INST 250 (Final Control Elements), section 2

Lab

Control valve rebuild and bench-set: *Questions 91 and 92*, **completed objectives due by the end of day 5**

Exam

Day 5 – only a simple calculator may be used! **Complete mastery of these objectives due by the next exam date**

Specific objectives for the "mastery" exam:

- Electricity Review: Calculate and annotate voltages and currents in a DC series-parallel resistor circuit given source and resistor values
- Determine response of a pneumatic force-balance mechanism to different conditions
- Determine the effect of a fault in a solenoid-controlled valve system
- Calculate instrument input and output values given calibrated ranges
- Solve for a specified variable in an algebraic formula
- Determine the possibility of suggested faults in a simple circuit given measured values (voltage, current), a schematic diagram, and reported symptoms
- Motor/relay/3phase/PLC Review: Determine status of a relay logic circuit given a schematic diagram and switch stimulus conditions
- INST241 Review: Identify (American) wire colors for different thermocouple types
- INST262 Review: Identify specific instrument calibration errors (zero, span, linearity, hysteresis) from data in an "As-Found" table

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Recommended daily schedule

Day 1

Theory session topic: Pneumatic instruments (continued)

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

Day 2

Theory session topic: Solenoid valves

Questions 21 through 40; answer questions 21-30 in preparation for discussion (remainder for practice)

Day 3

Theory session topic: Valve failure modes and packing systems

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

Day 4

Theory session topic: Review for exam (site visit)

Questions 61 through 80; answer questions 61-63 in preparation for discussion at an industrial site specified by your instructor. (All remaining questions for practice)

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

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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.

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

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

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

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

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

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

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

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

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

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

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

<u>file `expectations`</u>

#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)

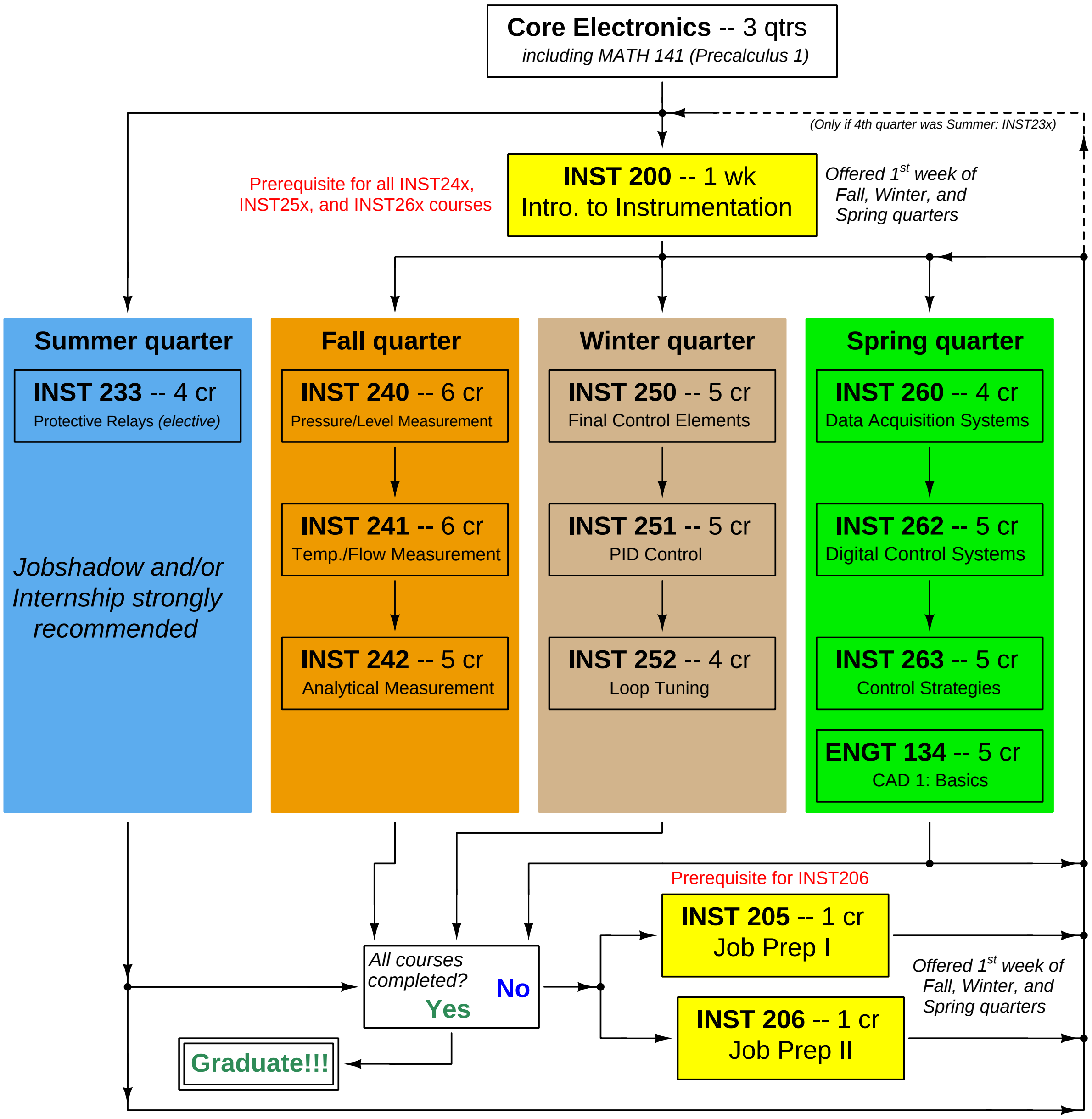
- Calculate and annotate voltages and currents in a DC series-parallel circuit. [Ref: Program Learning Outcome #4]
- Calculate voltages, currents, powers, and/or resistances in a DC series-parallel circuit. [Ref: Program Learning Outcome #4]
- Determine response of a pneumatic force-balance mechanism 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]

file `outcomes_INST250`

Sequence of second-year Instrumentation courses



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

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

Possible course schedules depending on date of entry into 2nd year

file sequence

General tool and supply list

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

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

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

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

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

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

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

file `tools`

Methods of instruction

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

Inverted theory sessions

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

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

Small sessions

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

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

Large sessions

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

Correspondence

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

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

Sample rubric for pre-assessments

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

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

Sample rubric for post-assessments

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

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

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

Lab sessions

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

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

Troubleshooting assessments must meet the following guidelines:

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

Distance delivery methods

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

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

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

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

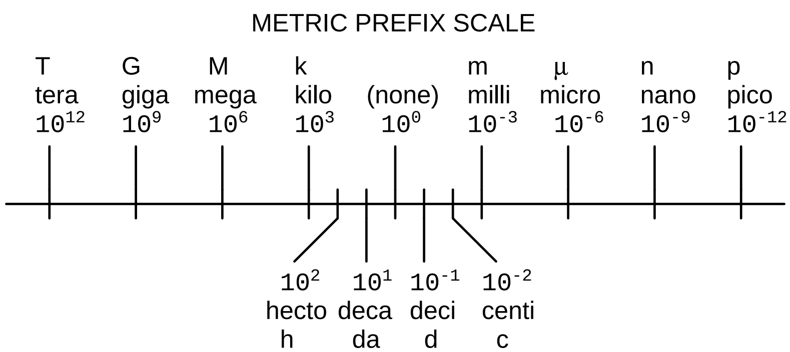
Labwork is perhaps the most difficult portion of the curriculum for a "distance" student to complete, since the equipment used in Instrumentation is typically too large and expensive to leave the school lab facility. "Distance" students must find a way to complete the required lab activities, either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

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

file `distance`

Metric prefixes and conversion constants

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



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

Conversion equivalencies for distance

1 inch (in) = 2.540000 centimeter (cm)

1 foot (ft) = 12 inches (in)

1 yard (yd) = 3 feet (ft)

1 mile (mi) = 5280 feet (ft)

Conversion equivalencies for volume

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

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

Conversion equivalencies for velocity

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

Conversion equivalencies for mass

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

Conversion equivalencies for force

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

Conversion equivalencies for area

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

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

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

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

Conversion equivalencies for absolute pressure units (only)

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

Conversion equivalencies for energy or work

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

Conversion equivalencies for power

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

Acceleration of gravity (free fall), Earth standard

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

Physical constants

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

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

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

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

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

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

Properties of Water

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

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

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

Specific heat of water at 14^oC = 1.00002 calories/g$\cdot^o$C = 1 BTU/lb$\cdot^o$F = 4.1869 Joules/g$\cdot^o$C

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

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

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

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

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

Properties of Dry Air at sea level

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

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

file `conversion_constants`

Question 0

How to get the most out of academic reading:

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

How to effectively problem-solve and troubleshoot:

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

How to manage your time:

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

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

file `question0`

Checklist when reading an instructional text

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

Francis Bacon's advice provides a blueprint for effective education: reading provides the learner with knowledge, writing focuses the learner's thoughts, and critical dialogue equips the learner to confidently communicate and apply what they have learned. The ability to independently acquire and apply knowledge is a powerful skill, well worth the effort to attain. To this end, students should read these educational resources closely, write their own outline and reflections on the reading, and discuss in detail their new knowledge with classmates and instructor(s). You should be able to do all of the following after reading an instructional text:

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

$\boxed{\surd}$ Demonstrate ACTIVE READING STRATEGIES, including verbalizing your thoughts as you read, simplifying long sentences to convey the same ideas using fewer words, annotating text and illustrations with your own thoughts, working through mathematical examples shown in the text, cross-referencing passages with relevant illustrations and/or other passages, identifying problem-solving strategies applied by the author, etc. The purpose of these strategies is to clarify the text and develop metacognition: the habit of monitoring your own thoughts.

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

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

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

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

General challenges following a tutorial reading assignment

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

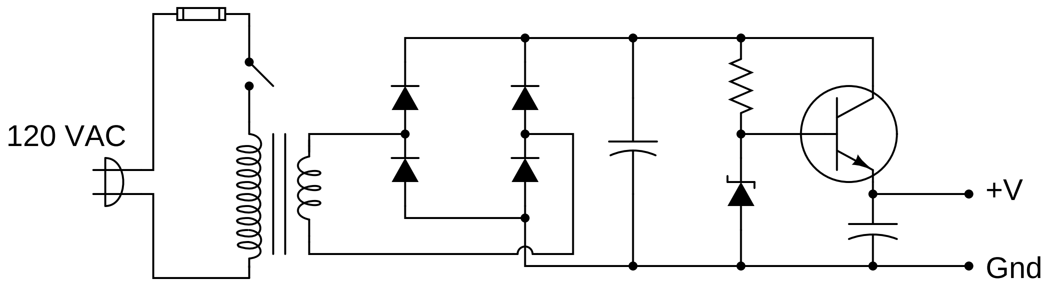
General follow-up challenges for assigned problems

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

file `license`

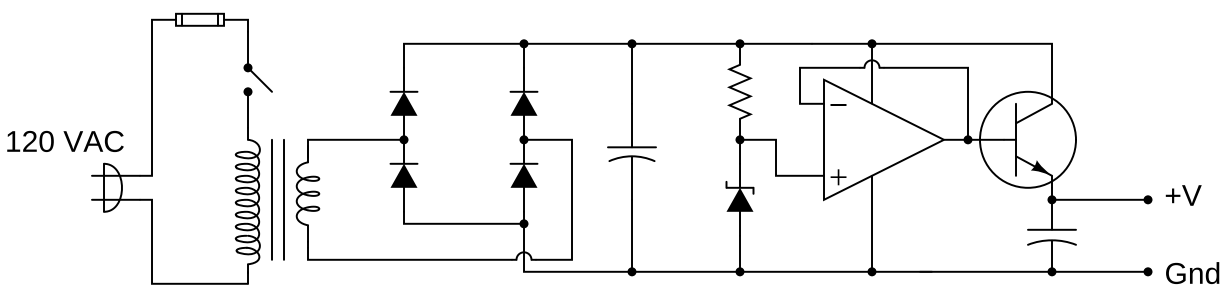
Question 1

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



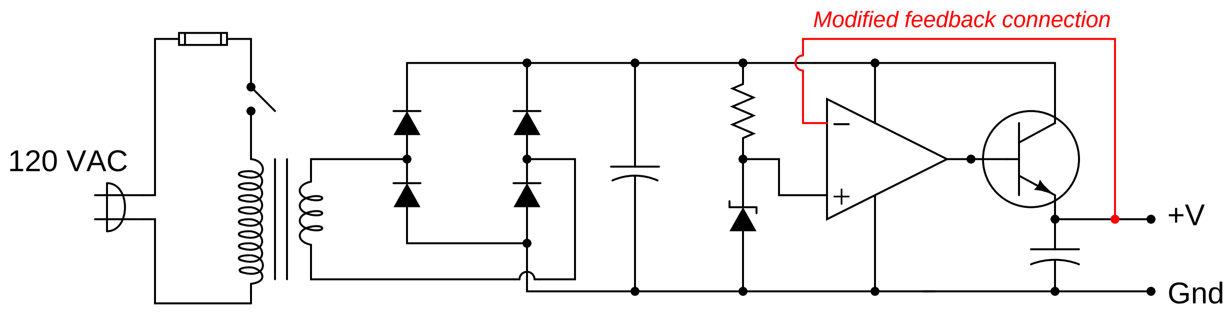
The voltage regulation is not as good as the student hoped. When loaded, the output voltage "sags" more than the student wants. When the zener diode's voltage is measured under the same conditions (unloaded output, versus loaded output), its voltage is noted to sag a bit as well. The student realizes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

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



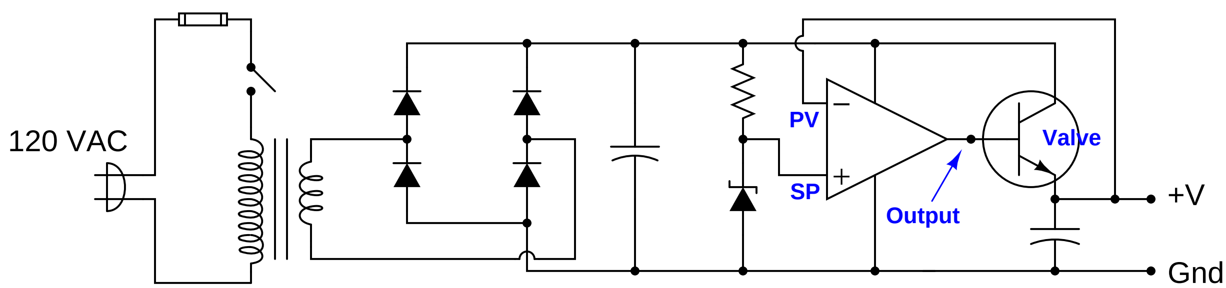
Now the zener diode is effectively isolated from the loading effects of the transistor, and by extension from the output load as well. The opamp simply takes the zener's voltage and reproduces it at the transistor base, delivering as much current to the transistor as necessary without imposing any additional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

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



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

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



Suggestions for Socratic discussion

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

file i01473

Question 2

Read and outline the "Analogy to Opamp Circuits" section of the "Pneumatic Instrumentation" chapter in your *Lessons In Industrial Instrumentation* textbook.

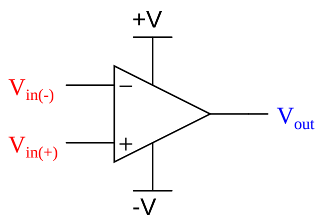
After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

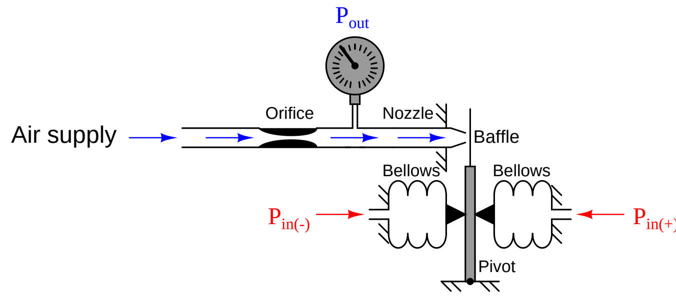
(1) Your written summary of all major points of the text, expressed as simply as possible in your own words.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations 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 i03930

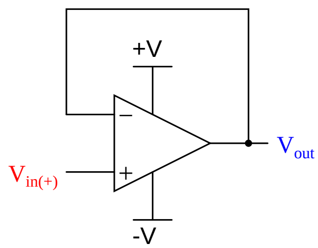
Question 3

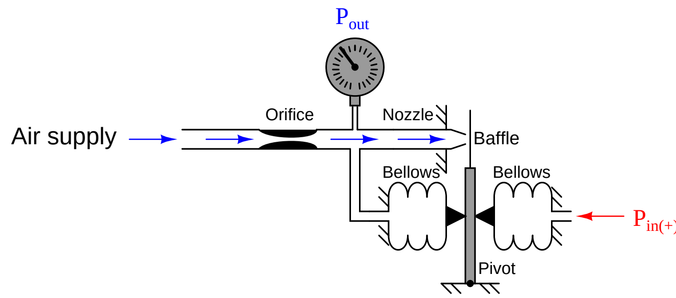
Explain how the following systems (analog electronic versus pneumatic) are similar in their behavior:





Explain how the following systems (analog electronic versus pneumatic) are similar in their behavior:





Further exploration . . . (optional)

Research the work of Harold Black in his patent ("Wave Translation System," U.S. Patent number 2,102,671 filed in 1932 and granted in 1937), when he applied the principle of *negative feedback* to the design of telephone amplifier circuits. How well was this novel concept accepted by the professional community?

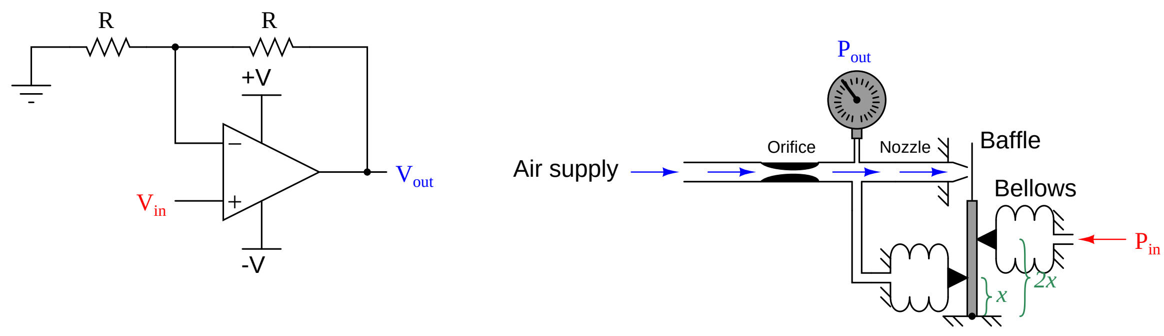
Suggestions for Socratic discussion

- Feedback systems are highly non-intuitive, and therefore cause much grief for students learning to master them. Discuss how to use "thought experiments" to help better understand the operation of a feedback system, whether it be an operational amplifier circuit or a pneumatic mechanism.
- In general terms, what does the addition of negative feedback do to the over-all *gain* of a system?
- What practical uses might we find for each of these circuits (and pneumatic systems)?
- Modify the lower circuit and lower mechanism so that both of them have *adjustable gains*.
- What would happen to the self-balancing pneumatic mechanism if the tube between the gauge and the nozzle were to develop a small leak (smaller than the nozzle bore itself)?
- What would happen to the self-balancing pneumatic mechanism if the tube between the gauge and the nozzle were to develop a large leak (equal to or greater than the nozzle bore itself)?

file i03928

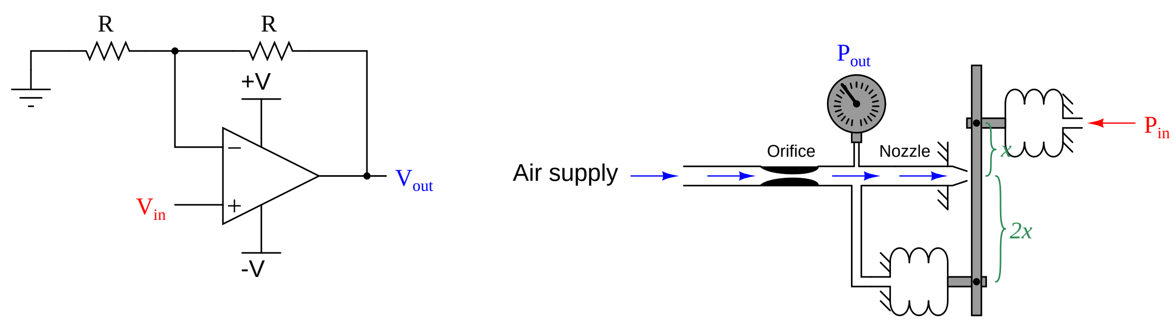
Question 4

Explain how the following systems (analog electronic versus pneumatic) are similar in their behavior:



Calculate V_{out} if $V_{in} = 3.4$ volts. Calculate P_{out} if $P_{in} = 3.4$ PSI. Is the pneumatic system a *motion-balance* or a *force-balance* mechanism?

Explain how the following systems (analog electronic versus pneumatic) are similar in their behavior:



Calculate V_{out} if $V_{in} = 5.1$ volts. Calculate P_{out} if $P_{in} = 5.1$ PSI. Is the pneumatic system a *motion-balance* or a *force-balance* mechanism?

