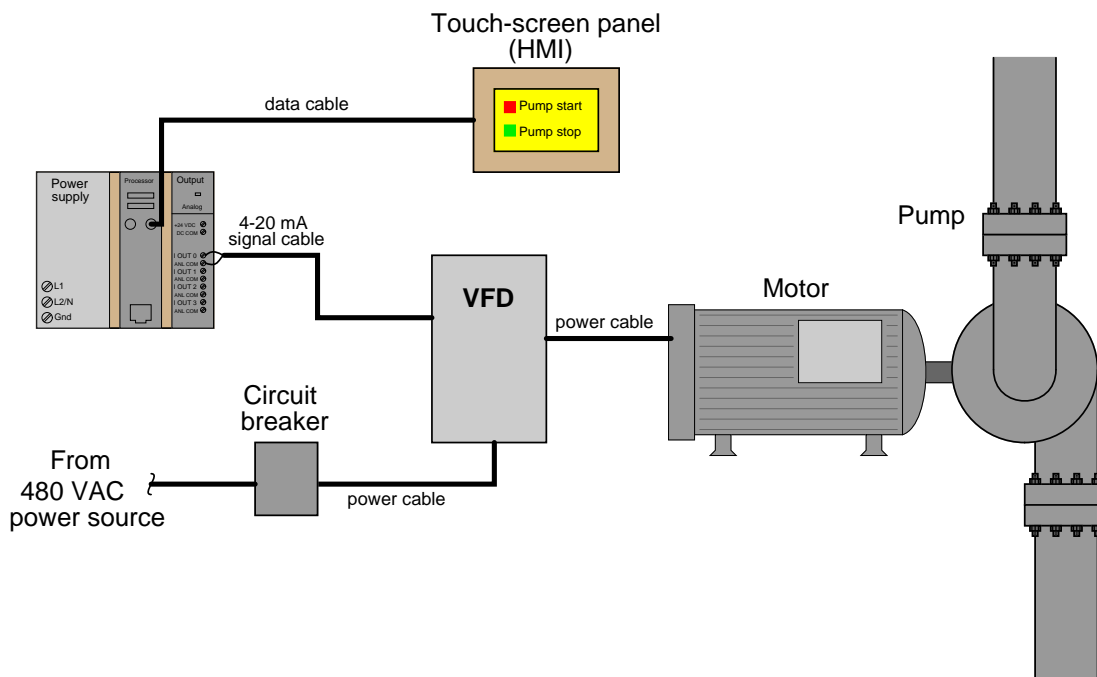
In this biogas generation system, cow manure is used as a feedstock to produce methane gas (CH_4), which is then used to fuel an engine to turn a generator and make electricity. The waste heat from the engine is used to maintain the cascaded digesters ("reactors" R-101 and R-102) at optimal temperatures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



- What kind of control valves are TV-41 and TV-48?
- Assuming LT-55 is a direct-acting level transmitter and LIC-55 is a reverse-acting level controller, determine the necessary split-range calibrations of LV-55a and LV-55b.
- What would the consequence(s) be if TT-43 failed with a high signal?

Question 84

A brand-new control system for a chemical reaction process uses a variable-frequency drive (VFD) to control the speed of the charge pump introducing chemical fluids into a reaction vessel. This VFD gets a 4-20 mA control signal from one of the channels of an analog output card on a programmable logic controller (PLC). The PLC in turn receives operating instructions from a touch-screen panel (“HMI”) where the operators can monitor and control the process:



This system is newly constructed, and has not yet worked. The operators try starting up the pump by pressing the “Pump start” icon on the touch-screen, but nothing happens. A technician disconnects the signal cable from the PLC’s analog output terminals and then connects the cable’s end to a “loop calibrator” to send 12 mA DC to the VFD for a test. At this, the motor starts up and runs at half speed.

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.

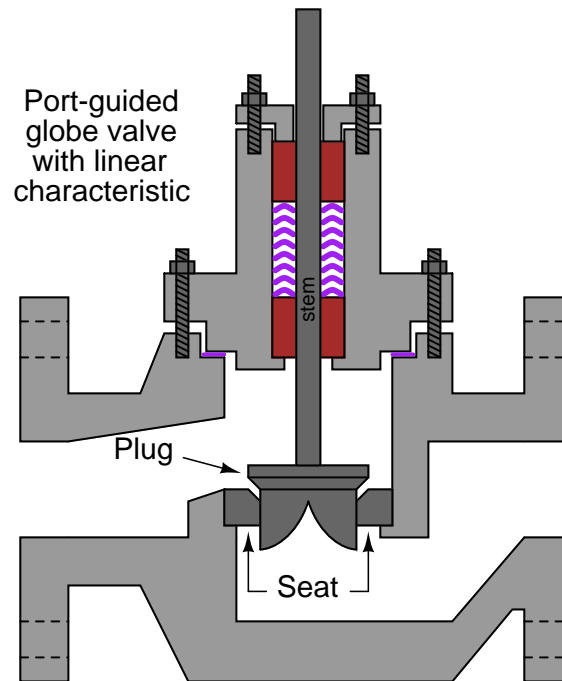
Fault	Possible	Impossible
Circuit breaker off		
Touch-screen panel malfunctioning		
Programming error in PLC		
Faulted power cable between VFD and motor		
Faulted power cable between breaker and VFD		
Analog output card malfunctioning		
Shorted signal cable		

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 i00067

Question 85

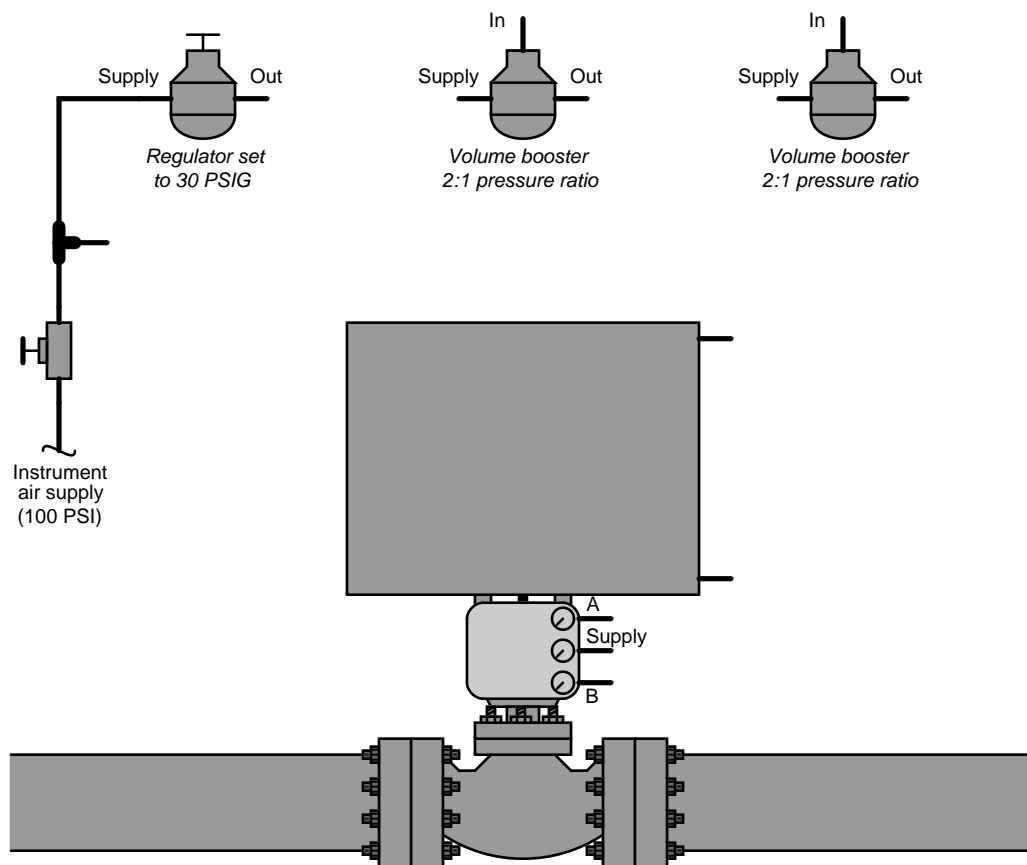
This illustration shows a port-guided globe valve with a *linear* throttling characteristic:



Describe *and* sketch what would have to be modified in this valve to give it an *equal-percentage* throttling characteristic.

Question 86

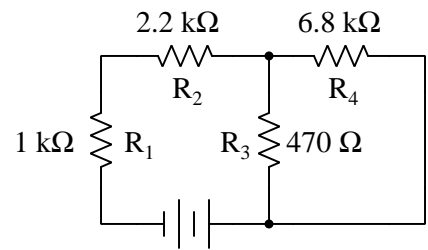
Sketch the necessary tube connections to make this Fisher model DVC6000 valve positioner work with the double-acting piston actuator shown on the valve. Two 2:1 volume boosting relays are provided for faster control valve action (for maximum of 60 PSI applied to either actuator port):



Assume the control valve body is direct-acting (stem *up* makes the valve *open*), and that you desire a valve action that is *signal-to-close* (4 mA = wide open ; 20 mA = shut).