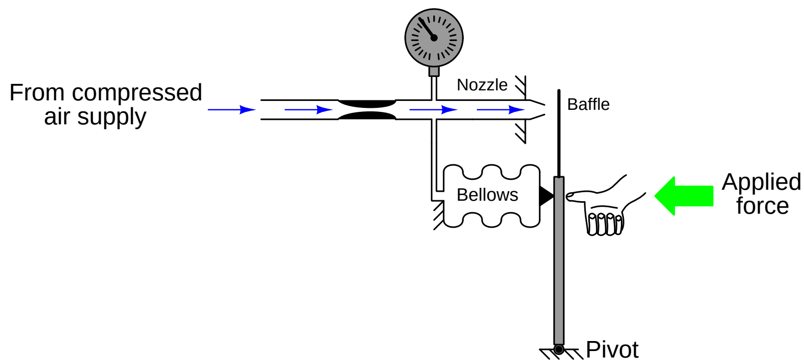
Suggestions for Socratic discussion

- The distinction between force-balance and motion-balance is one that tends to confuse students. A common tactical error students make is to attempt to memorize distinguishing characteristics in order to identify what type of balancing a particular mechanism employs. A better approach is to *think through* the operation of such pneumatic mechanisms using "thought experiments" to identify which balance principle they employ. Why do you think it is bad to go with the memorization approach instead of the "thought experiment" approach?
- To many students, the 2:1 lever lengths in each example seem very confusing, because the lever lengths are opposite yet the gain in each case is identical. For instance, in the top example the feedback has only *half* the lever length as the input, yet in the bottom example the feedback has *twice* the lever length as the input, yet these two different mechanisms exhibit the same overall gain. How is this possible?
- What difference does it make to us (as technicians) to know whether a mechanism is force- or motion-balance? In other words, who cares???

file i03929

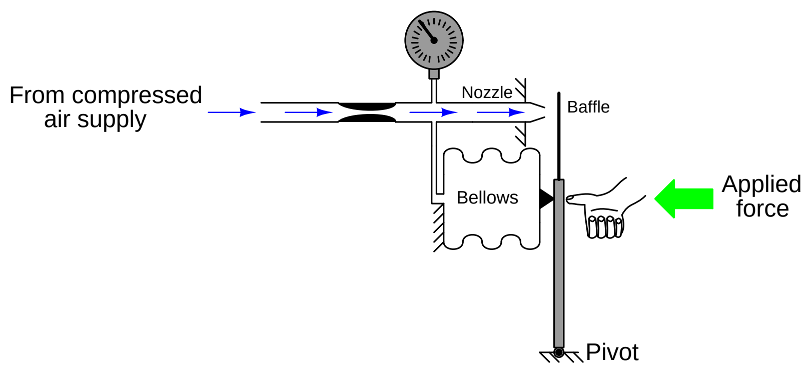
Question 5

In the following baffle/nozzle system, the nozzle pressure is allowed to react against any external force by generating a force with a bellows unit, to push the baffle away from the nozzle. The particular bellows in this mechanism is designed to be "slack," having little spring effect to self-restrain its motion. Whatever force generated by the pressure acting against the bellows' surface area gets directly transferred to the lever:



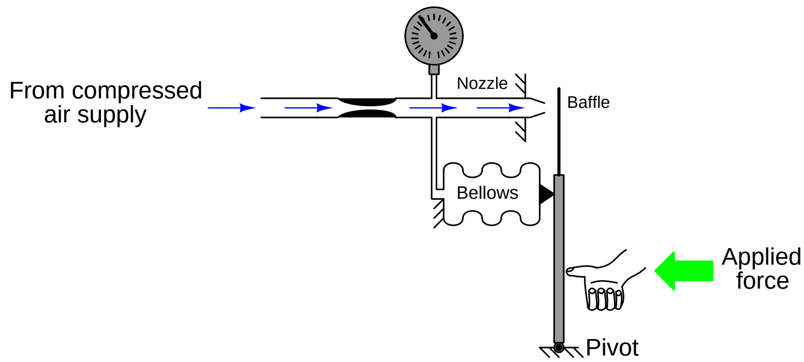
What will happen in this system if someone pushes the lever toward the nozzle with their thumb? Explain every step in your reasoning – don't just describe a final result!

Now, suppose we modify this system to have a bellows with a larger diameter:



What will happen in this system if someone pushes the lever toward the nozzle with the same amount of force as before (with the smaller bellows)? How will this system respond to the same stimulus? Again, explain every step in your reasoning – don't just describe a final result!

What will happen in this system if we were to take the original (smaller) bellows mechanism and push on it with the same force but at a position closer to the pivot point than the bellows? As usual, explain every step in your reasoning:



Suggestions for Socratic discussion

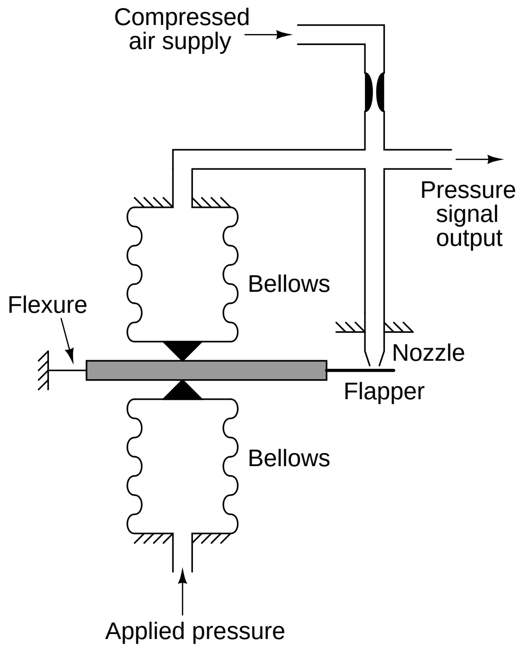
- Explain, in simple terms, what effect bellows size has on the *gain* of the system, and why.
- Suppose the compressed air supply pressure was 10 PSI in both cases. If this supply pressure were to drop to a lower value such as 8 PSI, what effect (if any) would this have on the gauge pressure in each scenario as the system responds to the same amount of applied force? Why or why not?
- Determine whether or not the output pressure would rise to the same level with force applied to the lever if the air supply was cut off (and the supply tube plugged so that air could not leak out).
- A common misconception among students first analyzing these mechanisms is that the output pressure is being generated by the bellows: that is to say, that the action of *collapsing* the bellows by the force of the hand is what makes the air inside become compressed. Explain why this is a misconception, and further explain how and why the resulting pressure arises.

file i00200

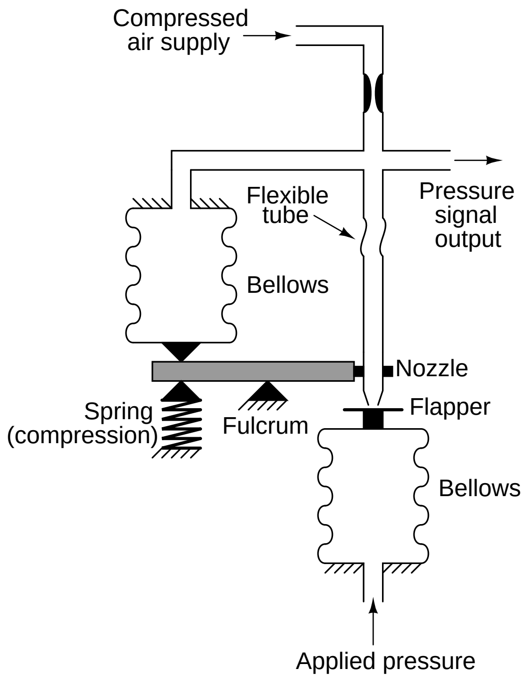
Question 6

Explain how each of the following pressure instruments works, identifying whether each one uses the principle of *motion-balance* or the principle of *force-balance*. Please note that a series of angled lines projecting from a vertical or horizontal line represents a point of anchoring, where that horizontal or vertical surface is stationary:

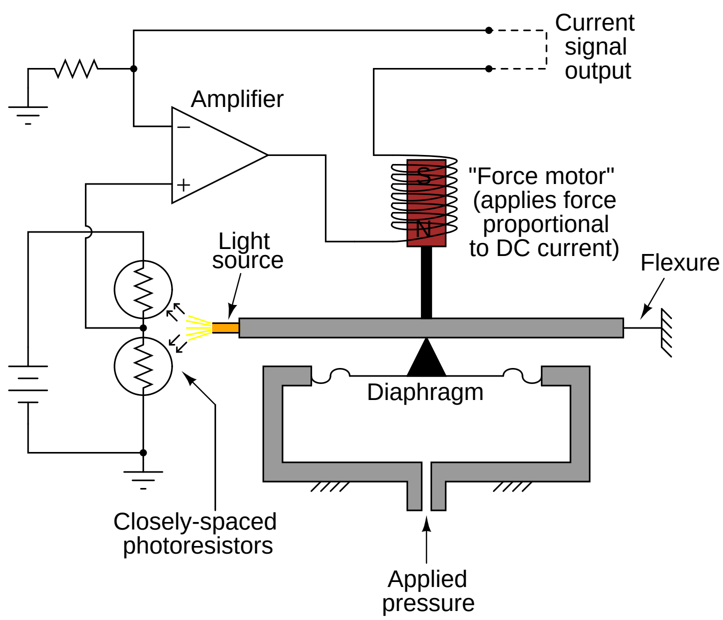
Example 1:



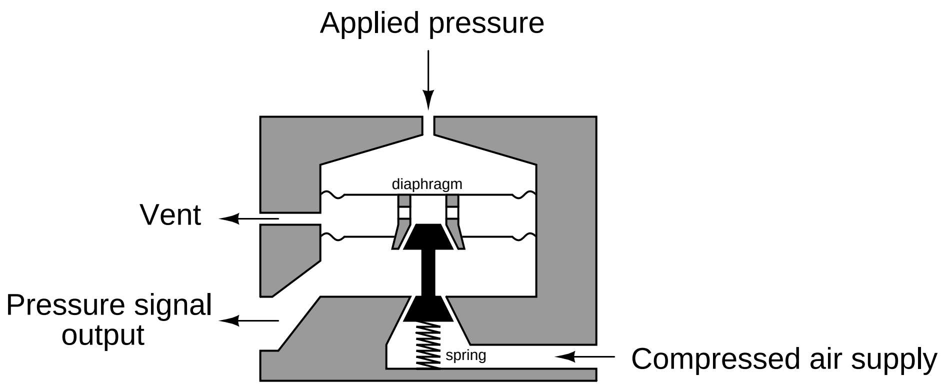
Example 2:



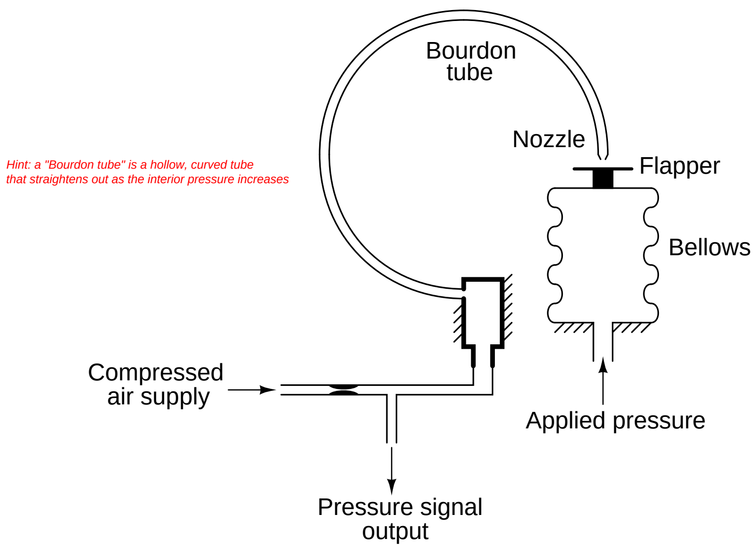
Example 3:



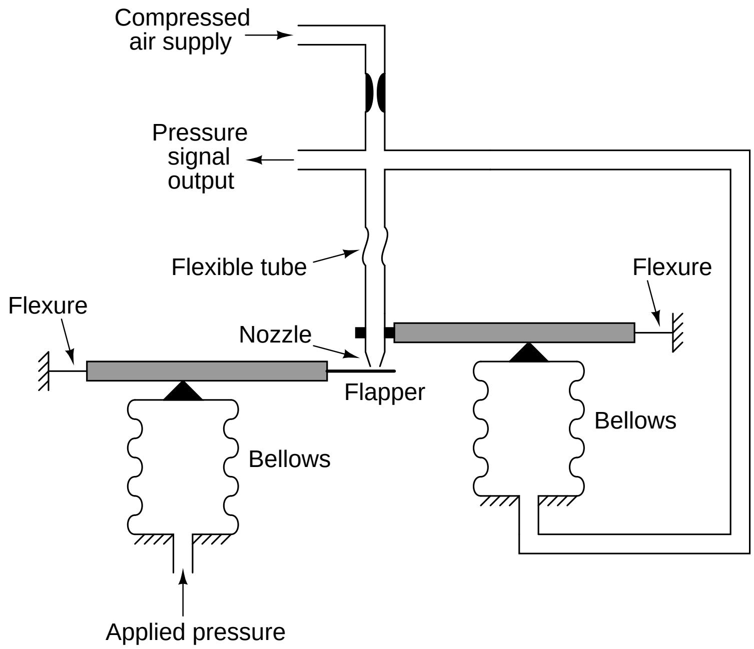
Example 4:



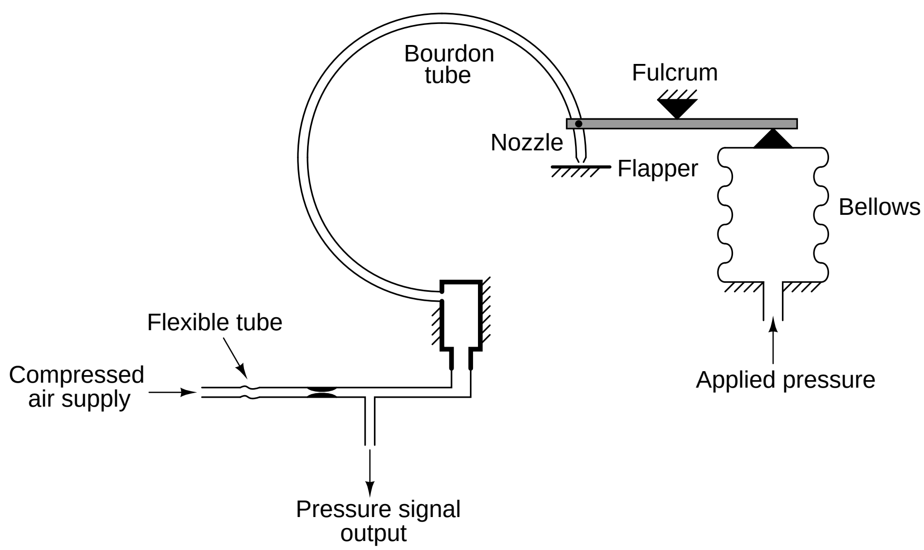
Example 5:



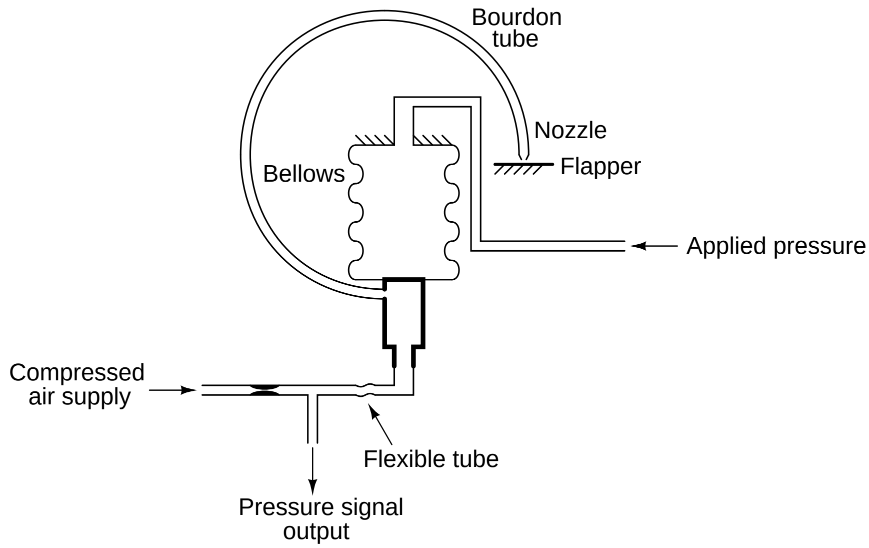
Example 6:



Example 7:

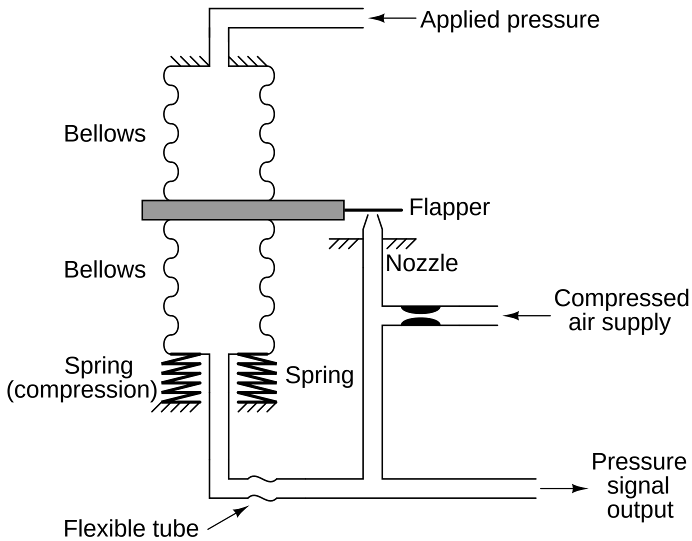


Example 8:



Bourdon tube
Nozzle
Flapper
Bellows
Applied pressure
Compressed air supply
Flexible tube
Pressure signal output

Example 9:



Suggestions for Socratic discussion

- The distinction between force-balance and motion-balance is one that tends to confuse students. A common tactical error students make is to attempt to memorize distinguishing characteristics in order to identify what type of balancing a particular mechanism employs. A better approach is to *think through* the operation of such pneumatic mechanisms using "thought experiments" to identify which balance principle they employ. Why do you think it is bad to go with the memorization approach instead of the "thought experiment" approach?
- What difference does it make to us (as technicians) to know whether a mechanism is force- or motion-balance? In other words, who cares???
- Identify changes that could be made to each mechanism in order to alter its *zero*.
- Identify changes that could be made to each mechanism in order to alter its *span*.
- An interesting "thought experiment" to run is to modify some aspect of the mechanism (e.g. stiffer spring, greater supply air pressure, relocating the orifice) and re-analyze that mechanism to see what effect(s) that change will have on its operation.

file i00208

Question 7

Read and outline the "Foxboro Model 13A Differential Pressure Transmitter" subsection of the "Analysis of Practical Pneumatic Instruments" section of the "Pneumatic Instrumentation" 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 i03931

Question 8

Read and outline the "Foxboro Model E69 'I/P' Electro-Pneumatic Transducer" subsection of the "Analysis of Practical Pneumatic Instruments" section of the "Pneumatic Instrumentation" 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.).
(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.

A video resource you may find helpful for understanding force-balance versus motion-balance I/P converter mechanisms may be found on BTC's YouTube channel (`www.youtube.com/BTCinstrumentation`).

file i03932

Question 9

Read and outline the "Fisher Model 546 'I/P' Electro-Pneumatic Transducer" subsection of the "Analysis of Practical Pneumatic Instruments" section of the "Pneumatic Instrumentation" 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.).
(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.

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file i03933

Question 10

Read the "Siemens model 61 Booster Relay" installation and service manual (document SD61, revision 7; originally a publication of the Moore Products company), and answer the following questions:

Identify how such a "volume-boosting" relay is used in conjunction with a pneumatically-actuated control valve.

Examine the cut-away drawing for the model 61F relay (page 7) and explain how it functions. Describe a "thought experiment" where the signal pressure increases, and the relay produces a matching output pressure.

The model 610F has a capability that the other models do not. Identify what this capability is, by examining the respective drawings (pages 6-8).

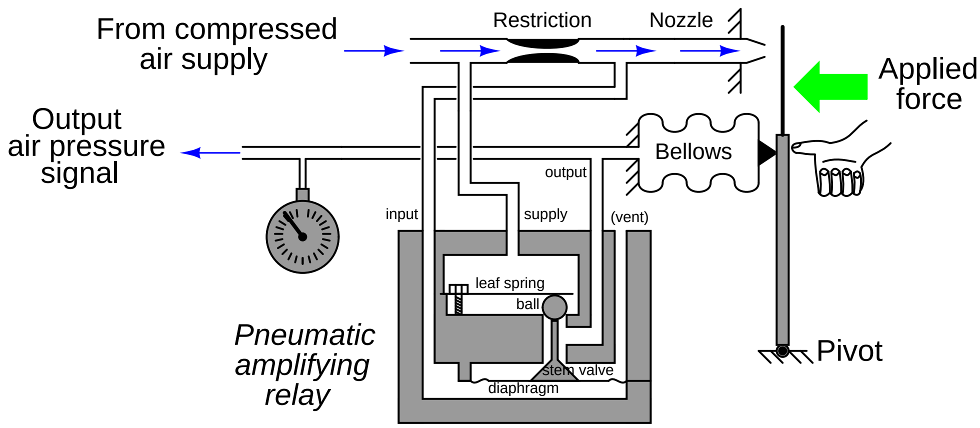
Suggestions for Socratic discussion

- Why would anyone use one of these booster relays in a control valve system?
- Devise a "thought experiment" to explain the operation of this pneumatic relay
- The model 610F relay has a special capability – what is that unique capability?

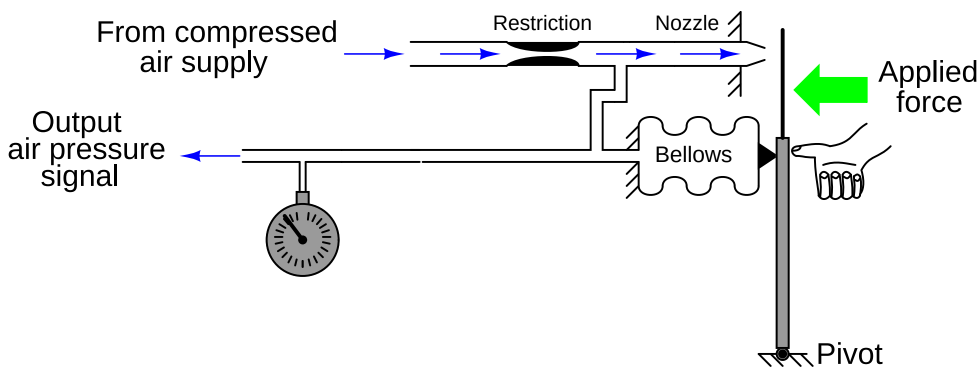
file i04181

Question 11

The sensitivity and linearity of a pneumatic force-balance instrument may be improved with the addition of a *pneumatic amplifying relay* to amplify the response of the flapper/nozzle assembly. It other words, the inclusion of an amplifier into the system increases the system's *gain*. Explain what happens, step by step, in the system shown, if force is applied to the lever by someone's thumb:



Also, determine whether the mechanism will still produce the same amount of output pressure for any given amount of applied force without the amplifying relay in place. In other words, if we removed the relay from the system, would the output pressure be greater than before, less than before, or the same as before given the same force applied to the lever?

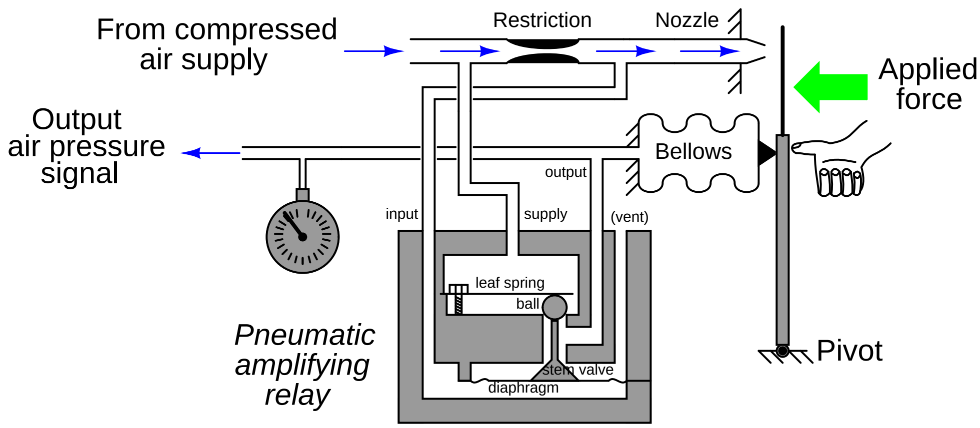


Challenge question: if we reduced the restriction (orifice) bore size in this system such that less air flowed through the nozzle, would the output pressure be greater than before, less than before, or the same as before given the same force applied to the lever?

file i00201

Question 12

Determine the final effect of each fault for this pneumatic force-balance system:



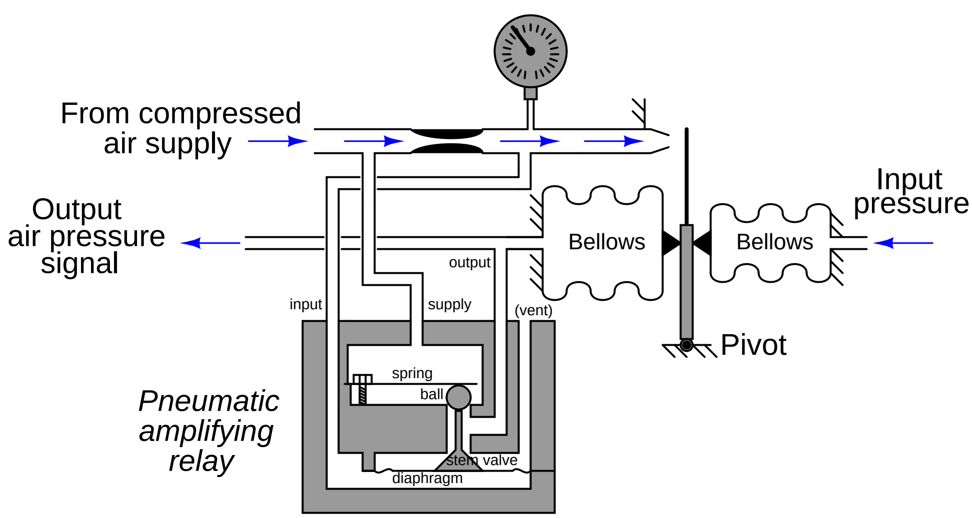
- Clogged nozzle
- Clogged restriction
- Clogged tube at supply port of amplifying relay
- Broken leaf spring inside amplifying relay
- Major hole or tear in diaphragm inside amplifying relay

Be sure to explain the final effects for each of these faults!

file i00202

Question 13

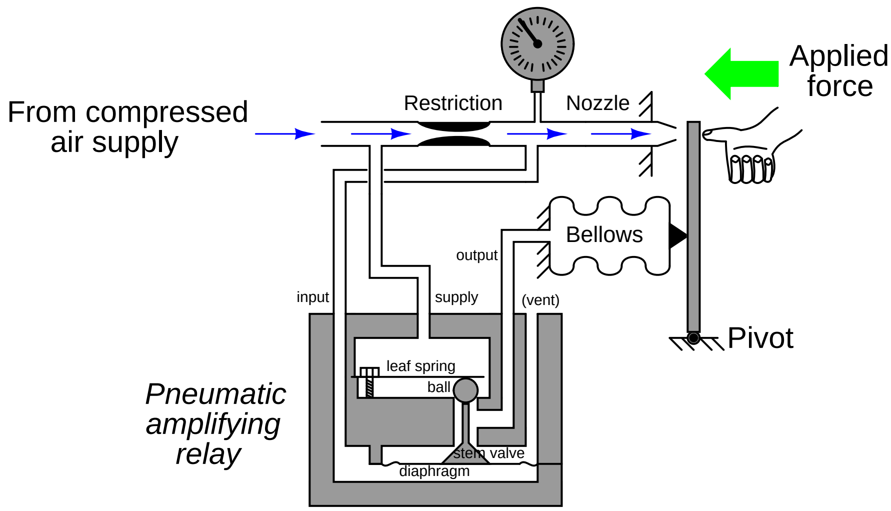
The following pneumatic transducer converts between a 3-15 PSI signal range and a 6-30 PSI signal range. Based on the illustration shown here, which pressure range corresponds to the input and which pressure range corresponds to the output? Does it input 3-15 PSI and output 6-30 PSI, or vice-versa? How can you tell??



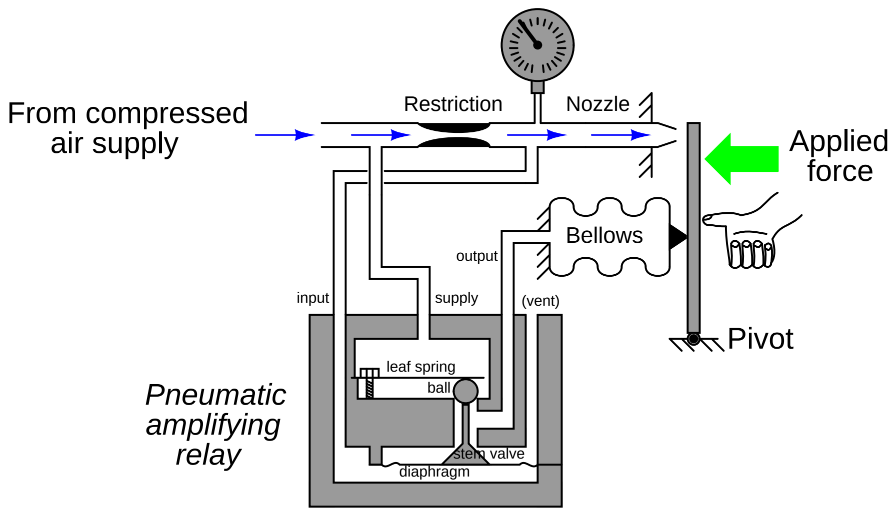
file i00680

Question 14

The following force-balance mechanism responds to an applied force by increasing its output pressure:



How will this mechanism respond to the exact same amount of manual force applied at a *lower* level, closer to the pivot point?

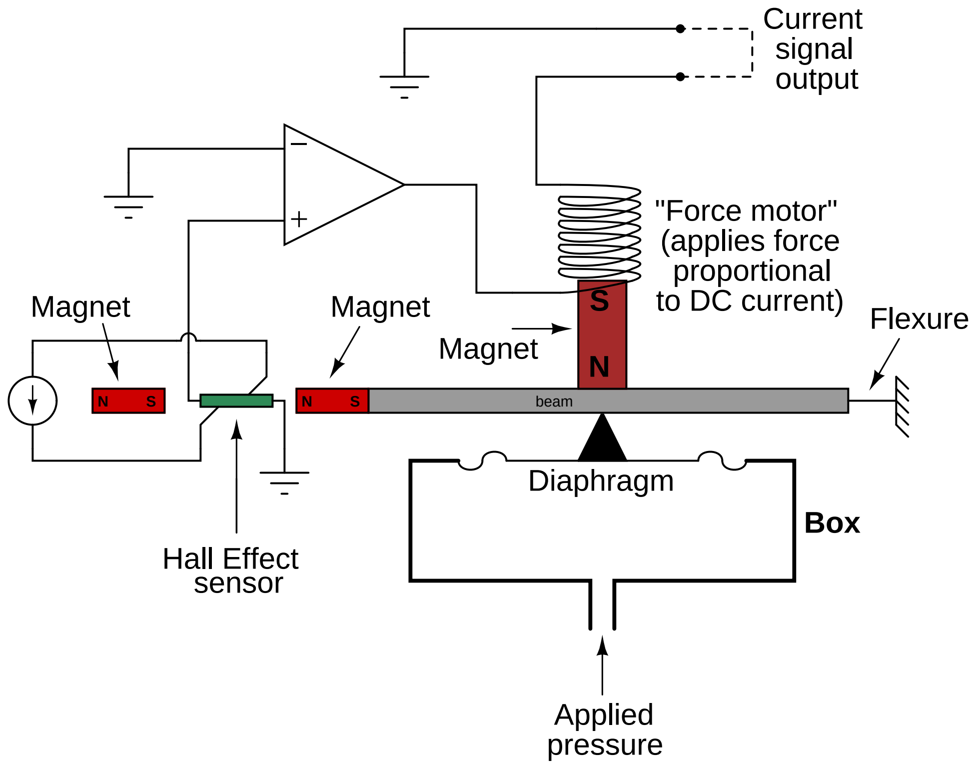


Be sure to explain *why* this is!

file i00798

Question 15

Shown here is a diagram for an *electronic* force-balance pressure transmitter:



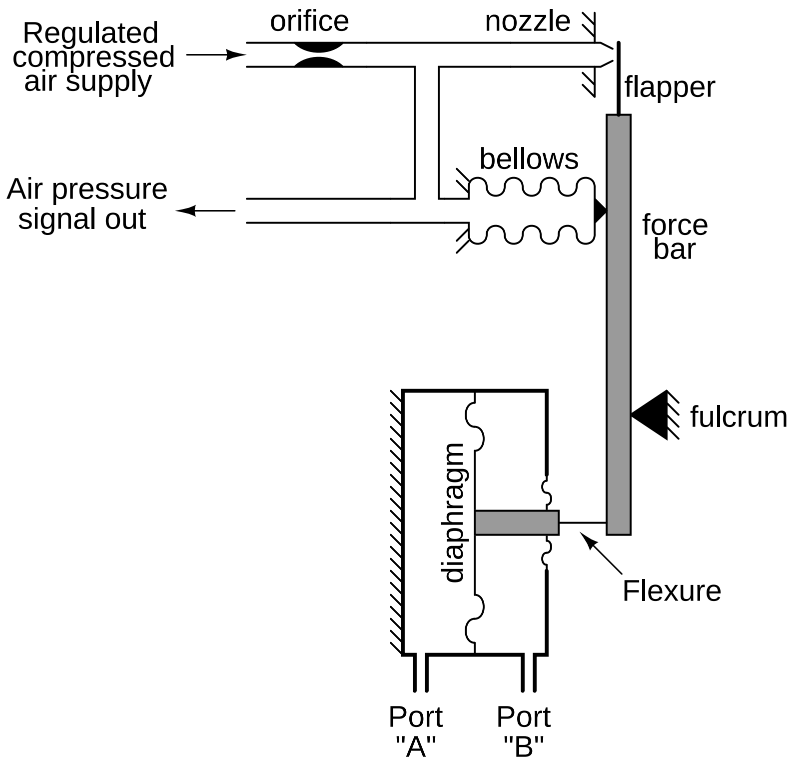
Explain the following things in reference to this transmitter:

- What is a *flexure*?
- How is the opposing force generated?
- What does a *Hall Effect* sensor do?
- How is an imbalance of force detected?
- How would you incorporate a zero adjustment into this transmitter?
- How would you incorporate a span adjustment into this transmitter?

file i00207

Question 16

Identify the "high" and "low" ports on this pneumatic differential pressure transmitter, and explain your reasoning:

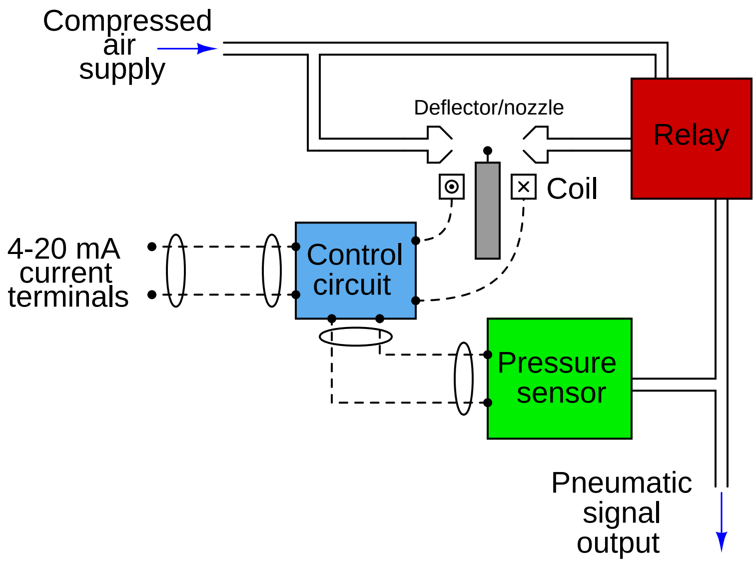


Also, explain how this transmitter will respond to an increasing pressure at each of its two ports, including the operation of the bellows feedback mechanism.

file i00223

Question 17

The Fisher model 846 I/P uses an interesting current-to-pressure transducer design, intended for use supplying variable-pressure air signals to position control valves. A simplified diagram of its mechanism is shown here:

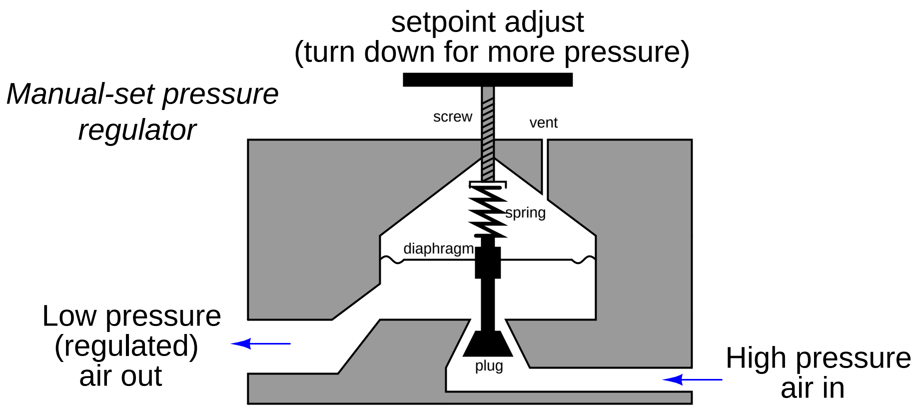


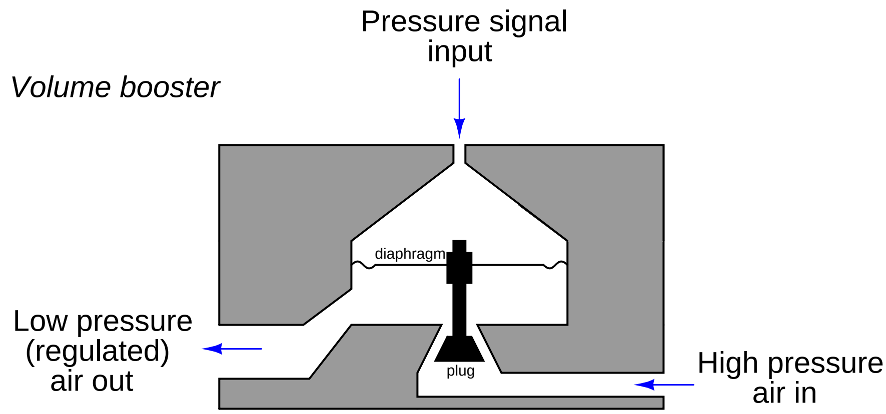
Explain how the feedback system works in this design, and how it differs substantially from classic pneumatic force-balance I/P transducer designs.

file i00916

Question 18

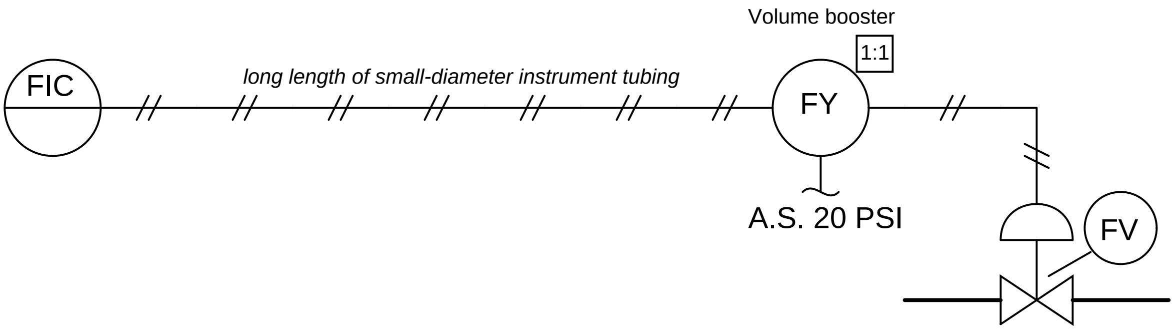
A device similar to a pneumatic pressure regulator is a pneumatic *volume booster* relay:





The purpose of a volume booster is to replicate the same air pressure as the input signal, yet at a greater flow rate than the input signal source would be capable of providing on its own.