Question 87

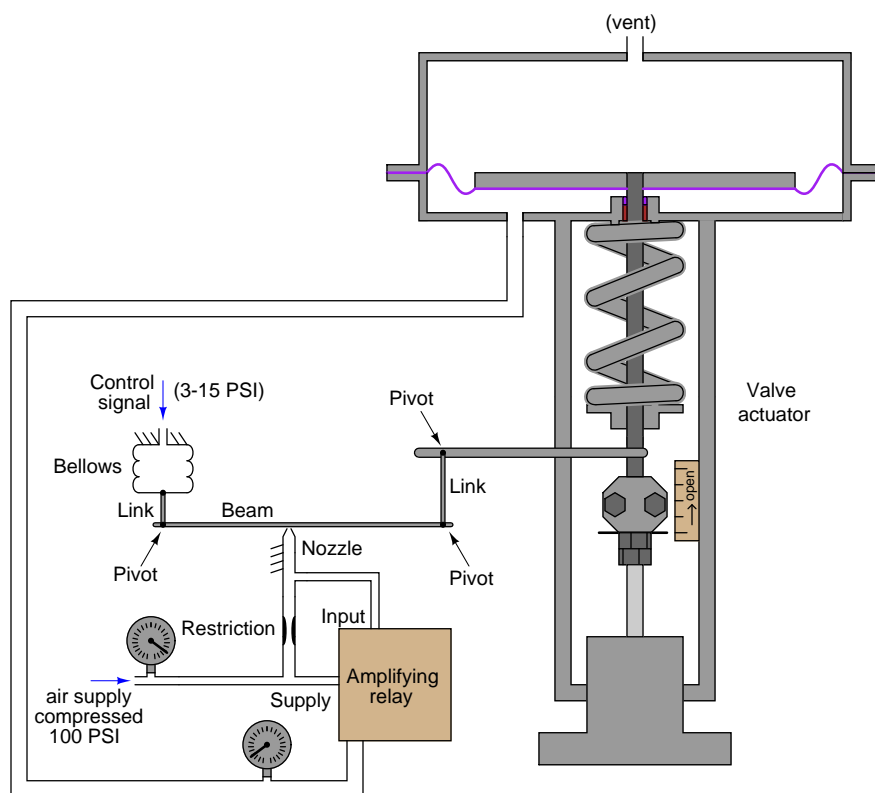
Complete the table of values for this circuit assuming a measured voltage of 725 mV across resistor R_3 . Be sure to show all your work!



	R_1	R_2	R_3	R_4	Total
V					
I					
R	1 kΩ	2.2 kΩ	470 Ω	6.8 kΩ	
P					

Question 88

Examine this valve positioner illustration, and then answer the following questions about it:



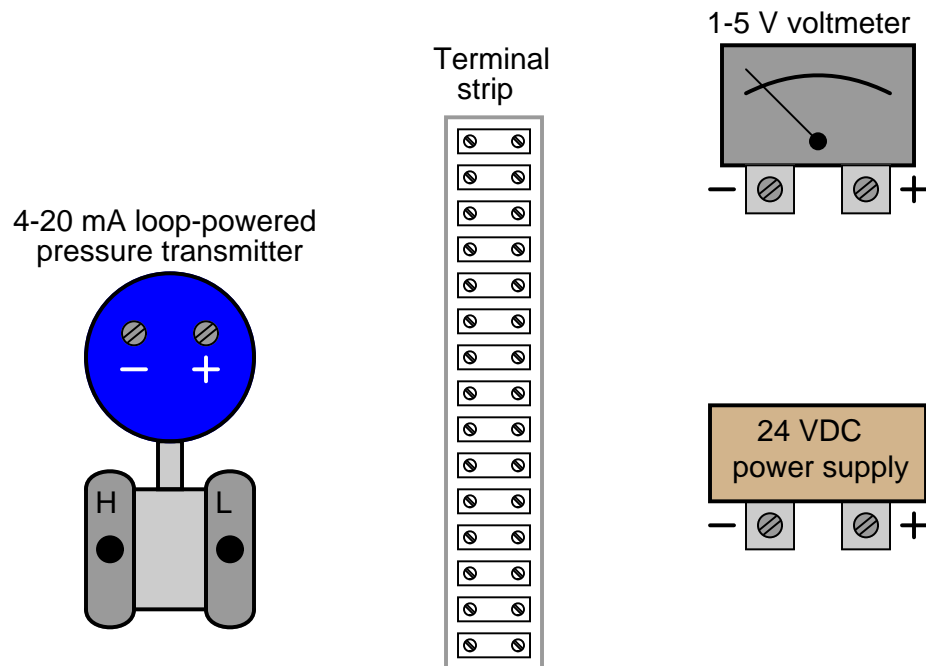
If a technician lengthened the link connecting the positioner's beam to the valve stem bracket, what effect would this have on the calibration of the whole control valve assembly? Would it introduce a *zero* shift, a *span* shift, or a change in *linearity*? Be as detailed as you can in your answer.

If a technician replaced the main spring in the valve actuator with one that was stiffer (i.e. a larger k spring constant), what effect would this have on the calibration of the whole control valve assembly? Would it introduce a *zero* shift, a *span* shift, or a change in *linearity*? Be as detailed as you can in your answer.

Suppose this very same positioner mechanism were attached to a direct-acting actuator (air to move the stem down) rather than a reverse-acting actuator (air to move the stem up) as shown here. What, if anything, would have to be altered in the positioner mechanism to make it function properly with this different actuator? Explain the rationale for any mechanism changes that would have to be made.

Question 89

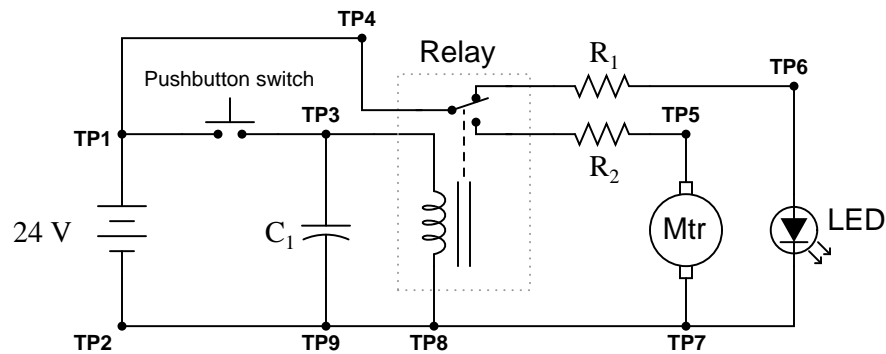
Sketch a circuit whereby this loop-powered pressure transmitter sends a signal to an analog voltage meter (acting as a remote pressure gauge). Be sure to route all wiring and attach any necessary components to terminals on the terminal strip:



Note: avoid connecting more than two wires to each screw terminal on the terminal strip, to avoid “overcrowding” any connection points, and avoid crossing wires over each other.

Question 90

In this time-delay relay circuit, the motor will immediately start when the pushbutton is pressed, and continue to run for about 5 seconds after the pushbutton is released. The green light-emitting diode (LED) is supposed to be on whenever the motor is stopped, and off whenever the motor is running:



However, a problem has developed with this circuit. Every time the pushbutton switch is pressed, the green LED turns off but the motor never starts. The LED turns back on after the 5 second delay time. Based on this information, determine the following:

- Two components or wires in the circuit that you know cannot be failed either open or shorted, besides the 24 volt source.
- Two components or wires in the circuit you think could possibly be bad (either one independently capable of causing the problem), and the type of failure each would be (either open or shorted).

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 <i>first!</i>)	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					– – – –
<i>Safety and professionalism</i>	deduction					
<i>Lab percentage score</i>	proportional					– – – –
Decommission and lab clean-up	(ungraded)	–	–	–	–	

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

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

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

Lab Exercise – objectives and expectations

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

Team meeting and prototype sketch

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

Circuit design challenge

Wire a VFD to a single-phase power source and a three-phase electric motor, then configure the VFD to control the 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 exceeds 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.

Your 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.

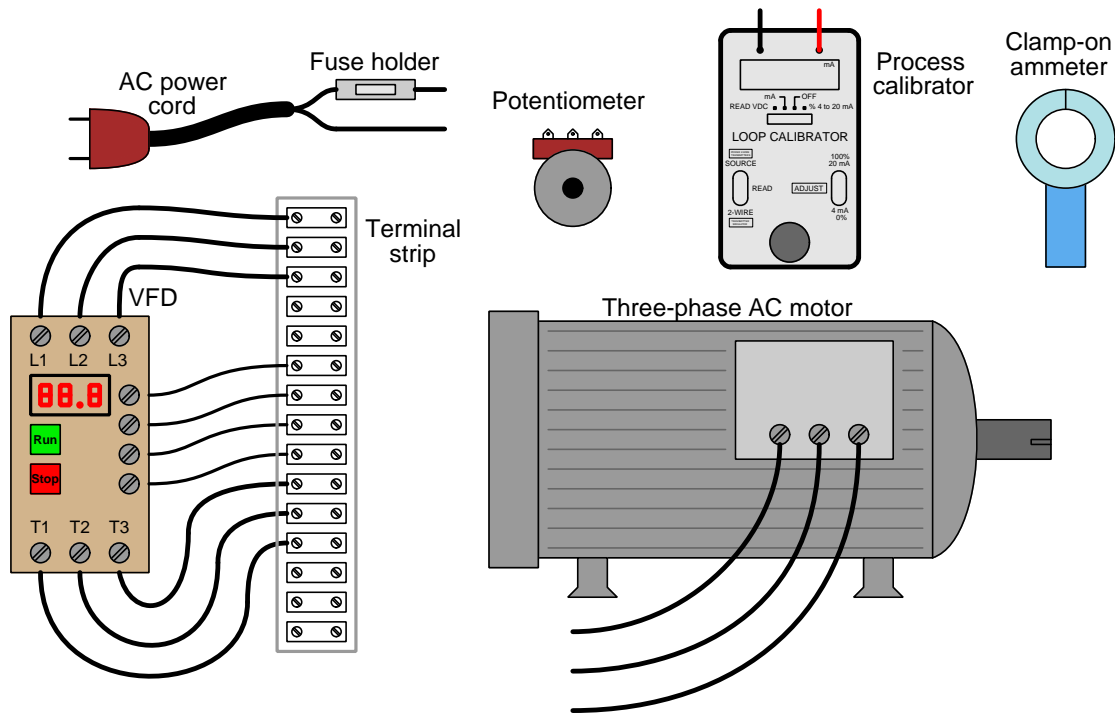
Common mistakes:

- 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)

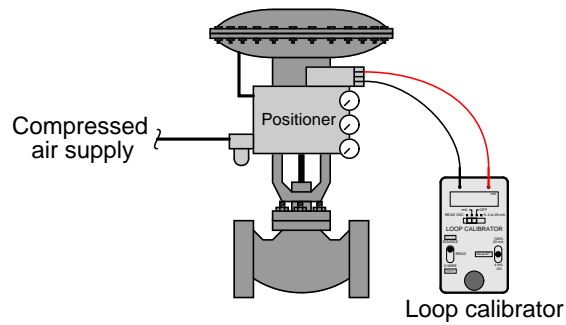
Base motor parameters (from nameplate):
 V_{line} = _____ Volts
 I_{line} = _____ Amps @ full load
 Speed = _____ RPM @ 60 Hz

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 By: _____ Date: _____ Range: _____	CALIBRATED By: _____ Date: _____ Range: _____	CALIBRATED By: _____ Date: _____ Range: _____	CALIBRATED By: _____ Date: _____ Range: _____
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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 simultaneous 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 separation 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 diagnostic 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:

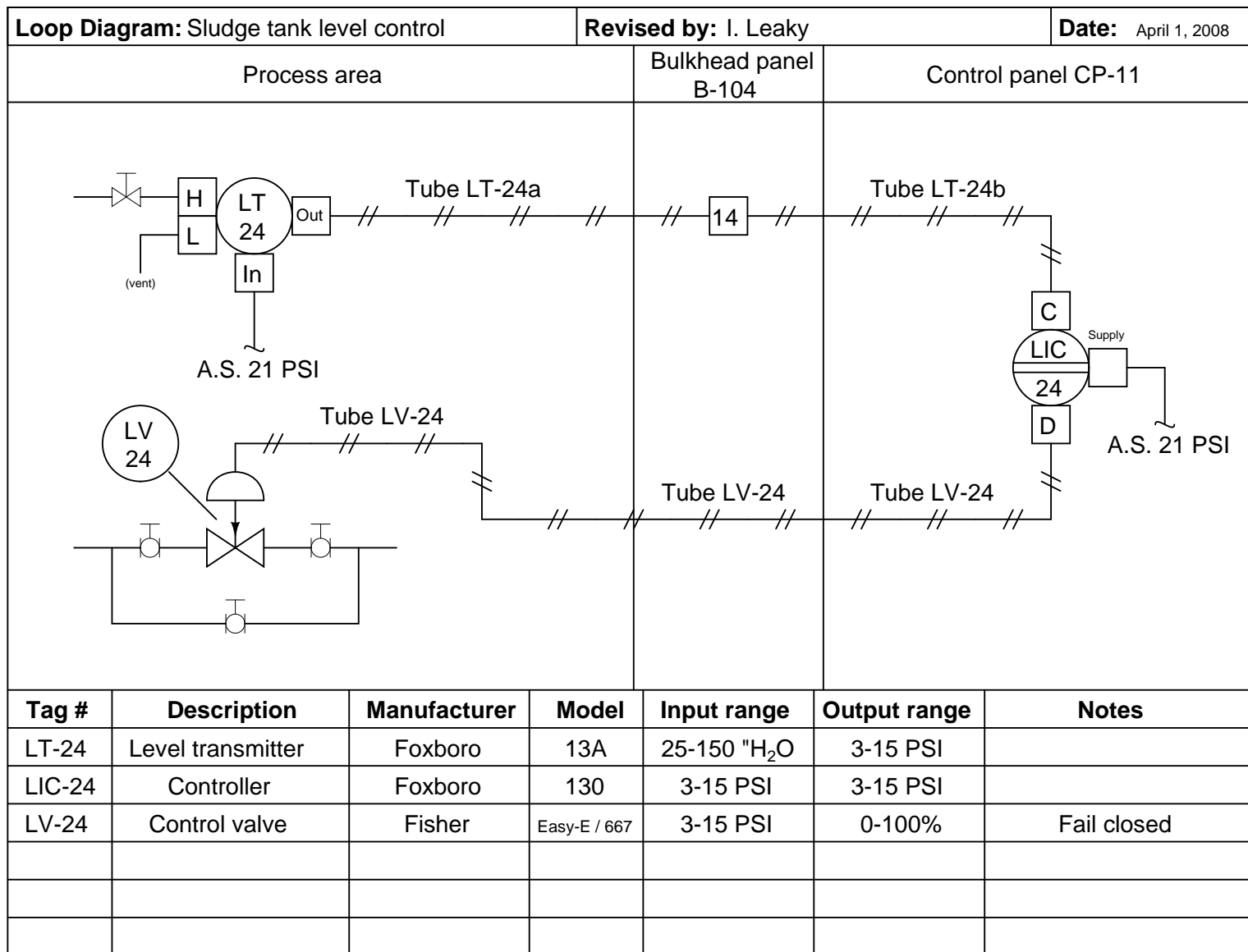
- Sensing elements (e.g. thermocouples, pH probes, etc.)
- Process transmitters
- “Jumper” cables used to connect terminal blocks within a single junction box
- Plastic tubing and tube fittings (disconnect compression-style tube fittings)
- Power cables and extension cords
- Adjustment (loading station)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









Lab Exercise – loop diagram and system inspection

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- Each location (e.g. field, junction box, control room) must be clearly delineated with vertical separation 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).

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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!*
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- Not placing loop sheet instruments in the correct orientation (field instruments on the left, control room instruments on the right).

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

[file i00654](#)

Capstone Assessment (end of quarter)

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

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

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

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

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

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

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

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

No teamwork is allowed while wearing the vest!

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

The time clock starts now!

Start time: _____

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

Now you may begin wiring and configuring the components

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

The time clock stops now!

Stop time: _____

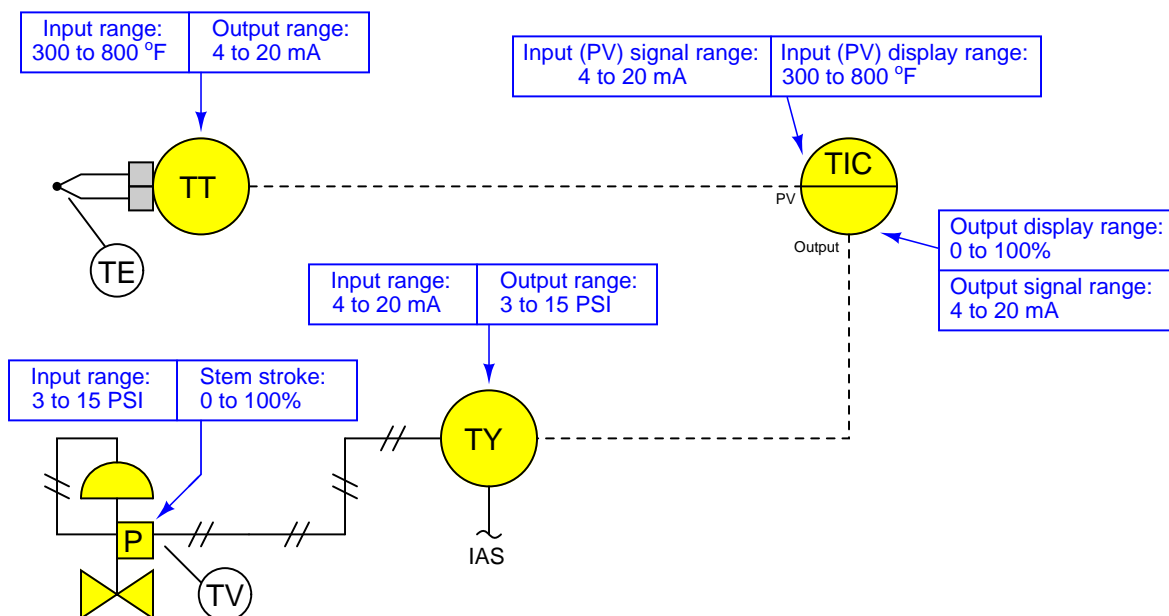
Criterion	(Instructor verifies)
Instructor verifies all signal wires/tubes disconnected	
Instructor verifies controller reset to original configuration	
Instructor verifies DAQ is returned to team tool locker	
Instructor collects your diagrams	

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

Notes on instrument ranging

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

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



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

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

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

Notes on instrument ranging (continued)