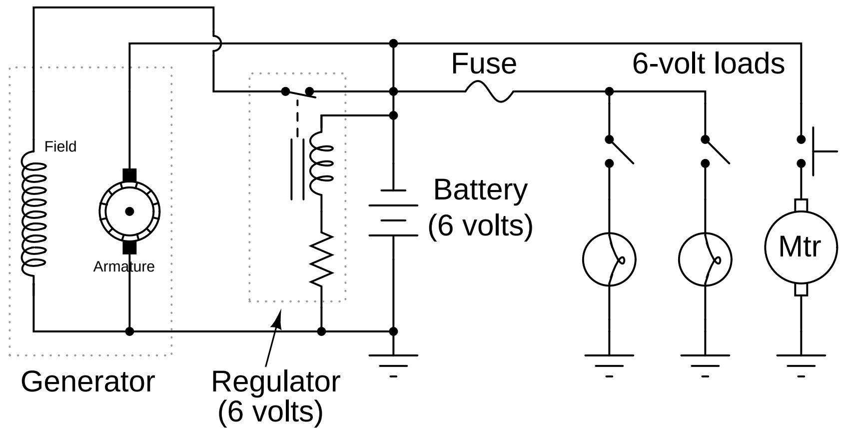
Explain how the volume booster works, and why it might be useful in a pneumatic instrumentation system such as this:



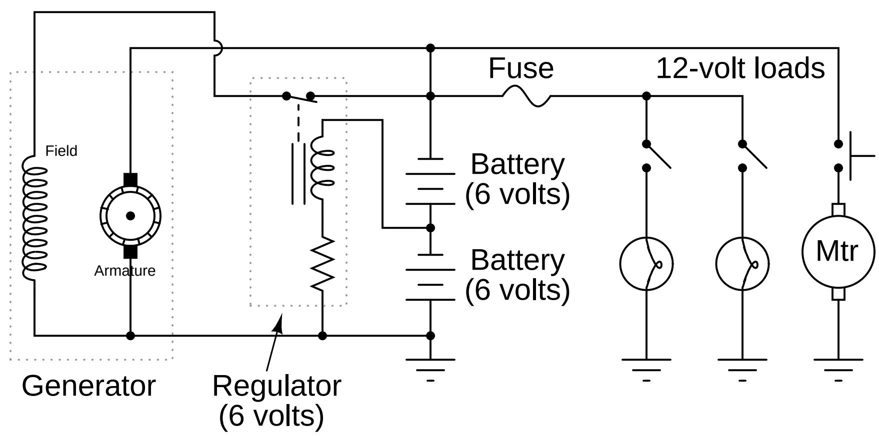
file i00756

Question 19

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



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



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

file i02651

Question 20

Question 21

Read and outline the introduction and the "2-Way Solenoid Valves" subsections of the "Solenoid valves" section of the "Discrete Control Elements" 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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(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 i04193

Question 22

Read and outline the "3-Way Solenoid Valves" subsection of the "Solenoid valves" section of the "Discrete Control Elements" 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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(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 i04194

Question 23

Read and outline the "4-Way Solenoid Valves" subsection of the "Solenoid valves" section of the "Discrete Control Elements" 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.
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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 i04195

Question 24

Read and outline the "Normal Energization States" subsection of the "Solenoid valves" section of the "Discrete Control Elements" 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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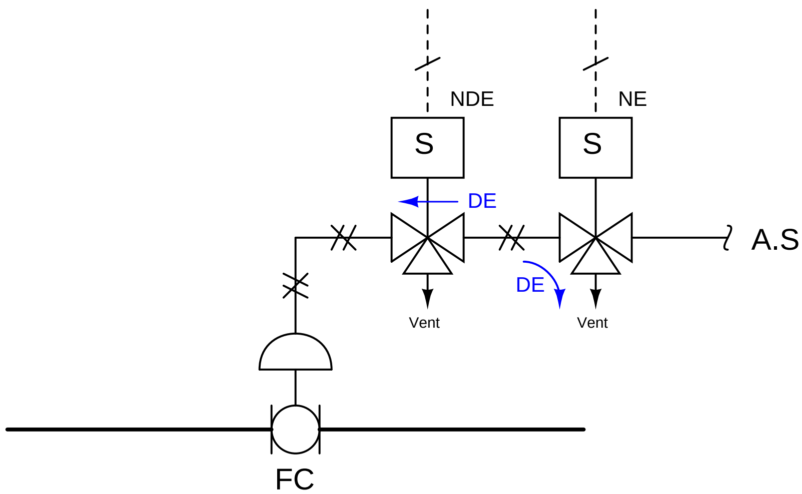
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

file i04141

Question 25

Examine this P&ID and answer the following questions:



Identify the "normal" mode of operation for this system as specified by the process engineer who built it: the status of the process valve and of both solenoid valves during typical process operations.

Identify the "normal" mode of operation for each solenoid valve as specified by the solenoid manufacturer: the status of each solenoid valve when it is in a condition of rest (no stimulation).

Explain what type of electrical signal status (power applied or power removed) is required at each solenoid valve to "trip" the process valve from its regular operating position. Must both solenoids change state to trip the process valve (2oo2 to trip), or is one sufficient (1oo2 to trip)?

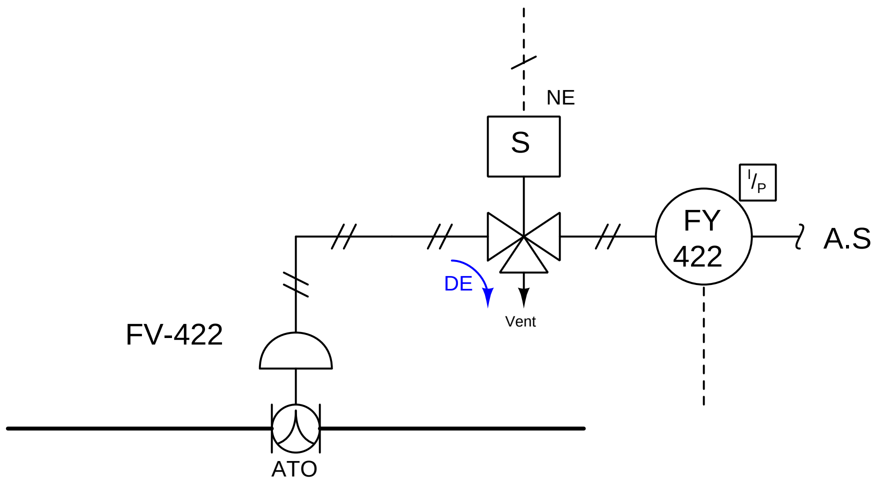
Suggestions for Socratic discussion

- The usage of the word "normal" is very different when describing a solenoid coil's energization state versus when the same word is used to describe a spring-return valve being "normally-open" or "normally-closed." Explain how these two meanings differ, and why this distinction – though confusing it may be – is important to understand.
- Explain the significance of the linetypes used in this diagram.
- Identify the type of process valve used in this system, from the symbol.
- Explain what *dependability* means in the context of this safety system.
- Explain what *security* means in the context of this safety system.
- If you have studied mathematical probability as it applies to system reliability, calculate the probability of the process valve shutting off when it shouldn't (i.e. this trip system's *unsecurity*) given the following probabilities of component failure:
  - $\rightarrow$ P of first solenoid valve accidently venting air pressure = 0.02
  - $\rightarrow$ P of second solenoid valve accidently venting air pressure = 0.01
  - $\rightarrow$ P of instrument air supply failing = 0.05
- If you have studied mathematical probability as it applies to system reliability, calculate the probability of the process valve shutting off during an emergency (trip) condition (i.e. this trip system's *dependability*) given the following component dependability figures:
  - $\rightarrow$ P of first solenoid valve dependably venting air pressure = 0.99
  - $\rightarrow$ P of second solenoid valve dependably venting air pressure = 0.97

file i04197

Question 26

Examine this P&ID and answer the following questions:



Identify the "normal" mode of operation for this system: the status of the process valve and of the solenoid valve.

Identify the "normal" mode of operation for the solenoid valve as specified by the solenoid manufacturer: the status of the solenoid valve when it is in a condition of rest (no stimulation).

Explain what type of electrical signal status (power applied or power removed) is required at the solenoid valve to force a "fail" state at the process valve.

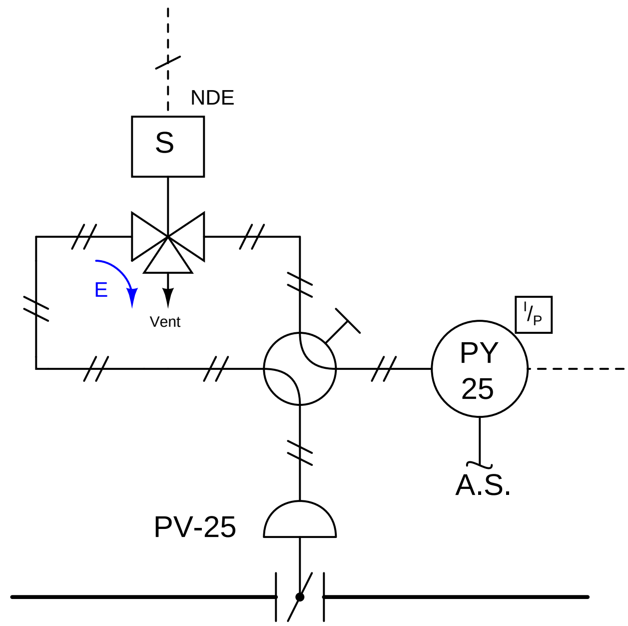
Suggestions for Socratic discussion

- The usage of the word "normal" is very different when describing a solenoid coil's energization state versus when the same word is used to describe a spring-return valve being "normally-open" or "normally-closed." Explain how these two meanings differ, and why this distinction – though confusing it may be – is important to understand.
- Identify the type of process valve used in this system, from the symbol.
- Explain what *dependability* means in the context of this safety system.
- Explain what *security* means in the context of this safety system.
- If you have studied mathematical probability as it applies to system reliability, calculate the probability of the process valve shutting off when it shouldn't (i.e. this trip system's *unsecurity*) given the following probabilities of component failure:
  - $\rightarrow$ P of solenoid valve passing air when commanded = 0.95
  - $\rightarrow$ P of instrument air supply maintaining good pressure = 0.99
  - $\rightarrow$ P of solenoid control signal remaining energized when it should = 0.985

file i04198

Question 27

Examine this P&ID and answer the following questions:



Identify the "normal" mode of operation for this system: the status of the process valve and of the solenoid valve, with the four-way hand valve in the position shown.

Explain what type of electrical signal status (power applied or power removed) is required at the solenoid valve to force a "fail" state at the process valve.

Identify the purpose of having the four-way hand valve in this system. Under what condition(s) would it ever be set to its other position (opposite from what is shown here)?

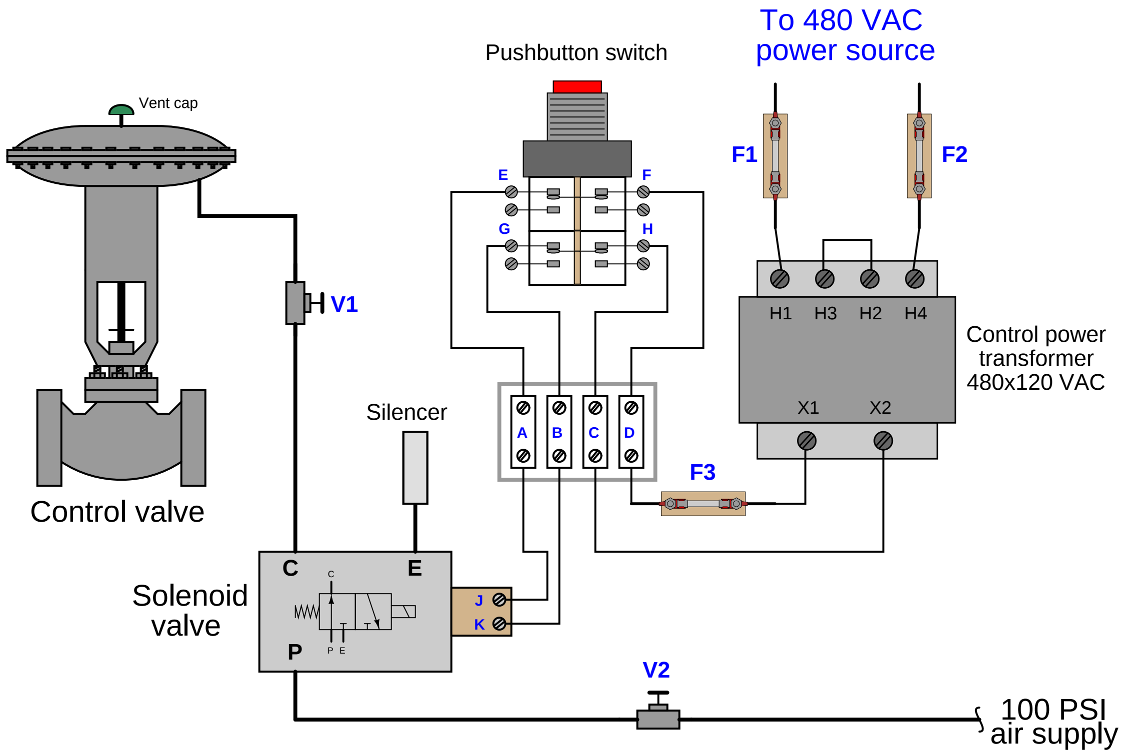
Suggestions for Socratic discussion

- The usage of the word "normal" is very different when describing a solenoid coil's energization state versus when the same word is used to describe a spring-return valve being "normally-open" or "normally-closed." Explain how these two meanings differ, and why this distinction – though confusing it may be – is important to understand.
- Identify the type of process valve used in this system, from the symbol.
- Explain what *dependability* means in the context of this safety system.
- Explain what *security* means in the context of this safety system.
- Devise a procedure by which the solenoid valve could be routinely tested for proper operation without interrupting the process (i.e. without causing PV-25 to go to its failed position).

file i04199

Question 28

Suppose this solenoid-controlled valve refuses to move when the operator pushes the switch. Whether the switch is pressed or unpressed, the control valve remains in the fully-closed (down) position:



Another technician has already measured 475 volts between terminals **H1** and **H4** on the transformer, and 0 volts between terminals **D** and **X1**, in both pushbutton switch positions. At that point he gave up and left the system for you to troubleshoot.

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

Fault	Possible	Impossible
Fuse F3 blown (failed open)		
Solenoid stuck in "energized" position		
Solenoid stuck in "de-energized" position		
Solenoid coil failed open		
Solenoid coil failed shorted		
Silencer plugged		
Vent cap plugged		
Wire open between terminals A and E		
Wire open between terminals C and H		
Wire open between terminals K and B		
Valve V1 shut		
Valve V2 shut		

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

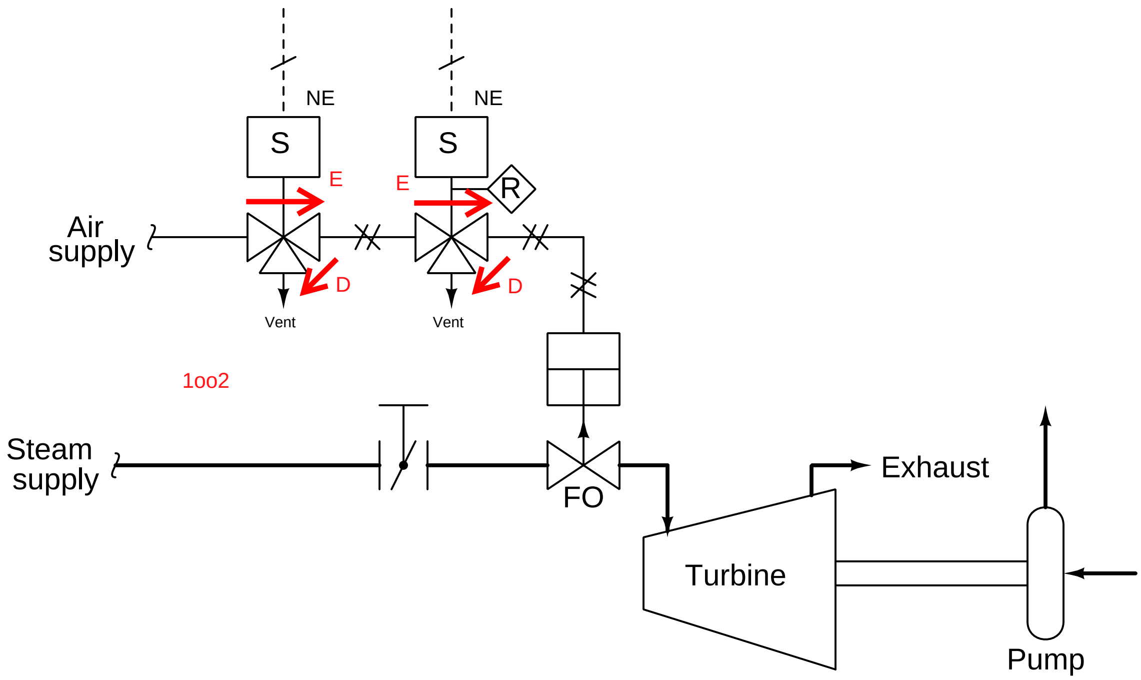
Suggestions for Socratic discussion

- Describe some of the problem-solving techniques you could (or did) apply to this question, explaining how your techniques translated the problem into something more manageable.

file i04202

Question 29

Analyze the following P&ID segment showing a solenoid-controlled steam turbine start-up system (designed to "back up" an electric motor drive in the event the motor shuts down from power loss), explaining what will happen if either of the two solenoid valves loses electric power:



Sketch arrows for both these solenoids showing the directions of air flow in their energized and de-energized states. Must both solenoids change state to start the turbine (2oo2 to start), or is one sufficient (1oo2 to start)?

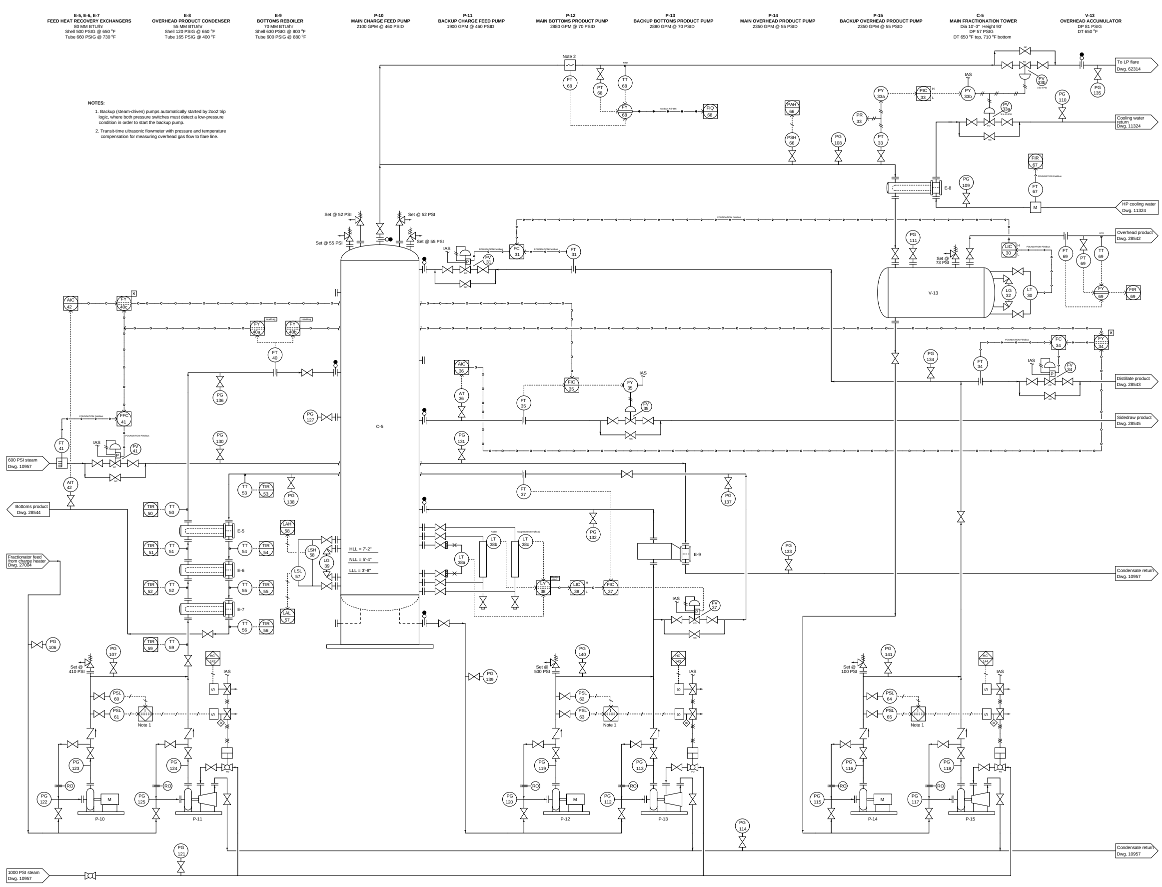
Suggestions for Socratic discussion

- What, exactly, is a *steam turbine* and what purpose does it serve in this system?
- What practical purpose might a steam-driven turbine such as this serve in a process system, especially one ready to start up with one or more solenoids "tripping"?
- Explain the meaning of the letter "R" in the flag on the right-hand solenoid valve.
- Explain what *dependability* means in the context of this turbine start-up system.
- Explain what *security* means in the context of this turbine start-up system.

file i04196

Question 30

Examine the control solenoids for the backup charge feed pump, which is driven by a steam turbine rather than by an electric motor as is the main charge feed pump:



The purpose of this backup pump is to turn on automatically if a low pressure condition is sensed at its discharge line, *or* turn on manually if an operator actuates a "hand" start control.

Label the energized and de-energized flow pathways through each solenoid valve with arrows, assuming the lower solenoid (the one with the reset flag) is normally de-energized and the upper solenoid is normally energized.