- Siemens/Moore 352 controller: process variable range parameters are located in the “Operator’s Display” function block (FB15):
 - LRV = *Process Lo*
 - URV = *Process Hi*
- Siemens/Moore 352P and 353 controller: process variable range parameters are located in the “Analog Input” function block (AIN):
 - LRV = *Minscale*
 - URV = *Maxscale*
- Emerson DeltaV DCS: process variable range parameters are located in the “Analog Input” function block (AI) and “PID” function block (PID):
 - (AI block) = the *OUT_SCALE* parameter contains both high and low range limits, engineering units (e.g. deg F), and decimal point position. The *L_Type* parameter needs to be set to “indirect” to allow scaling to occur (“direct” mode prohibits scaling), and the *XD_Scale* parameter needs to be ranged 0 to 100%. Note that the “direct” and “indirect” options for *L_Type* have absolutely nothing to do with “direct” and “reverse” PID controller action, which is configured elsewhere.
 - (PID block) = the *PV_SCALE* parameter contains both high and low range limits, engineering units (e.g. deg F), and decimal point position. Note: the PID block’s *PV_SCALE* range must exactly match the *OUT_SCALE* range of the AI block!
- Honeywell UDC 2500 controller: process variable input #1 range parameters are located in the “Input 1” set-up group of parameters:
 - LRV = *IN1 LO*
 - URV = *IN1 HI*
- Automation Direct “SOLO” controller: process variable range parameters are located in the following registers:
 - LRV = *P3-4 Input Range Low*
 - URV = *P3-3 Input Range High*
- Allen-Bradley PLC5, SLC500, and MicroLogix controllers: process variable scaling parameters are typically located either in a “Scale” instruction (SCL) or a “Scale with Parameters” instruction (SCP). In either case, the instruction takes the raw count value from the input channel’s analog-to-digital converter and scales it into the desired process variable display range. A YouTube video on our BTCInstrumentation channel shows how to do this for the networked MicroLogix PLCs in the lab using the SCP instruction. *Note: SCP instruction parameters may be edited online. For this reason, downloading edits is not necessary for the MicroLogix PLCs in our lab. In fact, it is very important that you not save or download the PLC program, because doing so may alter the PLC’s network address and lead to communication problems. Just make the changes while the PLC is in “Run” mode and then exit the program:*
 - (SCL instruction) = *Rate* and *Offset* values scale the signal according to the slope-intercept formula $y = mx + b$, where *Rate* is $10000m$ and *Offset* is b
 - (SCP instruction LRV) = *Scaled Min.*
 - (SCP instruction URV) = *Scaled Max.*
- Allen-Bradley Logix5000 controller: process variable scaling parameters are located in the “PID” instruction (PID):
 - LRV = *.MINS*
 - URV = *.MAXS*

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

Notes on controller action

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

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

- Siemens/Moore 352 controller: control action parameters are located in the “PID” function block (FB13). Note that the P, I, and D tuning parameters may be quickly accessed by pressing the “Tune” button rather than by entering the PID function block edit menu:
 - Direction (Direct/Reverse) = *SA1*
 - Proportional (P) = *SPG1* as a unitless gain value
 - Integral (I) = *STI1* in units of minutes per repeat
 - Derivative (D) = *STD1* in units of minutes
- Siemens/Moore 352P and 353 controller: control action parameters are located in the “PID” function block (PID). Note that the P, I, and D tuning parameters may be quickly accessed by pressing the “Tune” button rather than by entering the PID function block edit menu:
 - Direction (Direct/Reverse) = *DIR ACT*
 - Proportional (P) = *PG* as a unitless gain value
 - Integral (I) = *TI* in units of minutes per repeat
 - Derivative (D) = *TD* in units of minutes
- Emerson DeltaV DCS: control action parameters are located in the “PID” function block (PID) conforming to the FOUNDATION Fieldbus standard:
 - Direction (Direct/Reverse) = Found in the *CONTROL_OPTS* set of parameters as a “check-box” where a checked box sets direct action and an unchecked box sets reverse action.
 - Proportional (P) = *GAIN* as a unitless gain value
 - Integral (I) = *RESET* in units of seconds per repeat
 - Derivative (D) = *RATE* in units of seconds
- Honeywell UDC 2500 controller: control direction is located in the “CONTRL” set-up group of parameters, while the PID tuning coefficients are located in the “TUNING” set-up group of parameters:
 - Direction (Direct/Reverse) = *Action*
 - Proportional (P) = *PB* or *Gain* as a proportional band percentage or as a unitless gain value, respectively
 - Integral (I) = *I Min* or *I RPM* in units of minutes or repeats per minute, respectively
 - Derivative (D) = *Rate T* in units of minutes

Notes on controller action (continued)

- Automation Direct “SOLO” controller: process variable range parameters are located in the following registers:
 - Direction (Direct/Reverse)= *P3-7 Heating/Cooling*
 - Proportional (P) = *P1-4 Proportional band* as a proportional band percentage
 - Integral (I) = *P1-5 Integral time* in units of seconds
 - Derivative (D) = *P1-6 Derivative time* in units of seconds
- Allen-Bradley PLC5, SLC500, and MicroLogix controllers: control action parameters are located in the “PID” instruction. A YouTube video on our BTCInstrumentation channel shows how to do this for the networked MicroLogix PLCs in the lab (reading the PV on the first analog input and sending the output to the first analog output of the I/O card):
 - Direction (Direct/Reverse)= Found in the *Control Mode* field where $E = PV - SP$ represents direct action and $E = SP - PV$ represents reverse action.
 - Proportional (P) = *Controller Gain K_c* as a unitless gain value
 - Integral (I) = *Reset T_i* in units of minutes per repeat
 - Derivative (D) = *Rate T_d* in units of minutes
- Allen-Bradley Logix5000 controller: control action parameters are located in the “PID” instruction (PID):
 - Direction (Direct/Reverse)= *E* where $PV - SP$ represents direct action and $SP - PV$ represents reverse action.
 - Proportional (P) = K_p or K_c as a unitless gain value
 - Integral (I) = K_i in units of seconds per repeat
 - Derivative (D) = K_d in units of minutes
- caSCADA “pid” control program: control action parameters are located on the operator interface screen, above the trend graph. This control program may be initiated from the Linux command line by typing `./pid` and pressing the Enter key. Once the `pid` control program is running (reading the PV on analog input AIN0 and sending the output to analog output DAC0 of the LabJack DAQ), each parameter may be selected by pressing the **S** key as often as needed, and the parameter values changed by pressing the arrow and page up/down keys. Note that the control direction may only be switched while the controller is in manual mode. Tuning parameters may be altered in either manual or automatic modes.
 - Direction (Direct/Reverse)= will either show “**Direct-acting**” or “**Reverse-acting**”
 - Proportional (P) = K_P as a unitless gain value
 - Integral (I) = K_I in units of repeats per minute
 - Derivative (D) = K_D in units of seconds

Notes on controller tuning

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

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

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

Answers

Answer 1

Answer 2

$$C_v = 44.395$$

Answer 3

This graph relates pressure output versus liquid flow rate for a centrifugal-style pump operating at a constant rotational speed.

Answer 4

$$C_v = 0.71$$

Answer 5

Partial answer:

$$C_v = 20.77$$

Answer 6

There is too much uncertainty in the given information to calculate a sure C_v value. An extremely uncertain answer, though, is $C_v = 1.033$.

Answer 7

Answer 8

$$Q = 7,689.91 \text{ SCFH}$$

Answer 9

Answer 10

Answer 11

$$C_v = 65.6$$

A 2.5 inch control valve should be sufficient.

Answer 12

$$C_v = 2482$$

A 10 inch control valve should be sufficient.

Answer 13

$$C_v = 0.416$$

Answer 14

C_v is approximately proportional to the *square* of the nominal valve size. The idea here is that the cross-sectional area for flow to go through will increase with the square of the flow path diameter ($A = \pi r^2$).

We see this in the formula for relative flow capacity (C_d), which is roughly constant for a given valve type (ball versus globe versus butterfly, etc.):

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

Manipulating this to relate diameter (d) to flow coefficient (C_v):

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

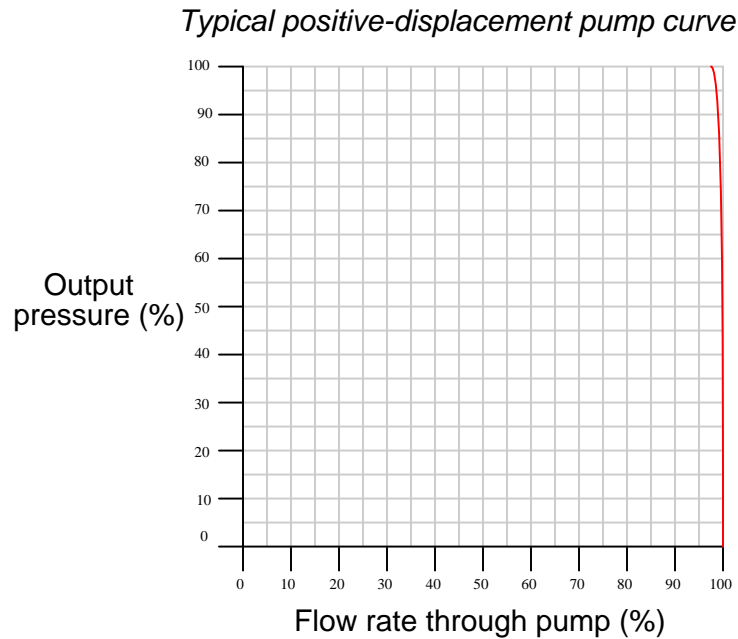
Given a constant C_d value, the flow coefficient (C_v) will increase with the *square* of the increasing diameter.

Answer 15

If there is any residual fluid pressure inside the pipe, loosening the flange bolts on the opposite side of the pipe from where you're standing will ensure that any leak will spray *away* from you rather than toward you.

Answer 16

The ideal pump curve for a positive-displacement pump is a vertical line, but due to internal leakage the real pump curve looks something more like this:



Answer 17

- Flow rate at a discharge head of 70 feet = **175** GPM
- Discharge head at 112 GPM = **127** feet

Answer 18

The inlet control valve sees a pressure drop of $95 \text{ PSIG} - 8 \text{ PSIG} = 87 \text{ PSIG}$, while the outlet control valve only sees a pressure drop of 8 PSIG (as it vents gas to atmosphere at 0 PSIG). However, both valves will be flowing the same rate of gas assuming no other paths for gas flow into or out of the vessel. This means the outlet valve must flow the same amount of gas with less than one-tenth the pressure drop across it.

Therefore, the outlet valve must have a much greater C_v than the inlet valve. The calculated ratio is thus:

$$\sqrt{\frac{87}{8}} = 3.2977$$

Answer 19

Answer 20

Answer 21

Answer 22

Answer 23

Answer 24

Did you think I would give away the answer here?

Answer 25

Answer 26

Remember this formula for predicting the behavior of an equal-percentage control valve:

$$C_v = C_{vm} R^{(x-1)}$$

Where,

C_v = Flow coefficient of control valve at stem position x

C_{vm} = Flow coefficient of control valve while wide-open ($x = 100\%$)

x = Stem position, as a per unit value (ranging from 0 to 1) inclusive

R = Rangeability coefficient of equal-percentage trim

Partial answer:

Stem position	C_v
0%	0.697
25%	1.9
50%	
60%	
70%	11.6
80%	17.3
90%	
100%	38.5

Answer 27

Hint: does the pressure drop across the control valve vary substantially with flow?

Answer 28

Did you think I would reveal details here and spoil your fun?

Answer 29

Based on the first measurement (only), we could conclude the wiring fault *may* be an “open” in cable 26, or a “short” in *any* cable.

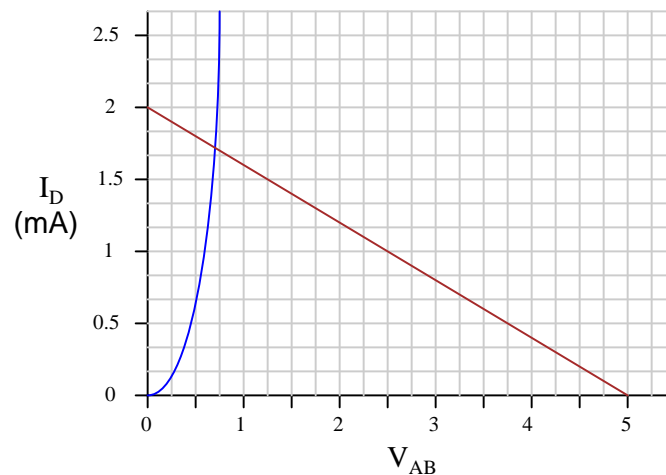
Answer 30

$I_R = 8 \text{ mA}$ is the same value of current you would calculate if you had analyzed this circuit as a simple series resistor network.

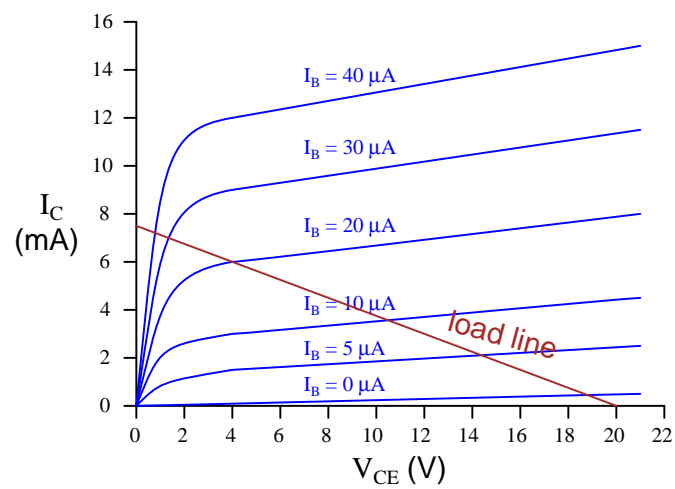
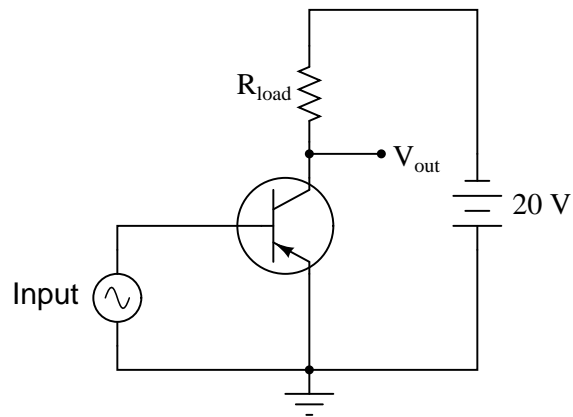
Follow-up question: you might be wondering, “what is the point of plotting a ‘characteristic curve’ and a ‘load line’ in such a simple circuit, if all we had to do to solve for current was add the two resistances and divide that total resistance value into the total voltage?” Well, to be honest, there is no point in analyzing such a simple circuit in this manner, except to illustrate *how* load lines work. My follow-up question to you is this: where would plotting a load line actually be helpful in analyzing circuit behavior? Can you think of any modifications to this two-resistor circuit that would require load line analysis in order to solve for current?

Answer 31

The two lines intersect at a current of approximately 1.72 mA:

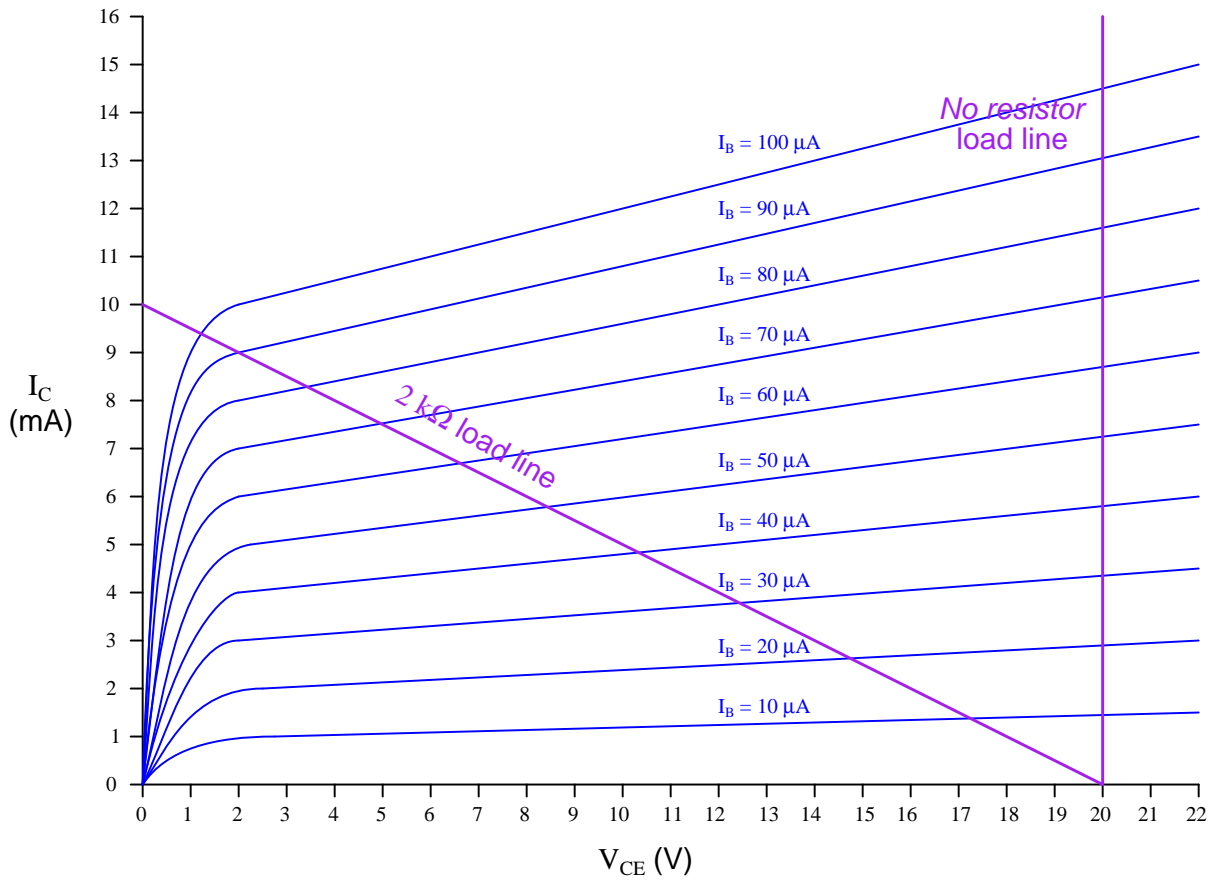


A “load line” describes how much voltage is available to power a transistor for any given amount of collector current:



Note: the amount of load resistance suggested by the load line in the above graph is 2.67 k Ω .