Suggestions for Socratic discussion

- Why do you suppose the backup pump is driven by a steam turbine, while the main pump is driven by an electric motor? Why not drive both with motors, or both with turbines?
- What is the purpose of having *two* low-pressure switches in the auto-start control system rather than a single low-pressure switch?

file i03432

Question 31

Explain the operating principles of these valve actuator types, then answer the questions that follow:

- Spring-and-diaphragm (pneumatic)
- Piston (pneumatic)
- Electromechanical (electric motor)
- Electromagnetic (electric solenoid)
- Electrohydraulic

Excluding the solenoid style of valve actuator, which is not used for proportioning control, which actuator type listed here is the simplest?

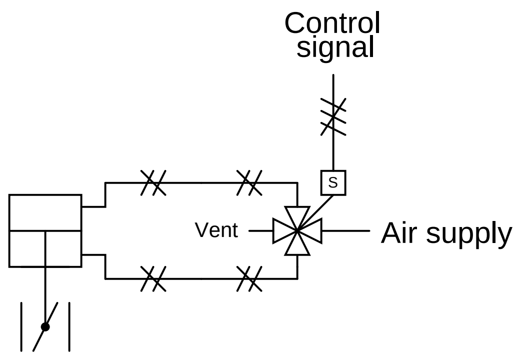
Which of the actuators listed here inherently hold their position under a loss of electric power or compressed air supply?

Which of the actuators listed here inherently "fail" in one direction (either full-open or full-closed) under a loss-of-supply condition, or else may be modified to do so?

file i00781

Question 32

Draw the appropriate arrow symbols next to the body of the four-way solenoid valve so that it pushes the piston valve actuator (on the butterfly valve) *down* when energized and *up* when de-energized:



file i00920

Question 33

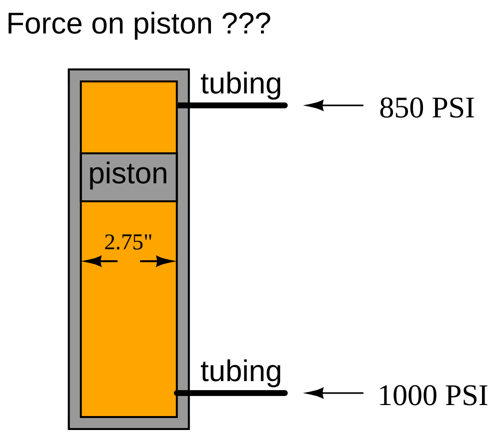
Complete the following table of equivalent pressures. Assume units of "gauge" pressure except where "absolute" is implied by the unit:

inches Hg	inches H_2O	Atmospheres	PSI
82			
	250		
		1.5	
			10
		9	
0			
	-25		
			40

file i00024

Question 34

A free-floating piston inside a hydraulic cylinder has a 1000 PSI of fluid pressure applied to one side of the piston, and 850 PSI of pressure applied to the other side of the piston. The piston itself is 2.75 inches in diameter. How much force will act on the piston, with these pressures applied to it?



file i00155

Question 35

Complete the following table of equivalent pressures:

Atm	PSIG	inches W.C. (G)	PSIA
3.5			
	81		
		8834	
			0
		7.12	
			368
	2		
100			

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.

file i02939

Question 36

Explain what is wrong with this attempt to convert a gauge pressure of 65 PSI into units of atmospheres (atm):

$$\left(\frac{65 \text{ PSI}}{1}\right)\left(\frac{1 \text{ atm}}{14.7 \text{ PSI}}\right) = 4.422 \text{ atm}$$

Suggestions for Socratic discussion

- The mistake made here is common for new students to make as they learn to do pressure unit conversions. Identify a "sure-fire" way to identify and avoid this mistake.

file i02940

Question 37

2.036 inches of mercury ("Hg) is an equivalent pressure to 27.68 inches of water ("W.C. or "H_2O). This fact allows us to create a "unity fraction" from these two quantities for use in converting pressure units from inches mercury to inches water or vice-versa. Two examples are shown here:

$$\left(\frac{310 \text{ "Hg}}{1}\right)\left(\frac{27.68 \text{ "W.C.}}{2.036 \text{ "Hg}}\right) = 4215 \text{ "W.C.}$$

$$\left(\frac{45 \text{ "W.C.}}{1}\right)\left(\frac{2.036 \text{ "Hg}}{27.68 \text{ "W.C.}}\right) = 3.31 \text{ "Hg}$$

But what if we are performing a unit conversion where the initial pressure is given in inches of mercury or inches of water *absolute*? Can we properly make a unity fraction with the quantities 2.036 "HgA and 27.68 "W.C.A as in the following examples?

$$\left(\frac{310 \text{ "HgA}}{1}\right)\left(\frac{27.68 \text{ "W.C.A}}{2.036 \text{ "HgA}}\right) = 4215 \text{ "W.C.A}$$

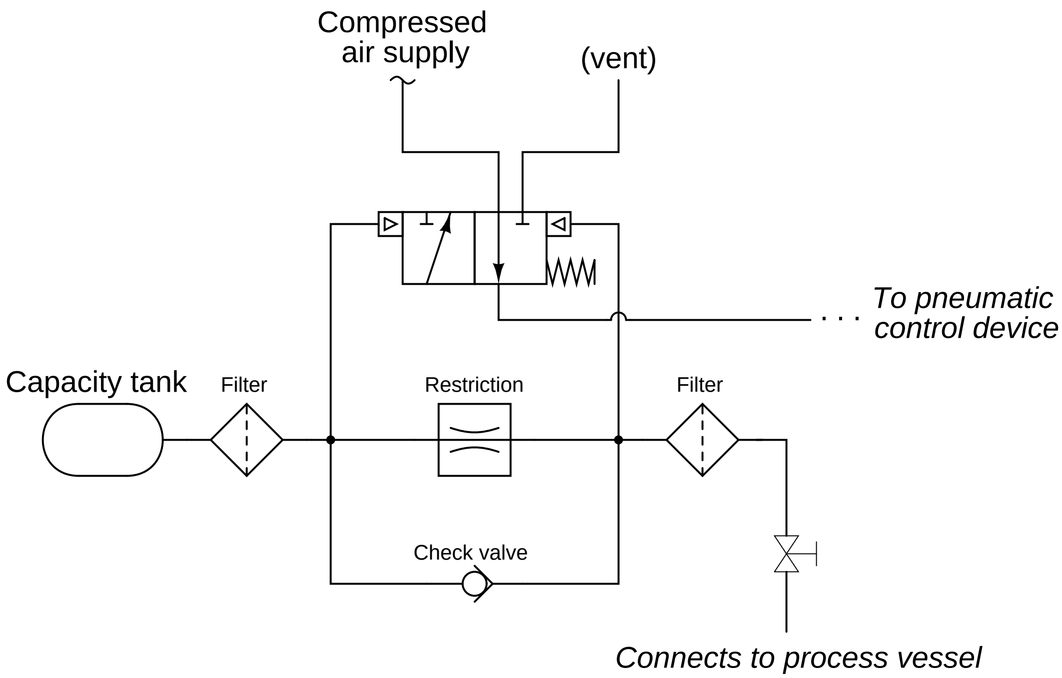
$$\left(\frac{45 \text{ "W.C.A}}{1}\right)\left(\frac{2.036 \text{ "HgA}}{27.68 \text{ "W.C.A}}\right) = 3.31 \text{ "HgA}$$

Explain why or why not.

file i02942

Question 38

This schematic diagram shows a pneumatic sensing mechanism (based loosely on the Bettis DeltaMatic pipeline valve shutoff system) designed to take action when the gas pressure inside of a process vessel begins to change at a sufficient *rate* over time:



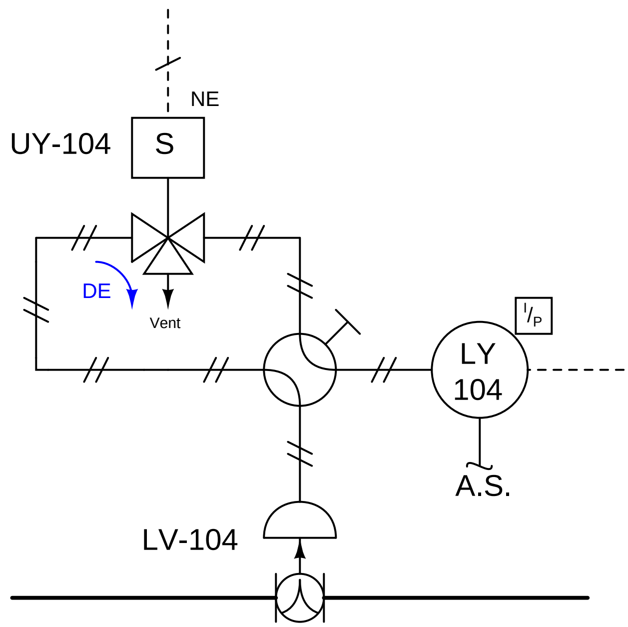
Analyze this diagram, then answer the following questions:

- Does this mechanism activate (i.e. switch out of its "normal" state) when the process pressure's rate of change *rises* quickly over time, *falls* quickly over time, or rapidly changes in *either* direction?
- Identify what would have to be altered in this mechanism to make the previous answer different (i.e. make the mechanism respond to a different direction of process pressure change).
- Identify the direction of air flow through the line leading to the "pneumatic control device" when the process pressure is not changing at all.
- Identify one component that would have to be altered in this mechanism to make it *more sensitive* to rates of process gas pressure change over time, and also identify how that component would have to be altered (e.g. size, shape, etc.).

file i01769

Question 39

Suppose this valve control system has a problem. The control valve (LV-104) does not move to the full-open position as it should when the solenoid is de-energized, although it will move when the 4-20 mA current signal to the I/P transducer is varied while the solenoid is energized:



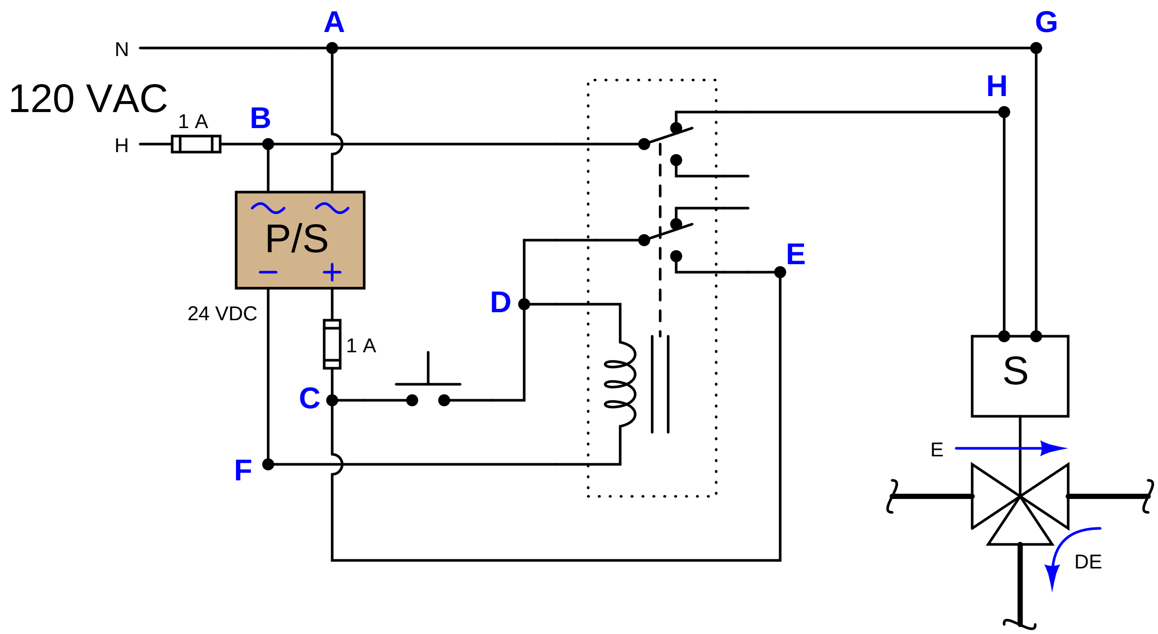
Identify the likelihood of each specified fault for this circuit. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this circuit.

Fault	**Possible**	**Impossible**
Manual valve in "bypass" position		
Solenoid coil failed open		
Solenoid coil failed shorted		
Solenoid valve (UY-104) spool stuck		
Solenoid valve (UY-104) vent plugged		
Air supply to LY-104 failed		
4-20 mA signal wiring to LY-104 failed open		
4-20 mA signal wiring to LY-104 failed shorted		
Control valve (LV-104) stuck		

file i04692

Question 40

Suppose this solenoid control circuit is not working as it should. When the pushbutton is pressed, the solenoid de-energizes as it should. However, the solenoid does not *remain* de-energized as it should when the pushbutton is released – instead, it energizes as soon as the switch is released:



A technician has already taken a DC voltage measurement between points C and E with the pushbutton released and the solenoid energized, and measured 0 volts.

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
Dead power supply		
Relay coil failed open		
Pushbutton switch failed open		
NO contact failed open		
NC contact failed open		
Relay coil failed shorted		
Pushbutton switch failed shorted		
Break in wire between points A and G		
Break in wire between points C and E		
Break in wire between point F and relay coil		

Suggestions for Socratic discussion

- Identify where to place a *commutating diode* to prevent switch contacts from excessive arcing when de-energizing an inductive load.

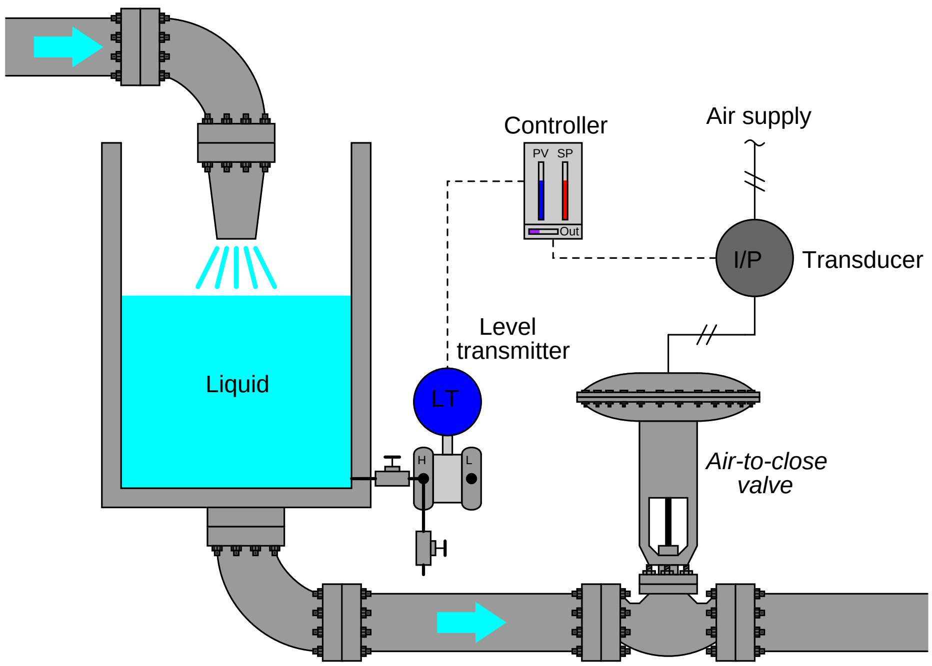
file i04690

Question 41

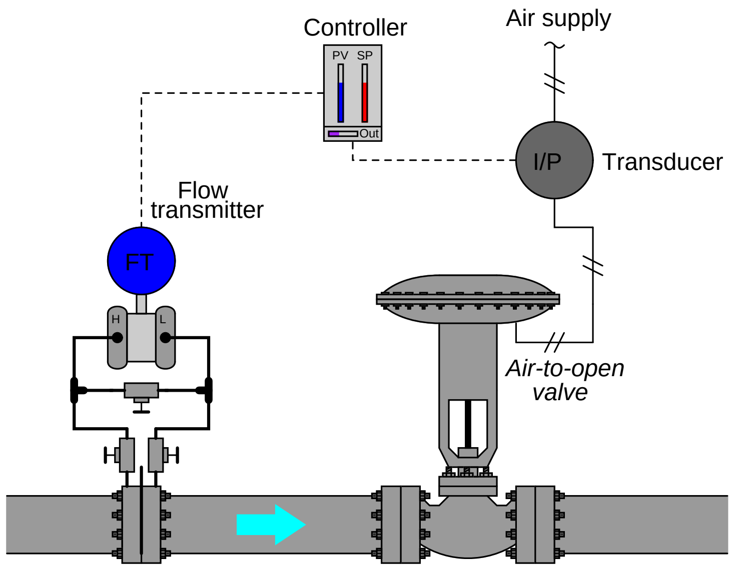
In each of these process control examples, the transmitter produces an increasing signal for an increase in process measurement (level, pressure, temperature, etc.), and the I/P transducer produces an increasing air pressure signal out for an increasing current signal in.

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

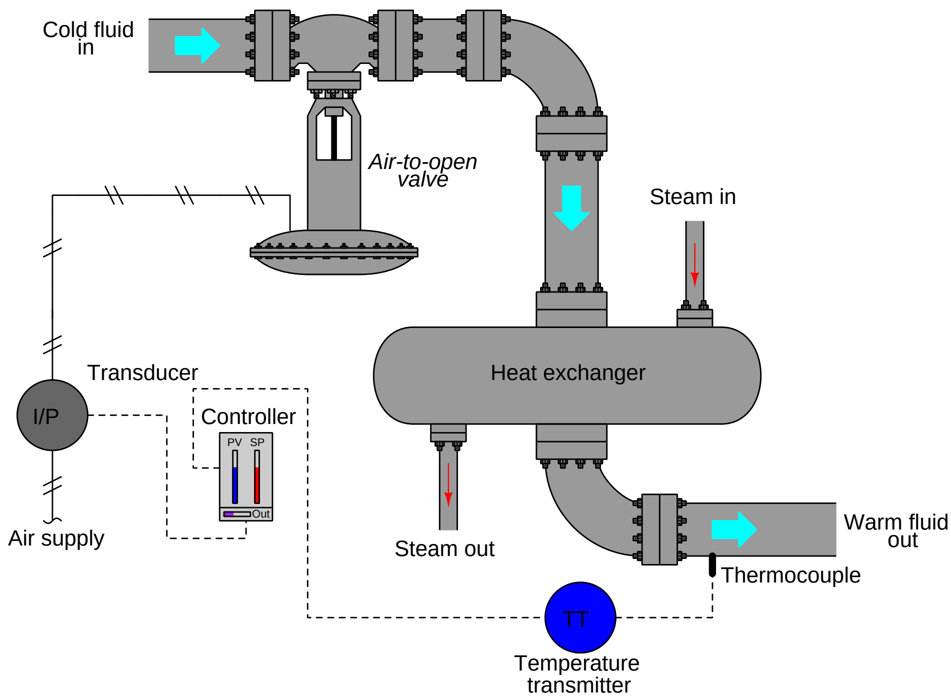
Example 1:



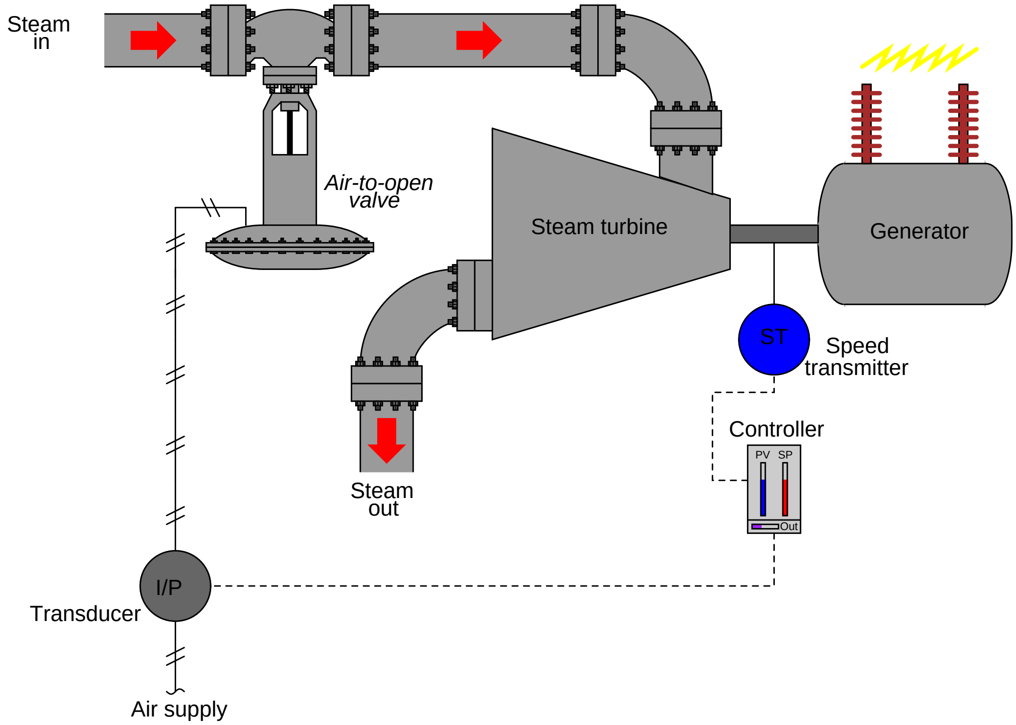
Example 2:



Example 3:

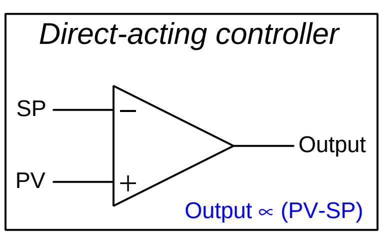


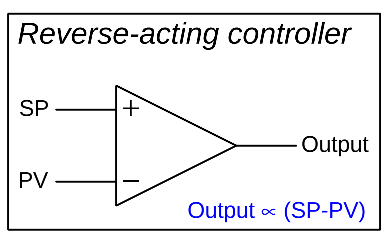
Example 4:



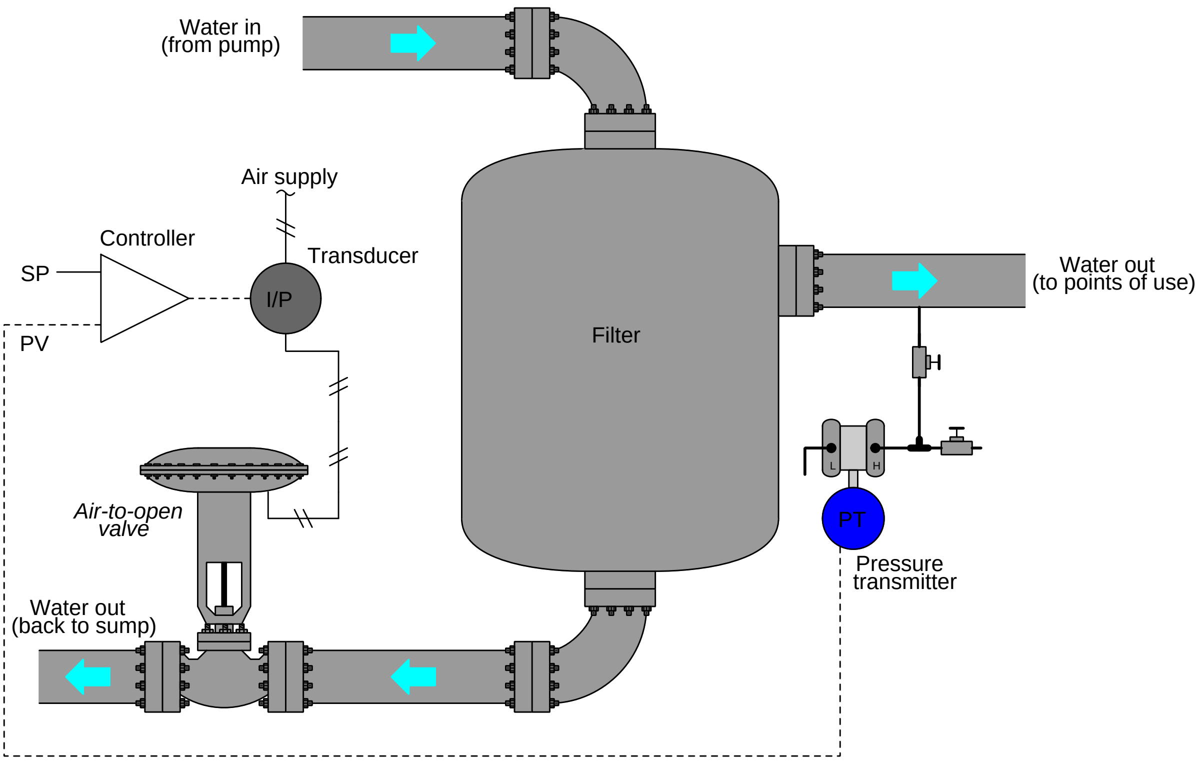
A concept familiar to students of electronics is the *differential amplifier*, a device built to compare two input signals and generate an output signal proportional to that comparison. The most common form of differential amplifier is the so-called *operational amplifier* or "opamp", drawn as a triangle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

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

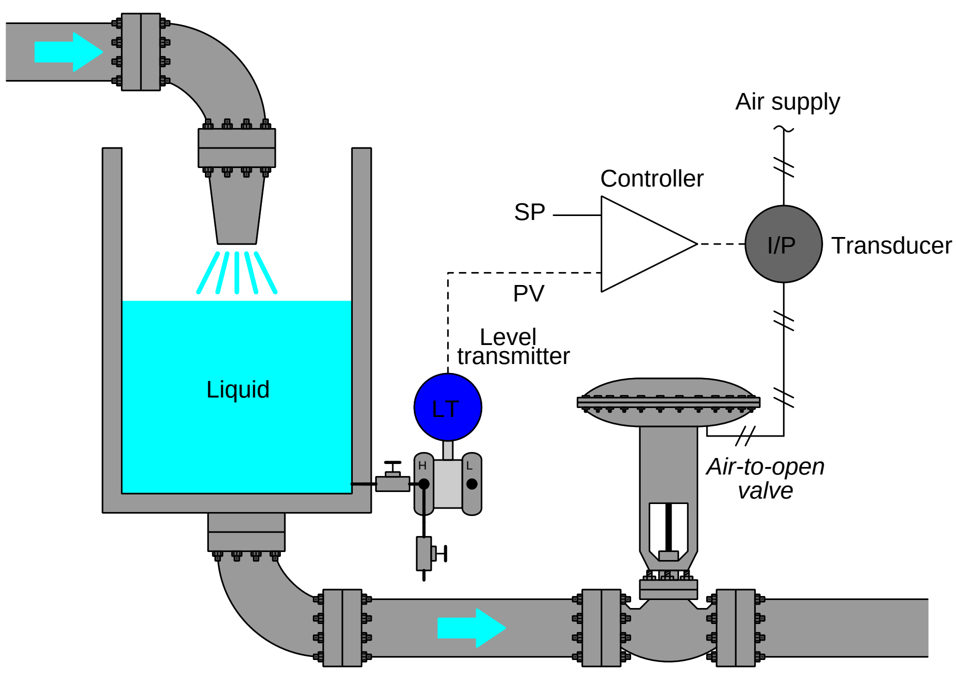




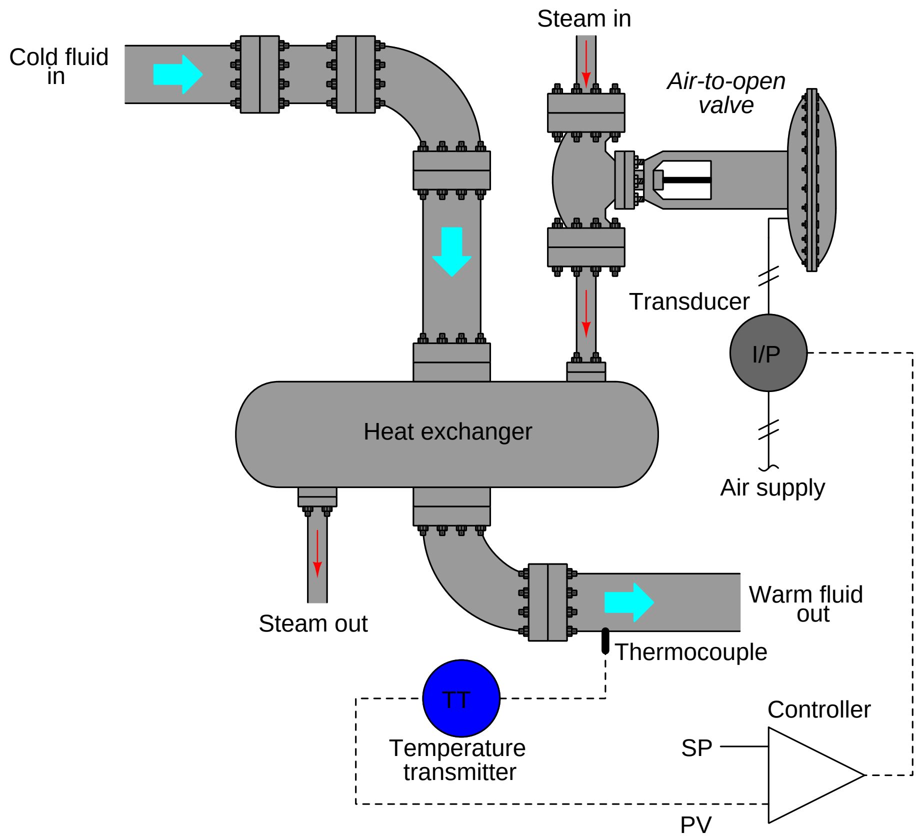
Example 5: *Label the PV & SP amplifier inputs for the correct controller action*



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



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



Suggestions for Socratic discussion

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

file i00788

Question 42

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

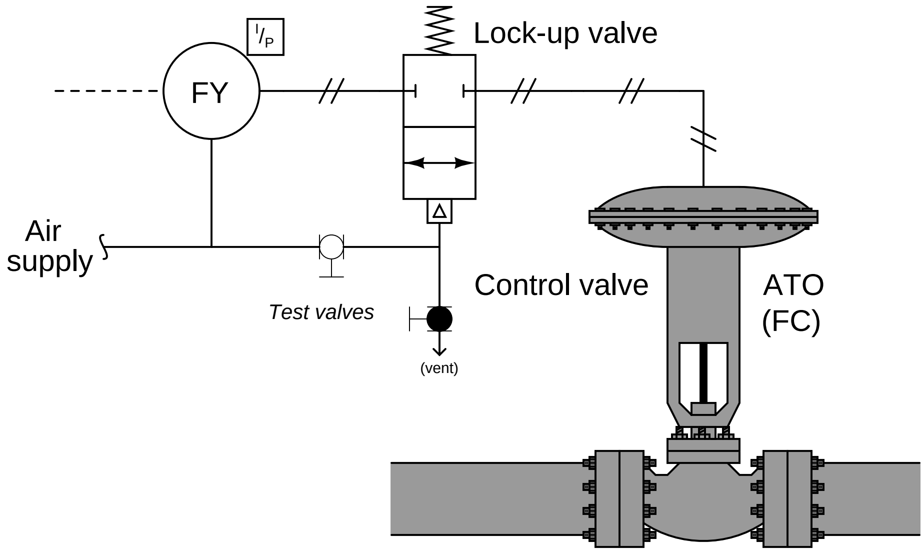
After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(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 i04201

Question 43

The following fluid power schematic diagram shows how a special pressure-actuated spool valve may be used to provide "lock-up" failure mode for a pneumatic control valve actuator with a return spring:



Explain how this "lock-up" valve works, and why it might be useful for a control valve.

Also, explain how to manipulate the two manual "test valves" to prove the operation of the lock-up valve, and why such a test might be important to perform on a regular basis.

Finally, determine a realistic pressure setting for this "lock-up" spool valve to trip at. Assume that the control valve has a bench set range of 3 to 15 PSI.

Suggestions for Socratic discussion

- A very useful problem-solving technique for figuring out the purpose of a device in a system is to analyze that system's behavior *without* the device in question. In this example, you should analyze how the system would respond to a falling supply air pressure, if it did not have the lock-up valve installed? Explain your answer.
- If "fail in place" action were strongly desired in a control valve, is there an alternative actuator technology we could consider other than pneumatic diaphragm?
- Identify a fault that could cause the control valve to *not* hold its position once the lock-up valve has switched to the "lock" position.
- Explain the significance of the lower test valve being drawn with a filled-in ("solid" color) ball.
- Explain the significance of the "ATO" and "FC" labels on the control valve.

file i04203

Question 44

Examine the fluid power diagram on page 2 of the Bettis "Self-Contained Hydraulic Actuator" service manual (document I-0019) and answer the following questions:

Explain how the hand pump builds hydraulic fluid pressure to actuate the process valve ("line valve"), and how that valve's piston actuator is protected against excessive pressure from pumping the hand pump too many times.

Four spool-type hydraulic valves must be in the proper positions in order to hold pressure on the actuator of the process "line" valve. Identify the necessary positions for each of these spool valves, and also the way in which each one is actuated (e.g. solenoid, hand, fluid pressure).

Explain how you could use the "Optional Isolation Test Valve" shown below the pilot to test this system, verifying that the line valve will go to its "fail" position under conditions of low process pressure and also under conditions of high process pressure.

file i04200

Question 45

Read selected sections of the US Chemical Safety and Hazard Investigation Board's report (2002-04-I-MO) of the 2002 chlorine release in Festus, Missouri, and answer the following questions.

Pages 29 through 31 of the report give a description of the incident, at a facility where liquid chlorine is transferred from rail cars to smaller containers for sale to industries using chlorine in their processes. A transfer hose from the rail car to the chlorine process piping burst, enabling liquid chlorine to freely escape. Explain why the "Emergency Shutdown" (ESD) system failed to stop the flow of chlorine as it should have.

Pages 23-28 and 41-44 of the report detail the ESD valves and chlorine piping system. Examine the diagram on page 42 to determine the leak path of the liquid chlorine. Note that one of the ESD valves actually managed to completely shut, and another closed off 40%. All the other ESD valves remained fully open.

Were these ESD valves fail-open (air-to-close) or fail-closed (air-to-open)?

Examine the "fault tree" shown on page 96, and explain the meaning of the `AND` and `OR` gate symbols. Note the directions of the arrows, which at first appear backwards to anyone familiar with logic gate analysis. Why do you suppose the arrows are drawn this way?

Suggestions for Socratic discussion

- What preventive measures could personnel have done at this facility to avoid this accident? Specifically, how could they have thoroughly tested the emergency shutdown system to ensure it was ready to operate as designed if needed?
- For those who have studied Safety Instrumented Systems (SIS), determine the safety *MooN* rating of each ESD valve pair isolating the chlorine header from the tank car (e.g. valves 1 and 5 ; valves 3 and 4) as shown on page 42. Also determine the safety *MooN* rating of the ESD valve system as a whole (i.e. Xoo5) in it ability to prevent releases such as the one that happened.
- Following the "fault tree" diagram, identify any factors that could have prevented the accident despite the primary component failure described in the report.

file i04205

Question 46

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

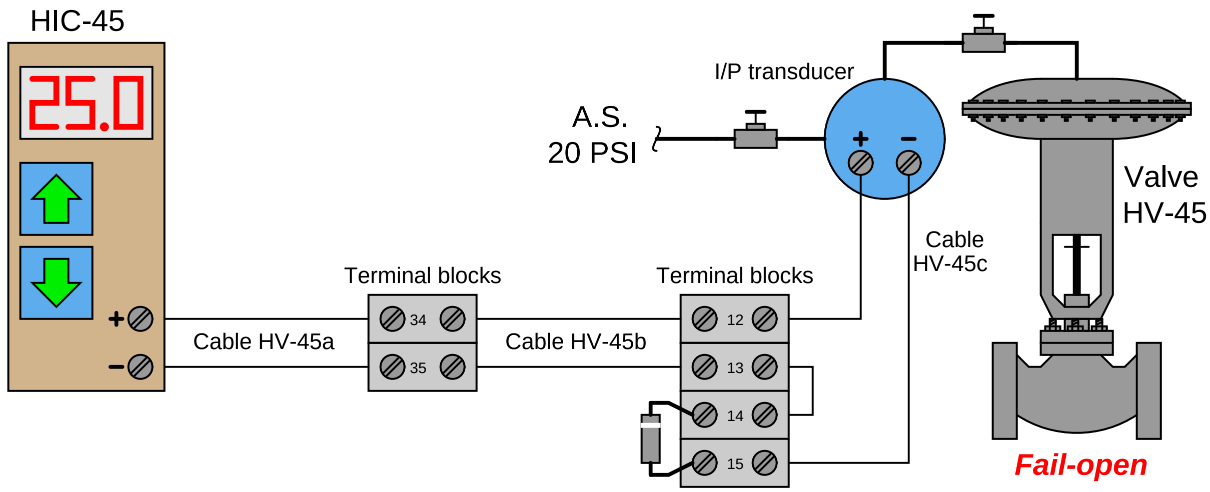
After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(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 i04206

Question 47

This hand indicating controller (HIC-45) allows a human operator to position the control valve (HV-45) simply by pressing "up" and "down" buttons on the controller faceplate:



As the instrument technician, you need to configure the controller so that its digital display registers the valve stem's actual position: 0 on the controller display should represent 0% open (fully shut) and 100 on the controller display should mean 100% open. This is necessary to make the interface easy to understand for the operators who must use it. The challenge is, the valve is *air-to-close*, which means it requires *full* air pressure to close it all the way, and it opens wide at minimum pressure.

There are two ways of accomplishing this goal. The first way requires calibrating the I/P transducer to be reverse-acting (4 mA = 15 PSI ; 20 mA = 3 PSI). The second way requires configuring the hand controller to be reverse *indicating* (4 mA = 100% display ; 20 mA = 0% display). Suppose you chose the second method, where the I/P calibration is normal (e.g. 4 mA = 3 PSI) and the controller is *reverse-indicating* (e.g. 100% display = 4 mA). Given this controller configuration, complete the following table:

Controller display	**Controller current**	**I/P pressure**	**Valve stem position**
77.5%			
	17.9 mA		
		4.29 PSI	
			64% open

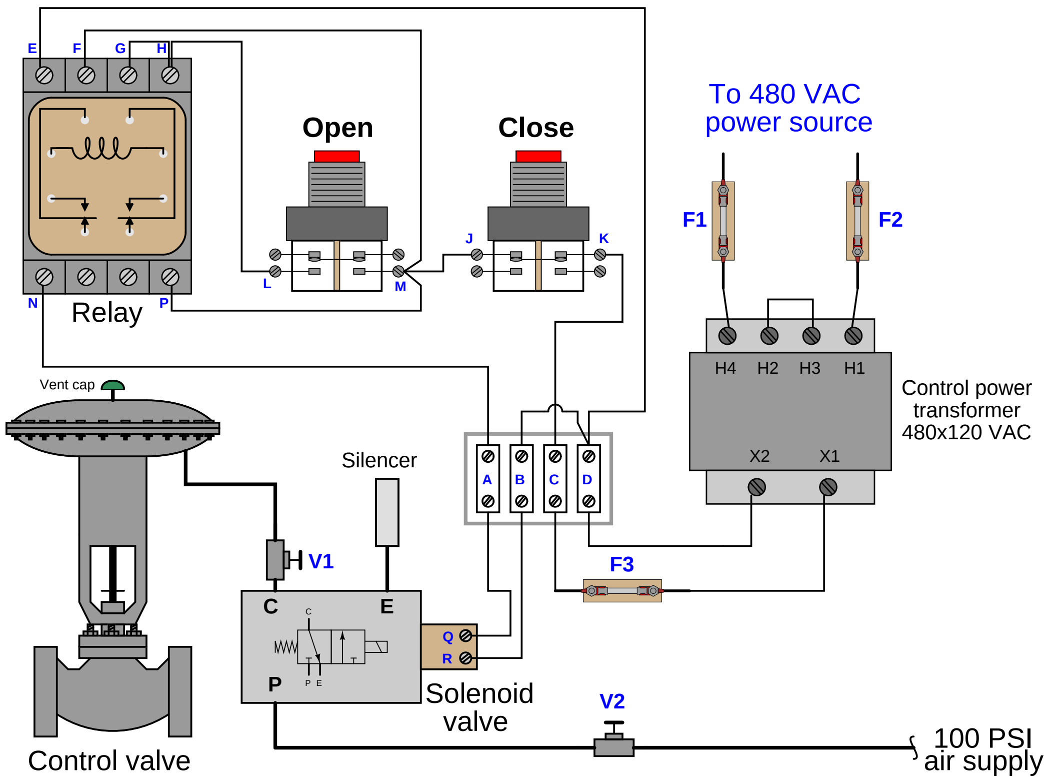
Suggestions for Socratic discussion

- Explain why anyone would choose to use an air-to-close (fail open) control valve.
- Explain why choosing to use a reverse-acting I/P might not be a good idea, considering fail-safe requirements of the system.
- Write a linear equation in the form $y = mx + b$ to describe the current signal output from the controller (y) in terms of its displayed percentage (x).
- Explain the distinction between a loop controller that is *reverse-acting* versus one that is merely *reverse-indicating*.
- Explain the purpose of the diode in the circuit.

file i02325

Question 48

Suppose this solenoid-controlled valve opens when the operator pushes the "open" switch, but closes immediately when the "open" switch is released rather than *latching* in the open position until the "close" switch is pressed:



You measure 481 volts between terminals **H1** and **H4** on the transformer, and 118 volts between terminals **M** and **D**, with both pushbutton switches unpressed.