The two load lines are shown here, superimposed on the same characteristic curve graph:



No load resistor

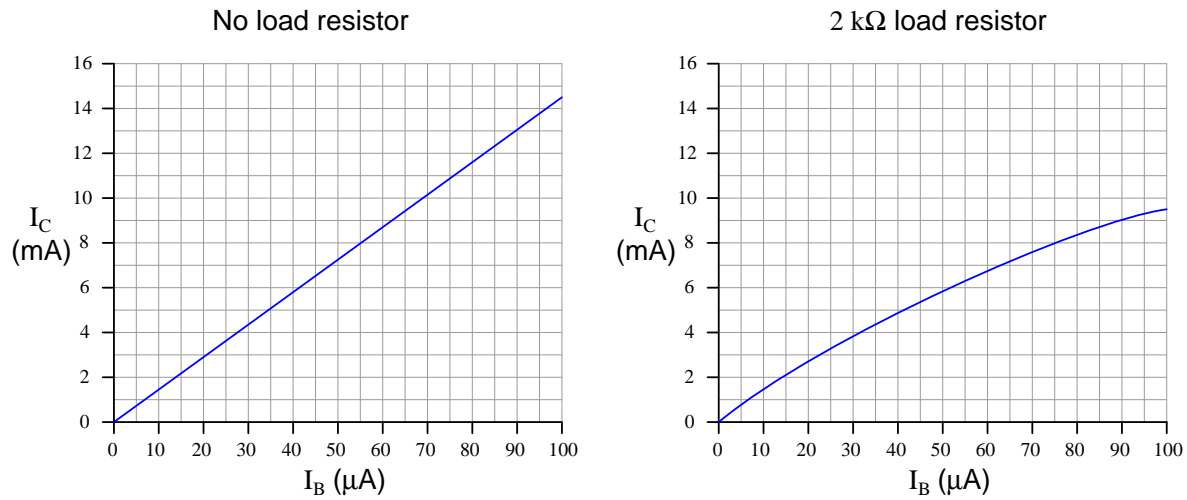
I_B	I_C
10 μA	1.4 mA
20 μA	2.9 mA
30 μA	4.4 mA
40 μA	5.8 mA
50 μA	7.25 mA
60 μA	8.7 mA
70 μA	10.1 mA
80 μA	11.6 mA
90 μA	13.1 mA
100 μA	14.5 mA

2 k Ω load resistor

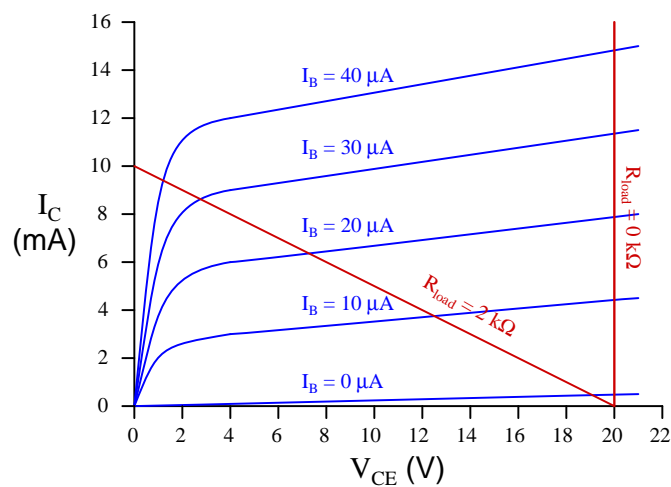
I_B	I_C
10 μA	1.4 mA
20 μA	2.6 mA
30 μA	3.75 mA
40 μA	4.8 mA
50 μA	5.75 mA
60 μA	6.7 mA
70 μA	7.5 mA
80 μA	8.25 mA
90 μA	9 mA
100 μA	9.4 mA

The analogous quantities between the transistor circuit and the control valve installation are as follows:

- Base current = C_v value, which is directly proportional to stem position for a linear control valve trim
- Collector current = flow (Q) through the valve
- Collector-emitter voltage = pressure drop ($P_1 - P_2$) across the valve
- Collector resistor (load) value = pressure losses due to flow through pipes, exchangers, pumps, etc.

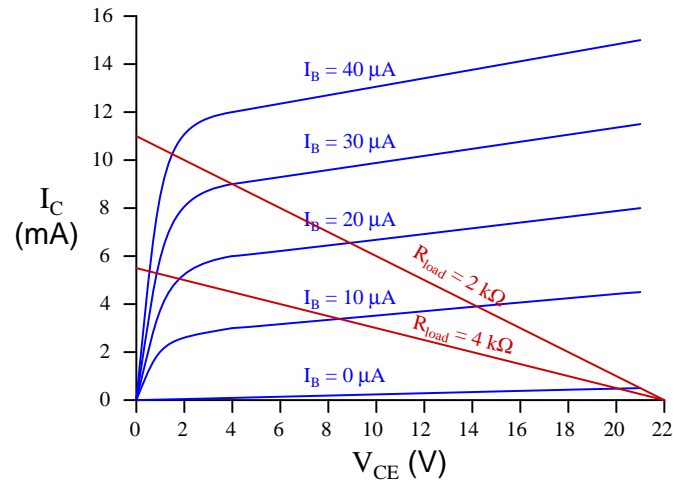


Superimposing a linear function on top of a set of nonlinear functions and looking for the intersection points allows us to solve for multiple variables in a nonlinear mathematical system. Normally, only *linear* systems of equations are considered “solvable” without resorting to very time-consuming arithmetic computations, but here we have a powerful (graphical) tool for approximating the values of variables in a nonlinear system. Since approximations are the best we can hope for in transistor circuits anyway, this is good enough!



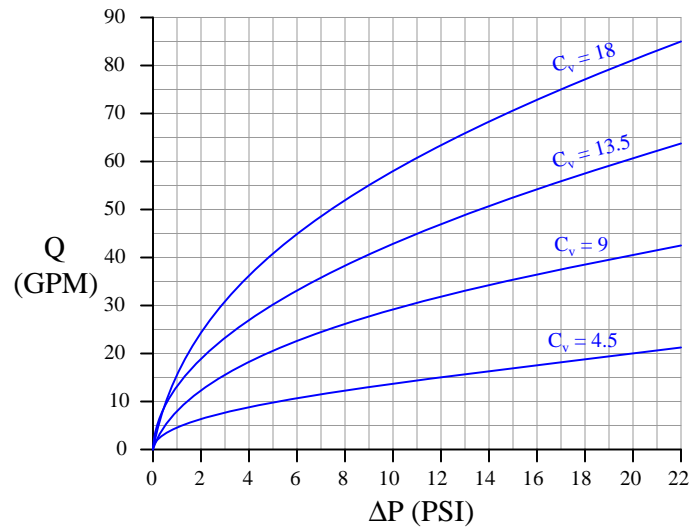
Base current (I_B)	Collector current (I_C) $R_{load} = 2 \text{ k}\Omega$	Collector current (I_C) $R_{load} = 0 \text{ k}\Omega$
$0 \text{ }\mu\text{A}$	0.5 mA	0.5 mA
$10 \text{ }\mu\text{A}$	3.8 mA	4.4 mA
$20 \text{ }\mu\text{A}$	6.3 mA	7.9 mA
$30 \text{ }\mu\text{A}$	8.6 mA	11.4 mA
$40 \text{ }\mu\text{A}$	9.4 mA	14.8 mA

No load resistance yields the most linear I_C -versus- I_B response from the transistor, because it is here that the transistor receives a constant supply voltage (V_{CE}) across the entire operating range of the circuit. The presence of a load resistance reduces the voltage available to the transistor at higher current values.

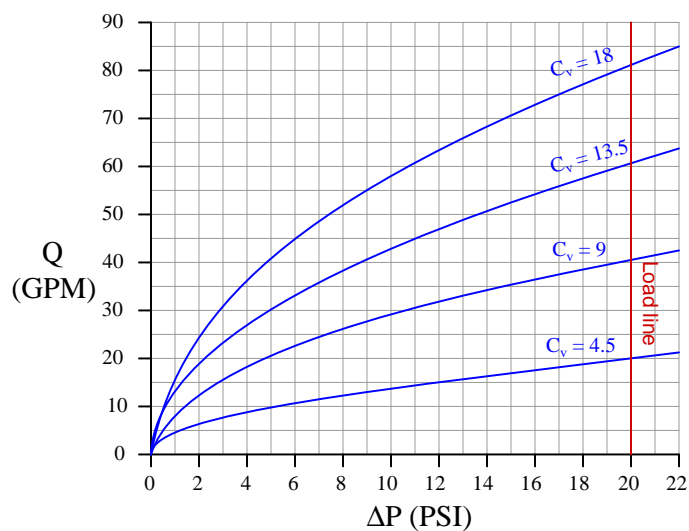


Base current (I_B)	Collector current (I_C) $R_{load} = 2 \text{ k}\Omega$	Collector current (I_C) $R_{load} = 4 \text{ k}\Omega$
$0 \text{ }\mu\text{A}$	0.5 mA	0.5 mA
$10 \text{ }\mu\text{A}$	3.9 mA	3.4 mA
$20 \text{ }\mu\text{A}$	6.5 mA	5.0 mA
$30 \text{ }\mu\text{A}$	9.0 mA	5.3 mA
$40 \text{ }\mu\text{A}$	10.2 mA	5.4 mA

Less load resistance yields the most linear I_C -versus- I_B response from the transistor, because it is with a lower load resistance that the voltage across the transistor (V_{CE}) is the most stable. Increased load resistance “starves” the transistor of voltage at higher current values.



Answer 37



Opening (%)	C_v	Flow rate (GPM)
0	0	0
25	4.5	20.1
50	9	40.2
75	13.5	60.4
100	18	80.5

Follow-up question: if we were to plot a graph of flow rate (Q) versus valve stem opening (%), would it be linear for this system? Explain why or why not.