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

Fault	Possible	Impossible
Fuse F3 blown (failed open)		
Solenoid coil failed open		
"Open" switch contacts (L to M) failed open		
"Close" switch contacts (J to K) failed open		
Relay coil failed open		
Relay contact (G to P) failed open		
Relay contact (F to N) failed open		
Wire open between terminals K and C		
Valve V2 shut		

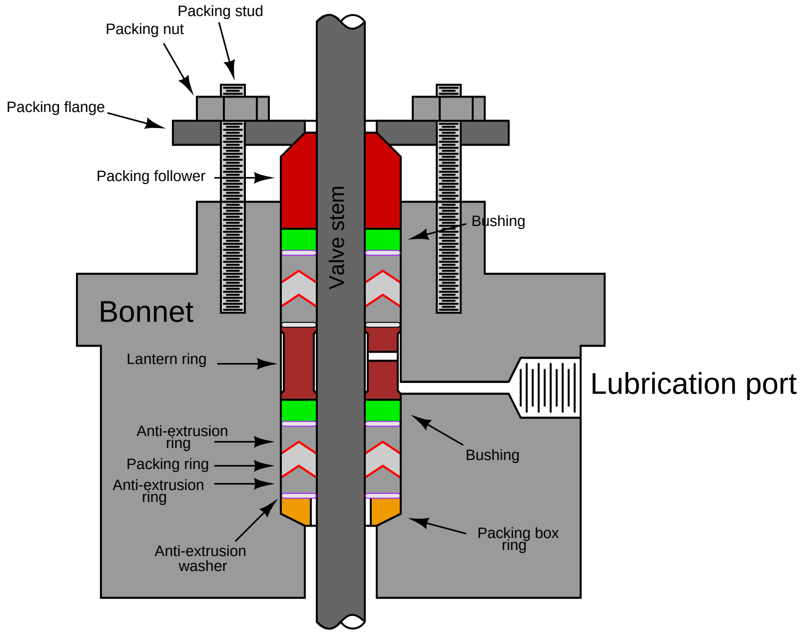
Also, explain why the very first voltage measurement of 481 volts between H1 and H2 was a wasted step, and identify one more possible fault not listed in the table.

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 i00774

Question 49

Examine this cut-away illustration of a control valve packing assembly, located inside the bonnet of the valve:

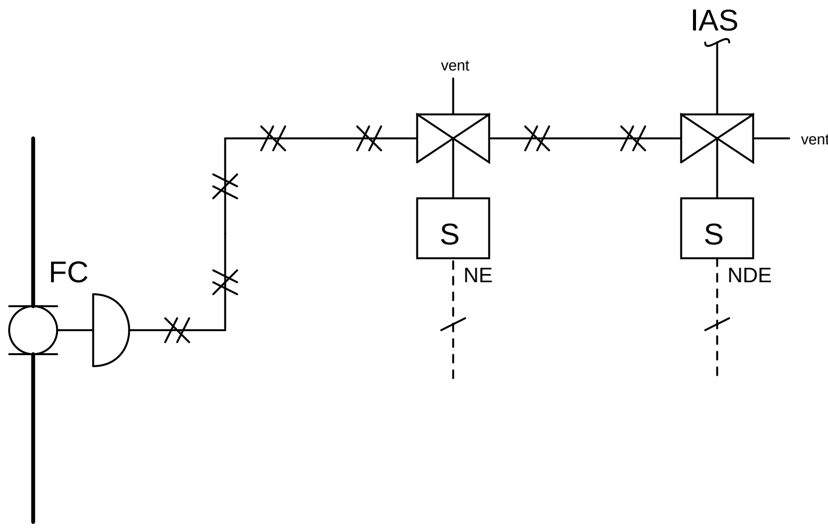


Explain the purpose of each labeled component within the packing assembly.

file i00879

Question 50

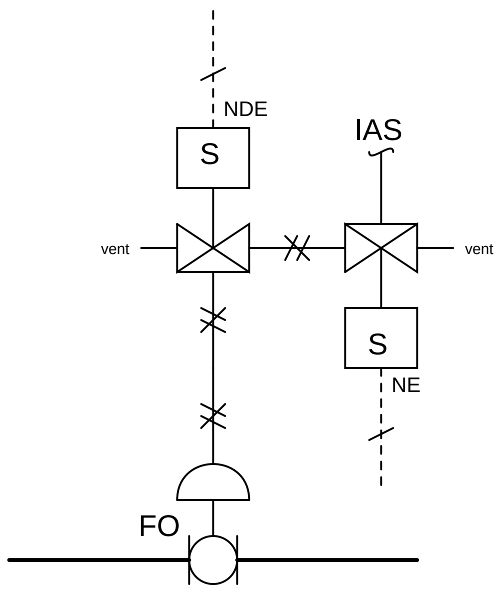
Sketch arrows next to each of the two solenoid valves showing the directions of air flow in the energized (E) and de-energized (D) states, assuming the process control valve is supposed to be open in regular operation and close if either of the solenoid valves "trips" (i.e. 1oo2 to trip):



file i04355

Question 51

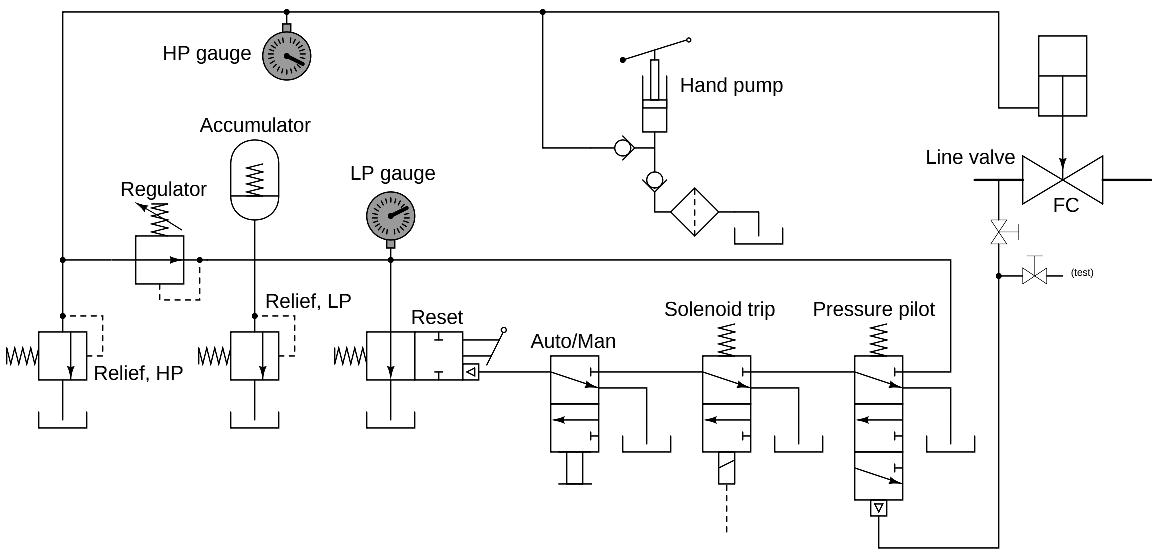
Sketch arrows next to each of the two solenoid valves showing the directions of air flow in the energized (E) and de-energized (D) states, assuming the process control valve is supposed to be open in regular operation and close if both of the solenoid valves "trip" (i.e. 2oo2 to trip):



file i04356

Question 52

This fluid diagram shows the components and connections of a Bettis self-contained hydraulic module used to automatically shut off a "line valve" on a natural gas pipeline in the event of the pipeline pressure going outside of its limits (either falling below the low-pressure limit or rising above the high-pressure limit):

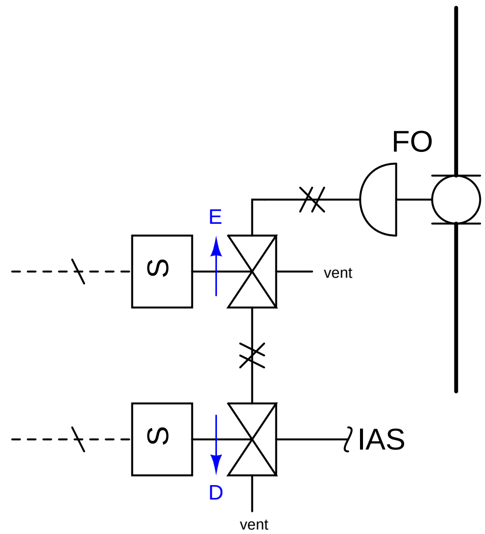


Identify all spool valve positions, and also trace the direction of oil flow, following a solenoid "trip" event.

file i04357

Question 53

Determine the "normal energization" states (e.g. NE or NDE) of each solenoid valve in this diagram, assuming the process valve needs to be *closed* when the process is running as it should:



Also, determine whether one or both solenoids need to "trip" in order to make the process valve go to its fail-state. In other words, is this a *1oo2 to trip* system, or a *2oo2 to trip* system?

Suppose the ball valve refused to shut off when it should. Identify at least two possible faults that could cause this to happen.

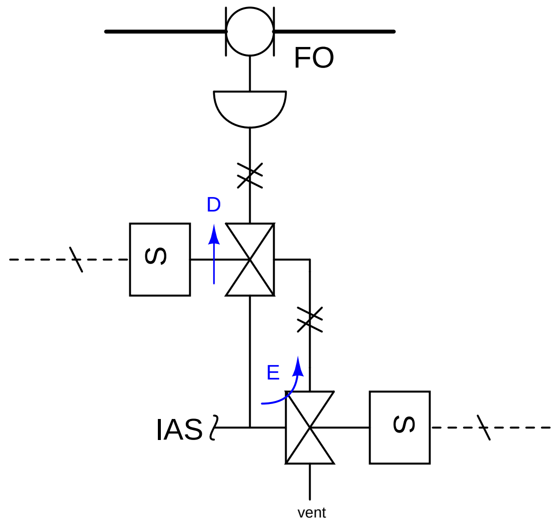
Suggestions for Socratic discussion

- Suppose the probability of each solenoid valve "sticking" in its regular operating position instead of tripping when commanded is 4.5×10^{-3}. Calculate the probability of the process valve refusing to trip when commanded as a result of this type of failure.
- Suppose the probability of each solenoid valve "sticking" in its tripped position instead of going to its regular operating position when commanded is 3.7×10^{-3}. Calculate the probability of the process valve refusing to go to its regular operating position when commanded as a result of this type of failure.
- Suppose the probability of each solenoid valve accidently tripping during regular operation is 9.5×10^{-4}. Calculate the probability of the process valve tripping accidently as a result of this type of failure.

file i04358

Question 54

Determine the "normal energization" states (e.g. NE or NDE) of each solenoid valve in this diagram, assuming the process valve needs to be *closed* when the process is running as it should:



Also, determine whether one or both solenoids need to "trip" in order to make the process valve go to its fail-state.

Suppose the ball valve refused to shut off when it should. Identify at least two possible faults that could cause this to happen.

Suggestions for Socratic discussion

- Suppose the probability of each solenoid valve "sticking" in its regular operating position instead of tripping when commanded is 6.2×10^{-3}. Calculate the probability of the process valve refusing to trip when commanded as a result of this type of failure.
- Suppose the probability of each solenoid valve "sticking" in its tripped position instead of going to its regular operating position when commanded is 7.7×10^{-3}. Calculate the probability of the process valve refusing to go to its regular operating position when commanded as a result of this type of failure.
- Suppose the probability of each solenoid valve accidently tripping during regular operation is 8.1×10^{-4}. Calculate the probability of the process valve tripping accidently as a result of this type of failure.

file i04359

Question 55

Convert between the following units of pressure:

- 71.5 PSIA = ??? PSIG
- 5.03 bar (gauge) = ??? "Hg
- 101 kPa = ??? PSIA
- 800 torr = ??? PSIG
- 41 "Hg = ??? "W.C.
- 2.2 feet Hg = ??? kPa
- 11 PSI vacuum = ??? torr
- 350 "W.C.G = ??? "W.C.A
- 66 cm W.C. = ??? "Hg
- 910 PSIG = ??? atm
- 35 "W.C. = ??? "HgA
- 125 PSIA = ??? kPa

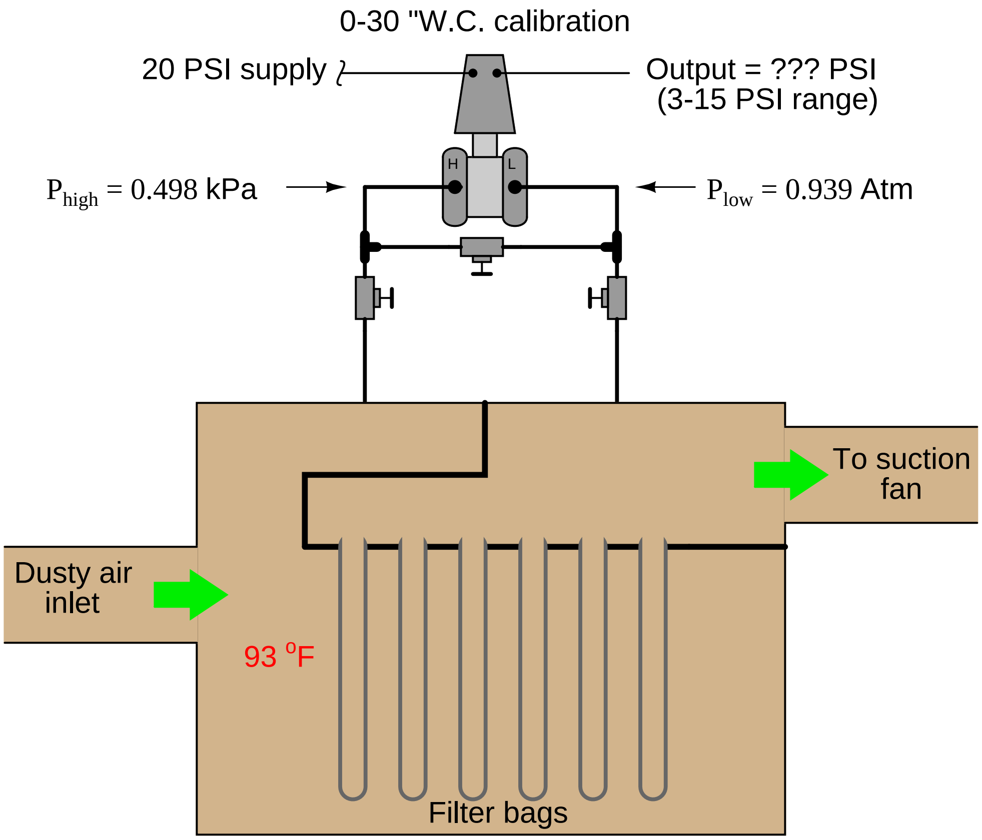
Suggestions for Socratic discussion

- Demonstrate how to *estimate* numerical answers for these conversion problems without using a calculator.

file i04177

Question 56

Calculate the amount of differential pressure "seen" by this pneumatic DP transmitter across this baghouse (used to filter dust from air) in units of PSID and units of bar (differential), then calculate its output signal (in units of PSIG) assuming a calibrated range of 0 to 30 inches water column differential:



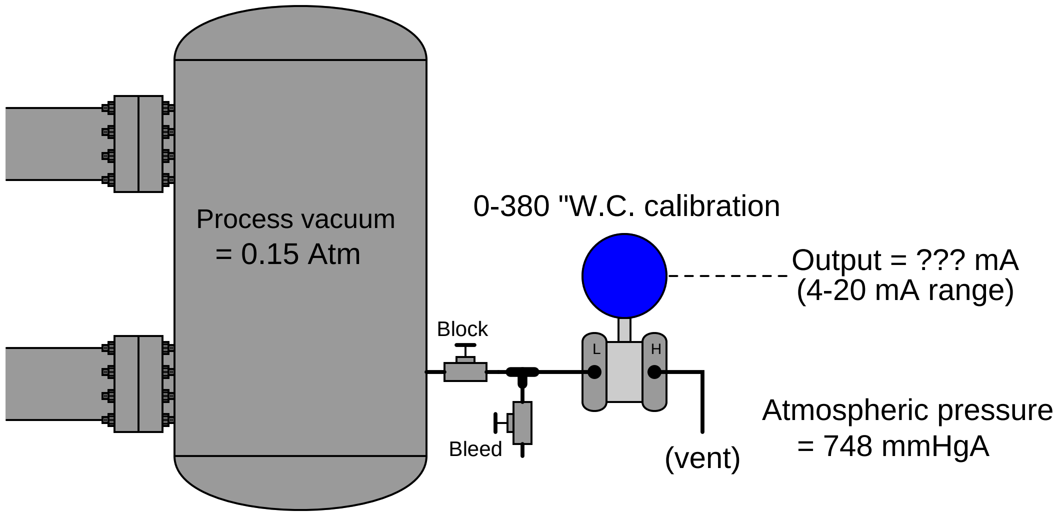
Suggestions for Socratic discussion

- Why do you suppose it is important to continuously measure the pressure differential across an industrial baghouse?
- Why measure *differential* pressure across the baghouse, rather than simply measure either the upstream or downstream (*gauge*) pressure?
- How would a rip in one of the fabric bags affect the differential pressure drop across the baghouse?
- Suppose a technician accidently left one of the block valves shut on one of the transmitter's impulse lines. How might this change affect the transmitter's ability to sense differential pressure?
- Suppose a technician accidently left the equalizing valve open between the transmitter's impulse lines. How might this change affect the transmitter's ability to sense differential pressure?

file i03935

Question 57

Suppose a DP transmitter is connected to a process vessel so it may measure a vacuum inside that vessel. Calculate the amount of differential pressure "seen" by this electronic DP transmitter in units of PSID, then calculate its output signal assuming a calibrated range of 0 to 380 inches water column differential and an output range of 4-20 mA:



There is definitely more than one way to calculate the transmitter's output signal value! Outline more than one of these solutions.

Furthermore, suppose an instrument technician decides to remove this transmitter from service in order to disconnect it from the process and then calibrate it back at the instrument shop. Describe how the technician should operate the block and bleed valves to safely remove it from service, and then describe what the technician should do *before* operating either the block or the bleed valve to ensure no process upsets occur as a result.

Suggestions for Socratic discussion

- What safety hazards might there be for a technician disconnecting and connecting a pressure transmitter to a process vessel such as this?
- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.
- What might happen if the vent tube on the "L" side of the transmitter were to become completely plugged?

file i03939

Question 58

Examine the fluid power diagram on page 2 of the Bettis "DeltaMatic Rate-of-Drop Linebreak Detection System" bulletin (document 41.00 Revision 10/03) and answer the following questions:

The Differential Pressure Pilot (part #120) signals the line valve to actuate when the pipeline pressure suddenly decreases. The key to this pilot valve's operation are the restrictor (part #105) and the Rate Tank (part #108). Explain how this system works to detect a sudden line pressure drop, performing a "thought experiment" where the pipeline has been holding a constant gas pressure for a long time and then that pressure suddenly falls to nothing (assuming a nearby break in the line).

Explain how the Differential Pressure Pilot, once "tripped" by the detection of sudden line pressure drop, subsequently causes the line valve to shut off (close).

Identify whether or not this automatic shutoff system has the capability to re-open the line valve after pressure is restored, and explain your answer based on the fluid power diagram.

Suggestions for Socratic discussion

- Explain why a *rate* of pressure drop detection scheme might be a better choice for an automatic pipeline shutoff valve to have than a simple low-pressure or high-pressure trip characteristic.

file i04204

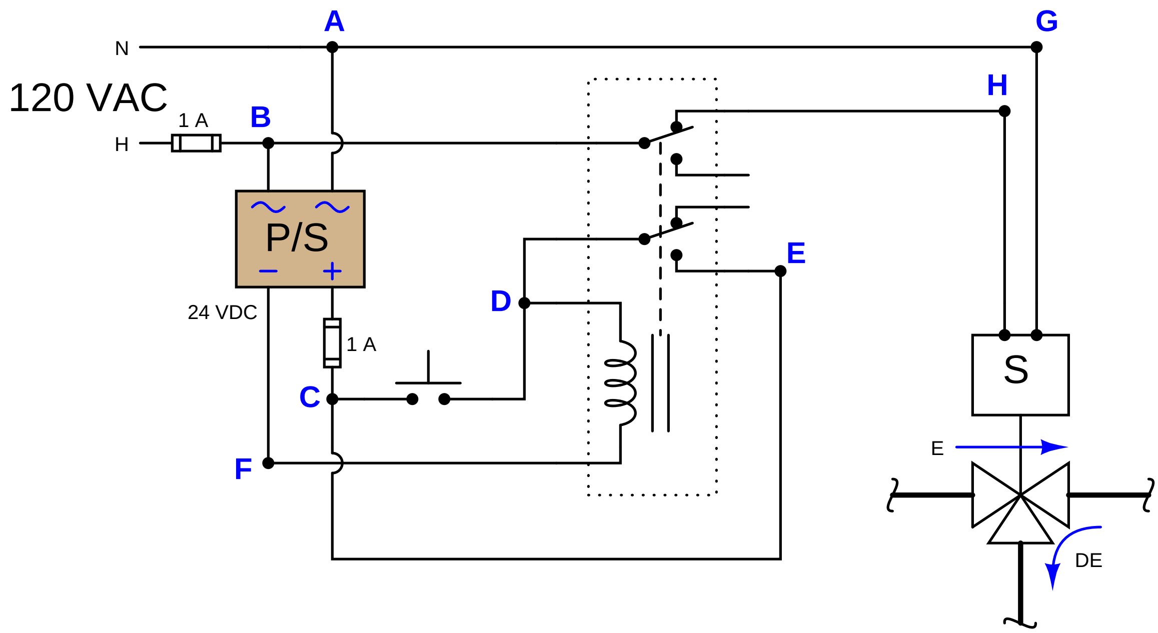
Question 59

An important concept in education is something called *schema*: the body of knowledge, expectations, and assumptions that someone uses to interpret any form of communication they are receiving, whether that communication be in the form of speech, text, or even something as abstract as art. One does not approach an action-adventure novel in the same way or with the same expectations that one would approach instructions for filing tax returns with the IRS. One does not interpret and appreciate a live jazz band in the same way they would interpret and appreciate choral music. We have different schema for understanding and appreciating these different forms of communication, even if they occur in the same medium (e.g. printed text, or audible tones).