Answer 38

Opening (%)	C_v	Flow rate (GPM)
0	0	0
25	4.5	19.4
50	9	38.1
75	13.5	53.8
100	18	67.5

Follow-up question: if we were to plot a graph of flow rate (Q) versus valve stem opening (%), would it be linear for this system? Explain why or why not.

Answer 39

Answer 40

Answer 41

Answer 42

Answer 43

Answer 44

Answer 45

Answer 46

Answer 47

Answer 48

The new valve location raises absolute pressure at all points within the valve, ensuring the lowest pressure (P_{vc}) never drops below the water's vapor pressure. I will let you identify other solutions.

Answer 49

Here's a hint: calculate the *differential pressure* across the valve for each flow rate, then determine how stable that ΔP is.

Answer 50

Here is a comprehensive list of faults, each one individually capable of accounting for the symptom (no light) and the measurement of 24 volts between **C** and **D**:

- Lamp burned out (failed open)
- Wire failed open between **A** and **C**
- Wire failed open between **B** and **D**

Based on this short list of possible faults – assuming only *one* of them is actually true – the value of each proposed test is as follows:

Diagnostic test	Yes	No
Measure V_{CF}		✓
Measure V_{ED}		✓
Measure V_{AB}	✓	
Measure V_{AD}	✓	
Measure V_{CB}	✓	
Measure V_{EF}		✓
Measure current through wire connecting A and C		✓
Jumper A and C together	✓	
Jumper B and D together	✓	
Jumper A and B together		✓

A good rule to apply when evaluating proposed tests is to ask the question: “Will this test give me the exact same result no matter which one of the possible faults is true?” If so, the test is useless. If not (i.e. the results would differ depending on which of the possible faults was true), then the test has value because it will help narrow the field of possibilities.

Answer 51

Rangeability of a measuring instrument refers to the fraction of full-scale process measurement may be made within the advertised accuracy. In reference to a control valve, “rangeability” refers to the fraction or ratio of full flow that the process fluid flow rate may be reliably controlled to.

Rangeability is important because it limits the practical working range of a process flow system. If a valve has insufficient rangeability, the process flow rate may not be “turned down” very much from full flow and still be able to maintain good-quality control.

Equal percentage valve characterization exhibits the best rangeability, because this opening characteristic maintains the finest degree of control toward the lower end of the valve’s stroke than any of the others.

Contrast the performance of an equal percentage valve with one that is quick opening, at low position settings: the quick opening valve will be very sensitive to stem/shaft position at the low end (very small movements resulting in large flow changes), while the equal percentage valve will retain good control characteristics toward the bottom end of its range. This is even more true in process systems with large amounts of characteristic “distortion” (resulting from large changes in valve ΔP over the flow range), where all inherent valve characteristics tend to be “bent” toward the quick-opening characteristic.

Answer 52

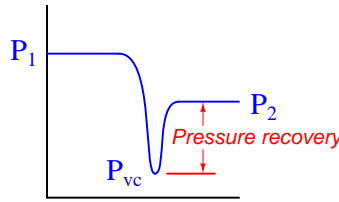
Choked flow is when the flow rate through a control valve “saturates” such that further decreases in downstream pressure do not result in any additional flow:

- Phase change (flashing) in liquid flows
- Sonic velocities in gas flows

I will let you figure out how F_L relates to choked flow.

Pressure recovery is the pressure difference between the outlet pressure (P_2) and vena contracta pressure (P_{vc}):

$$\text{Pressure recovery} = P_2 - P_{vc}$$



Pressure recovery factor is calculated by dividing the permanent pressure drop by the pressure drop from inlet (P_1) to the vena contracta (P_{vc}):

$$F_L = \sqrt{\frac{P_1 - P_2}{P_1 - P_{vc}}}$$

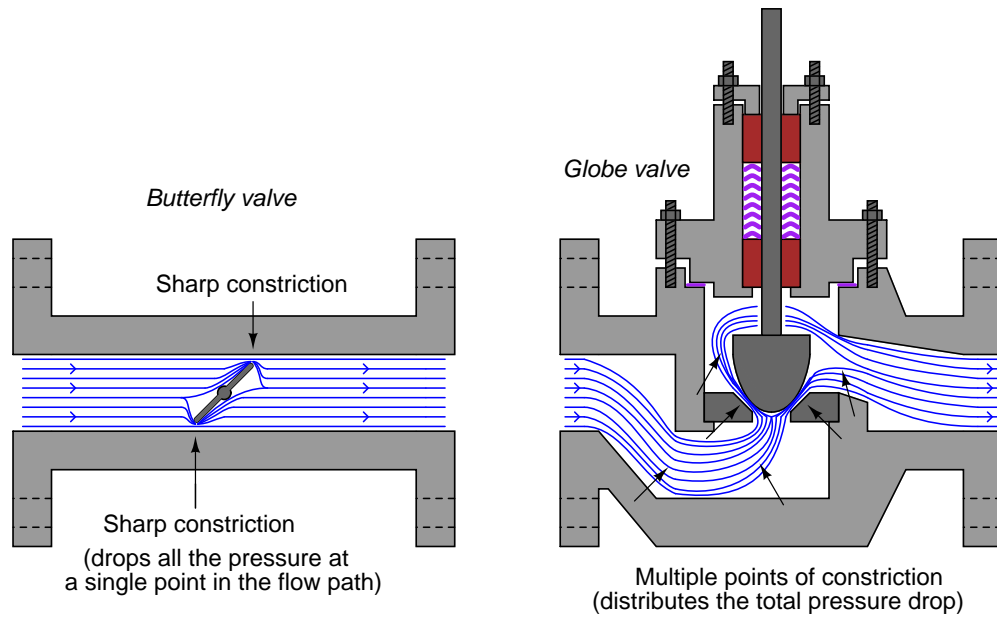
Based on this definition, valve #1 has the greatest pressure recovery and the lowest F_L , making it the most prone to cavitation. To avoid or reduce cavitation, it is best to use a control valve with low pressure recovery (a high F_L factor). Rotary valve designs such as ball, disk, and butterfly valves typically have greater pressure recovery (lower F_L figures) than globe valves, making them more prone to cavitation.

Ironically, control valves with low pressure recovery have high F_L values. Conversely, valves with high pressure recovery have low F_L values. To avoid or reduce cavitation, it is best to use a control valve with low pressure recovery (a large F_L factor). All other factors being equal (upstream and downstream pressures, flow rate, specific gravity, etc.), a valve with a large F_L will have a greater vena contracta pressure (P_{vc}) than a valve with a small F_L .

Rotary valve designs (ball, disk, butterfly, etc.) typically have greater pressure recovery (smaller F_L figures) than globe valves, making them more prone to cavitation. The reason for this greater pressure recovery is the relatively straight and wide flow path through a rotary valve body before and after the throttling element. Globe valves, with their more tortuous flow paths, drop more pressure along the whole valve body. As a result, the plug/seat opening in a globe valve does not have to do *all* the work of dropping process fluid pressure.

For the same total pressure drop ($P_1 - P_2$), a globe valve's trim will drop less pressure than a rotary valve's trim of comparable C_v . This results in a greater vena contracta pressure (P_{vc}) inside the globe valve, making it less prone to flashing and cavitation than a comparable rotary valve.

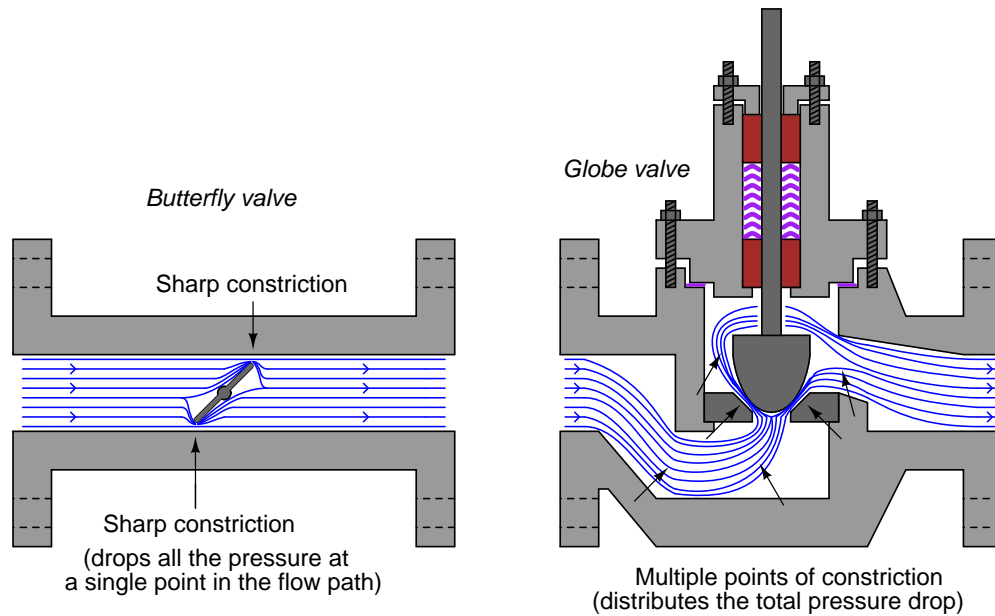
The following illustration shows the difference in flow paths between a butterfly valve and a globe valve. You can see here how the globe valve design does not rely on the plug/seat restriction to be the *only* point of pressure drop as is the case with the butterfly design:



F_L changes with valve stem position, just like C_v . For high- F_L valves such as globe valves, the amount of F_L change throughout the valve's travel is slight. For low- F_L valves such as butterfly valves, the amount of F_L change is much greater from fully open to fully shut.

Valve trim designed to reduce cavitation typically achieves very high (near-unity) F_L values. For Fisher's Cavitrol trim, the advertised F_L value for two-stage trim is 0.98, and for three-stage trim it is 0.99, which means P_{vc} is very nearly equal to P_2 (downstream).

Follow-up question: examine the following illustrations and then explain *why* rotary valve designs such as butterfly and ball valves tend to have lower F_L values than comparably-sized globe valves:



Answer 54

The answer to this question (no, I'm not going to just give it away!) relates to the physics of heated, pressurized water. What happens to a pressurized liquid when it is released into the atmosphere, if the temperature of that liquid is well above its boiling point at atmospheric pressure?

Answer 55

I won't give away the answer here, as the analogy contains enough details. If you need additional help, consult a control valve reference manual on the subjects of "installed characteristic" and "distortion."

Another analogy to help you understand how equal-percentage valves work, which is more closely related to control valves than audio amplifiers, is square-root extraction for head-based flow instruments. When measuring fluid flow by means of energy-exchanging primary elements such as orifice plates, venturi tubes, and pitot tubes, we must "square-root" the differential pressure measurement in order to change it into a flow measurement. In other words, we overcome one nonlinearity with a complementary nonlinearity: one that "un-does" the first to yield a final result that is linear.

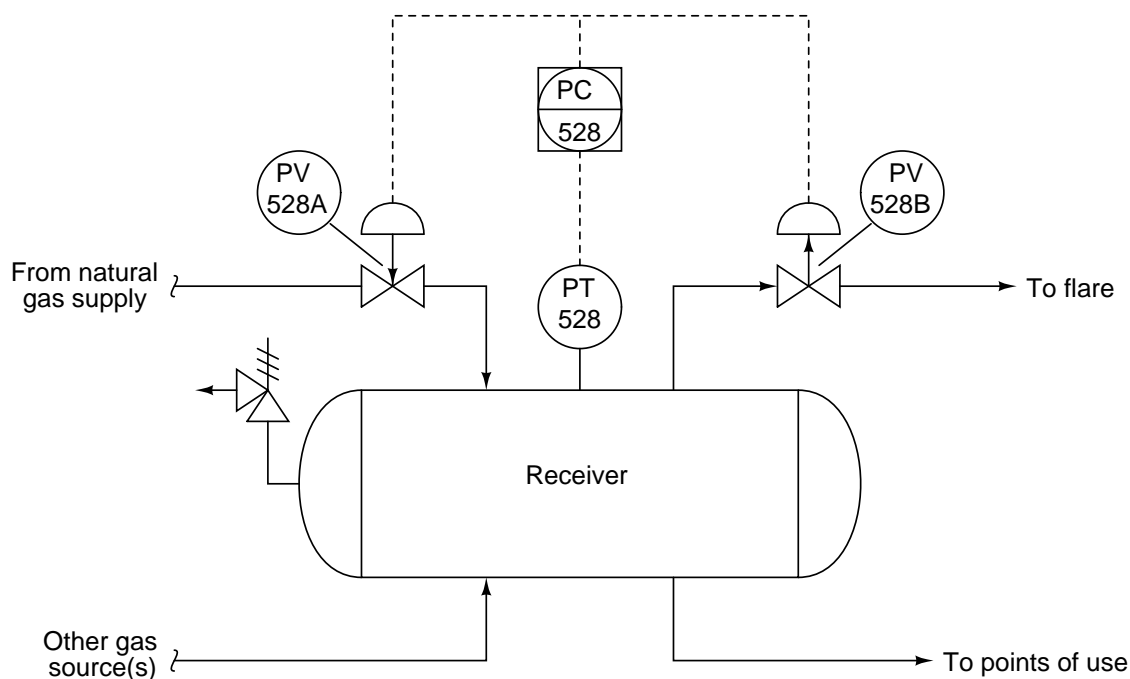
Answer 56

$F = 51.07$ pounds of force, downward (holding the cover onto the flange).

Although the eductor's suction will in fact hinder the pumps' ability to move liquid out of the sump to treatment, the effect will be minimal since 2 inches WC is tiny compared to the rated head (pressure) of the pumps at 40 feet WC.

- Begin by slowly opening the bypass valve until either PG-16 or PG-17 begins to register a rise in pressure. This tells you the pressure regulator PCV-105 is completely bypassed, with all natural gas passing through the hand-actuated bypass valve instead of PCV-105.
- Shut the block valves in any order.
- Open the bleed valve to de-pressurize the regulator.
- Place safety tags on all block and bleed valves to ensure no one turns them while the pressure regulator is removed from the piping.
- An operator needs to keep watch over the downstream pressure, turning the hand-actuated bypass valve as necessary to maintain proper gas pressure to the furnace.

Although the loop sheet shows no other gas sources entering the vessel or gas loads drawing from the vessel, the presence of split-ranged make-up and vent control valves implies the existence of these other lines:



Possible faults accounting for excessive pressure in the receiver vessel include:

- PT low calibration error
- PC left in manual mode (with demand less than supply)
- Analog output card AO 528A failed with high signal
- Analog output card AO 528B failed with low signal (with demand less than supply)
- Open or shorted wiring fault anywhere between AO 528B and PV-528B

Answer 59

Positioners may be intentionally made non-linear, so that the valve stem (or shaft) position is not linearly related to the control signal as it would normally be. Through the use of specially shaped cams and other mechanical components in the positioner's feedback mechanism, virtually any type of opening characteristic may be obtained from a single type of trim.

This does not mean, though, that *accurate* equal percentage opening characteristics may be obtained from a valve trim that is inherently quick opening. Because the positioner would have to move a quick-opening valve mechanism with supreme precision at the bottom end of its range in order to duplicate an equal percentage characteristic (to force an aggressively-opening valve to open gently instead as the control signal increases), this methodology cannot guarantee good accuracy throughout a valve's operating range. However, it does have the distinct advantage of allowing changes in a valve's opening characteristic without having to disassemble the valve or remove it from the piping!

Answer 60

Answer 61

Answer 62

- 25 PSIA = 1.701 atm
- 340 "W.C. = 26.983 PSIA
- 0.73 bar (gauge) = 21.557 "Hg
- 5.5 atm = 4,180 torr
- 2,300 cm Hg = 12,717.72 "W.C.A
- 500 m torr = 0.0096683 PSIA
- 91.2 cm W.C. = 8.9434 kPa
- 110 kPa = 441.62 "W.C.
- 620 mm HgA = 620 torr (*A "trick" question . . .*)
- 77 Pa = 14.711168 PSIA
- 1 atm = 406.91 "W.C.A
- 270 PSIA = 18.367 atm

Answer 63

- Hand lever is moved from the "stop" position to the "run" position ; return flow **decreases**.
- Hand lever is moved from the "run" position to the "stop" position ; return flow **increases**.
- While running, the hydraulic motor encounters a heavier mechanical load ; return flow **increases**, but only if the pressure has risen to its maximum value. Otherwise, the return flow will **stay the same** at zero.
- With the hydraulic motor stopped, the pump speed is decreased ; return flow **decreases**.

Answer 64

$$Q = 319.3 \text{ GPM}$$

Answer 65

If you calculated $C_v = 0.30248$, you made a serious mistake!

Hint: this is a “trick” question, to determine whether you are really thinking about the dynamics of gas flow, or just plugging numbers into equations. If you were to actually install a valve with a C_v rating of 0.30248 into this process, the resulting flow would be *much less* than 50,000 SCFH.

Answer 66

The problem is likely *not* with any of the instruments!

Answer 67

Fault	Possible	Impossible
Fuse F3 blown (failed open)		✓
Solenoid coil failed open		✓
“Open” switch contacts (L to M) failed open		✓
“Close” switch contacts (J to K) failed shorted	✓	
Relay coil failed shorted		✓
Relay contact (G to P) failed shorted		✓
Relay contact (F to N) failed shorted		✓
Wire open between terminals K and D		✓
Valve V1 shut	?	
Valve V2 shut		✓

In order for a “shut” V1 to account for the control valve remaining open all the time, that hand valve would have had to be shut while the system was in a very particular condition! Simply shutting V1 under *any* condition(s) would not necessarily produce this effect.

A good “next test” would be to measure voltage between terminals Q and R on the solenoid.

Answer 68

You may locate the `grades_template` on the Y: network drive at BTC, provided you log in to the computer system using your individual student ID and password (not a generic login such as “btc”). It is also available for download at the *Socratic Instrumentation* website.

Answer 69

The fluid pressure will be 12.575 PSI, and cylinder #1’s piston force will be 88.889 pounds.

Piston #1 will travel further than piston #2.

Answer 70

Answer 71

$Q = 24,634.9$ SCFH

Answer 72

$C_v = \underline{\mathbf{0.5257}}$

Nominal pipe size = 1/4 inch (0.235 inches calculated)

Answer 73

This valve clearly experiences more friction as the plug nears the seat. If this is a cage-guided globe valve, I would suggest looking for interference between the piston and cage resulting from mis-alignment of the parts or poor machining. Another possibility is stem friction against the packing at that same (nearly-closed to closed) position.

Answer 74

Answer 75

Answer 76

Answer 77

Answer 78

Answer 79

Answer 80

Answer 81

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

Answer 82

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

Answer 83

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

Answer 84

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

Answer 85

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

Answer 86

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

Answer 87

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

Answer 88

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

Answer 89

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

Answer 90

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

Answer 91

Answer 92

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

Answer 93

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