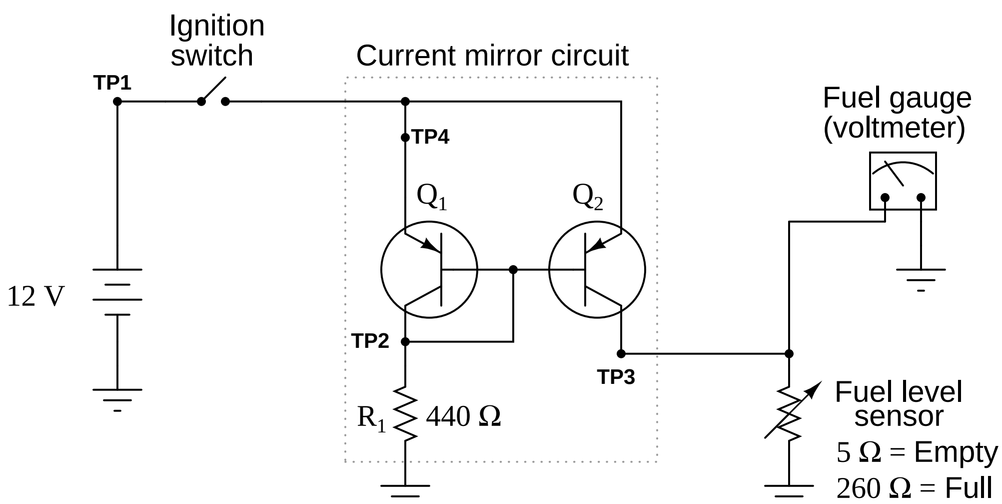
Industrial system diagrams also have *schema* associated with them. One does not interpret a P&ID in the same manner that one interprets an electronic schematic or a block diagram, despite their many similarities. This exercise will ask you to identify the meanings of similar symbols used in several types of diagrams, in order to expose some of the schema you have (or that you are in the process of building).

Reference the following diagrams, and then answer the comparison/contrast questions that follow:

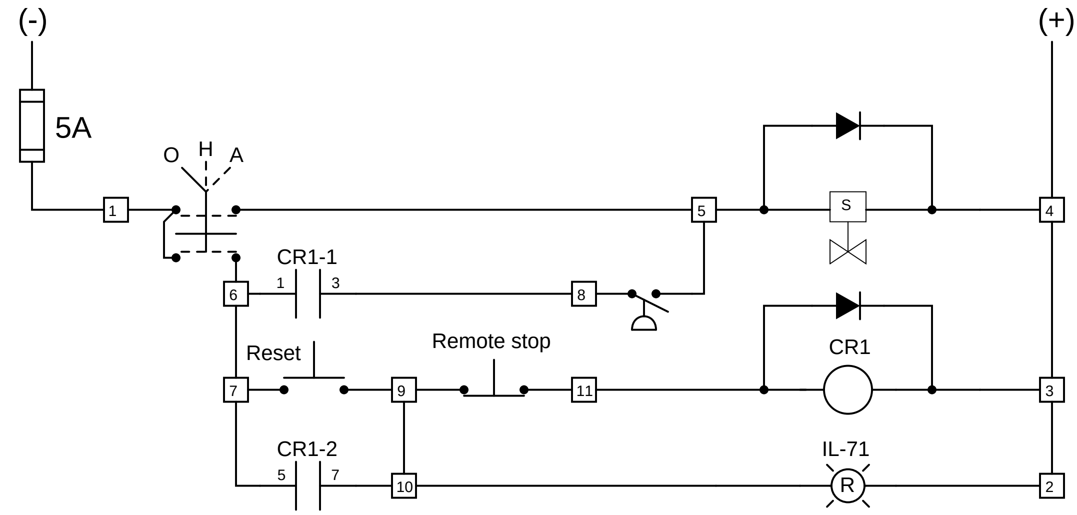
Schematic diagram of a relay circuit



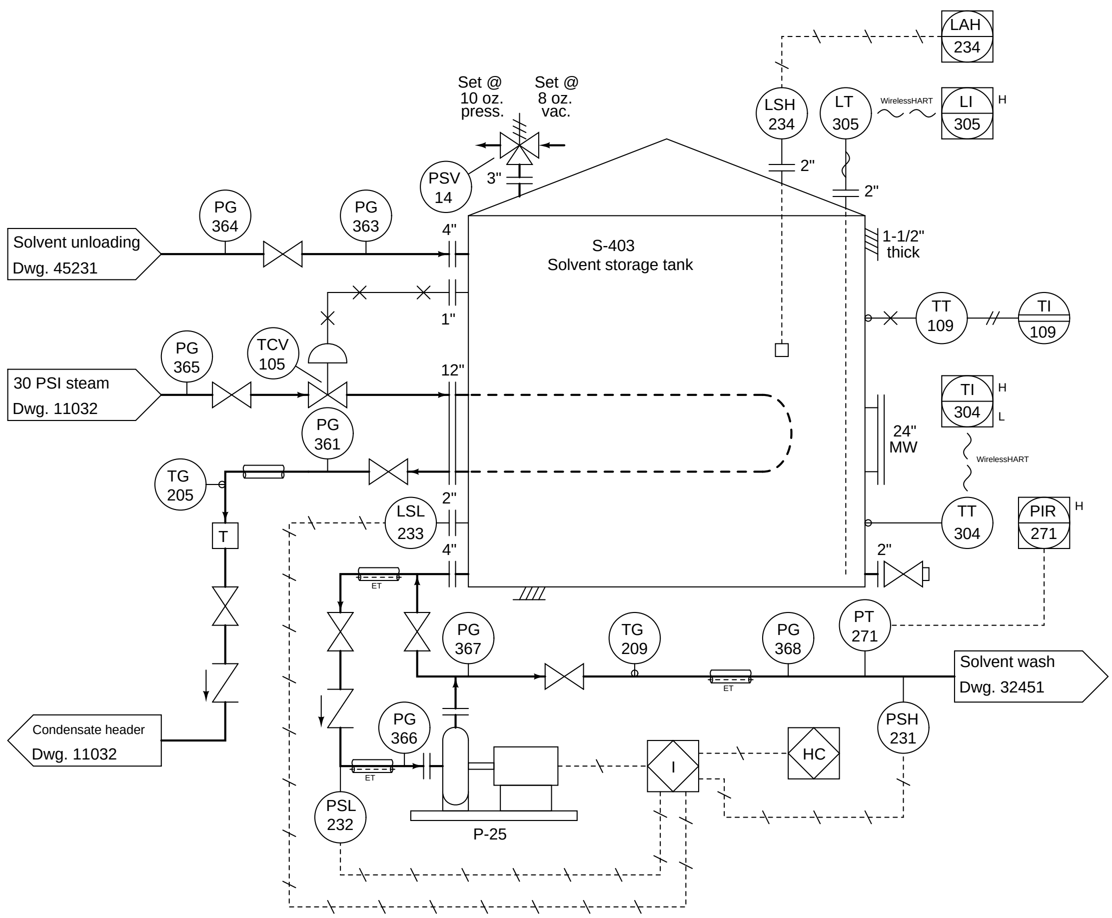
Schematic diagram of a fuel tank level sensor circuit



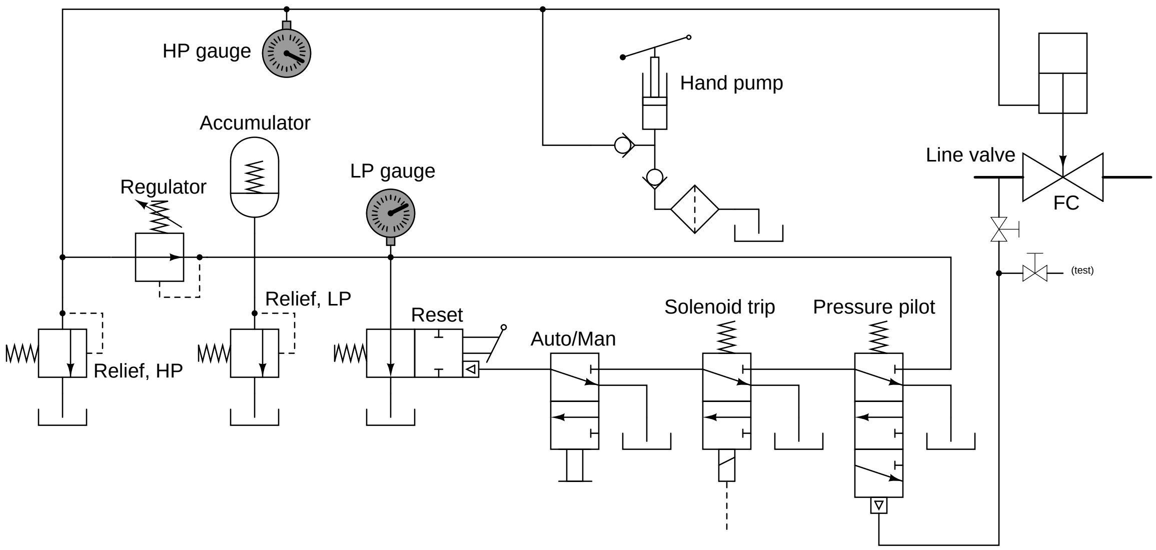
Ladder diagram of a solenoid valve control circuit



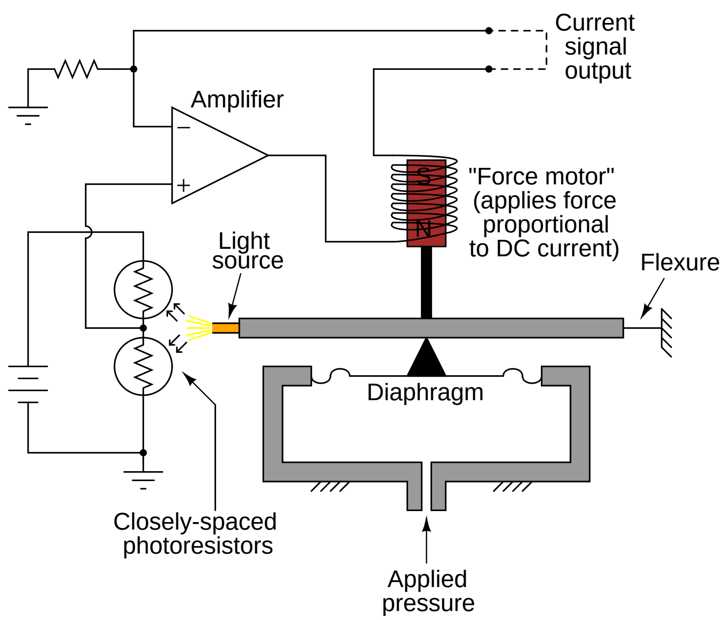
P&ID of a solvent storage tank



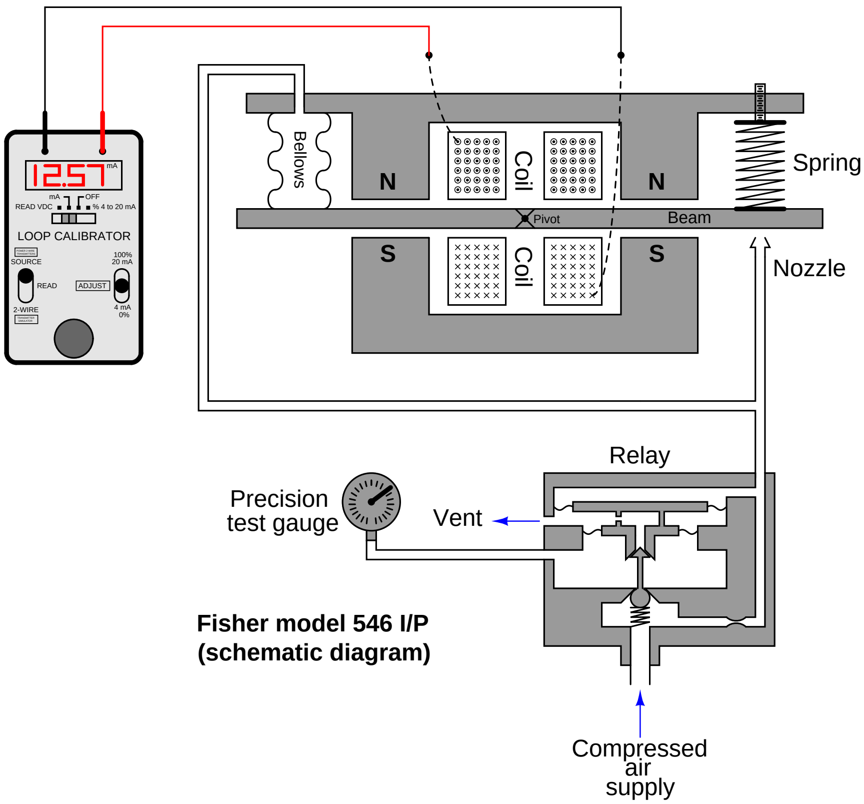
Schematic diagram of a hydraulic valve control system



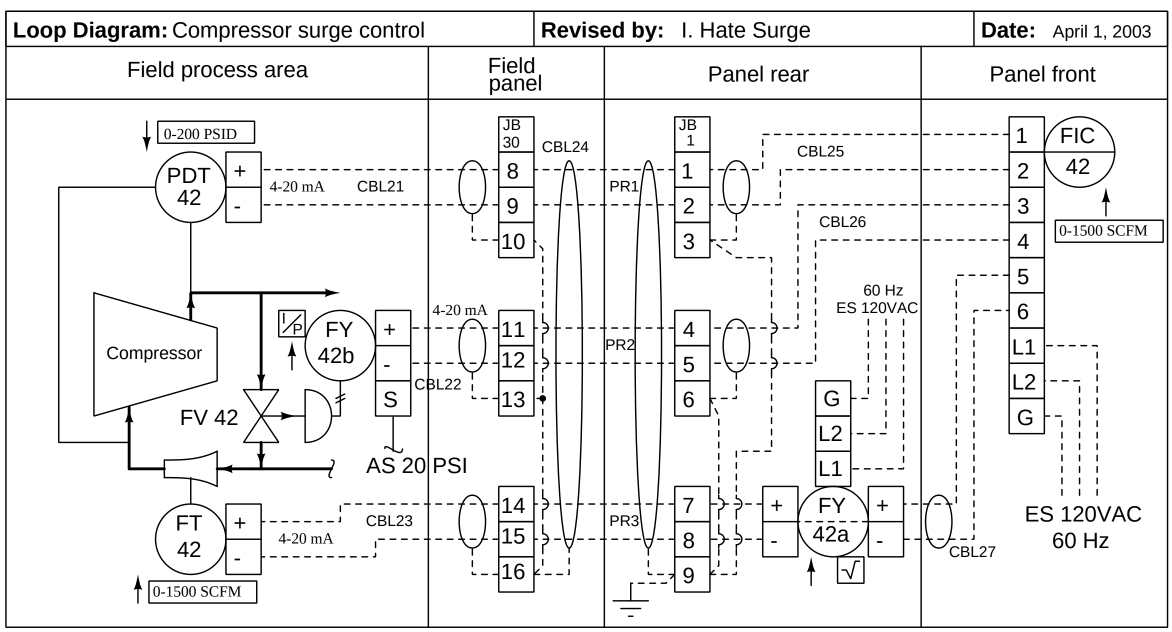
Schematic/pictorial diagram of a pressure transmitter



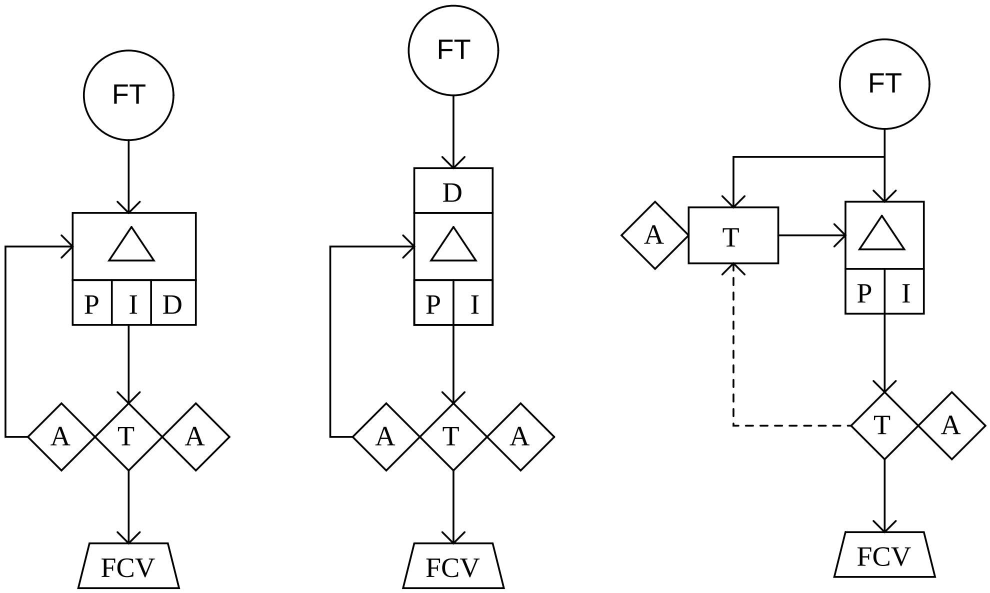
Pictorial diagram of an I/P transducer



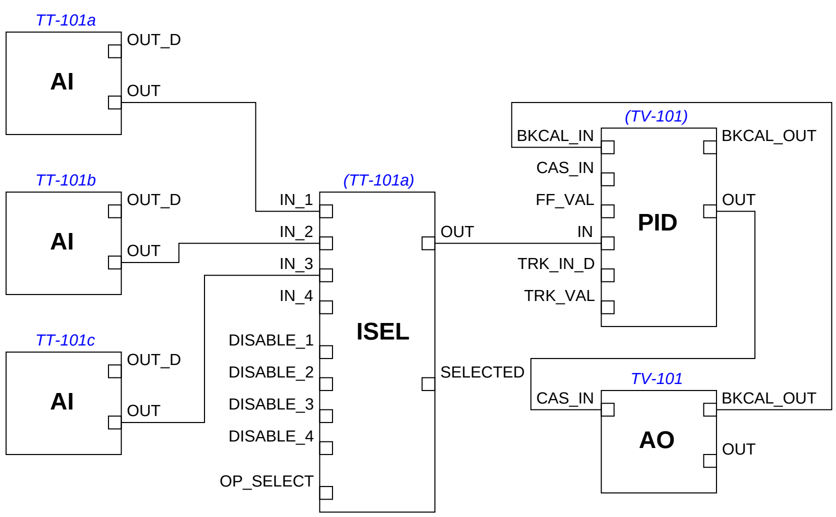
Loop diagram of a compressor surge control system



Functional diagram of control loops



FOUNDATION Fieldbus function block diagram



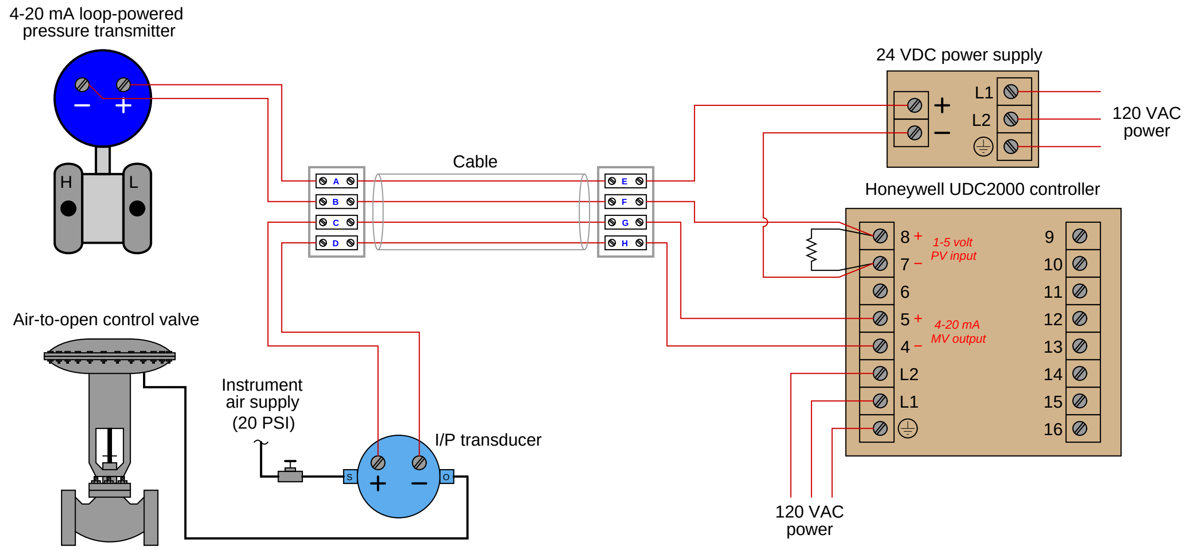
Questions:

- Identify the meaning(s) of all *dashed lines* in these diagrams
- Identify the meaning(s) of all *arrows* in these diagrams
- Identify the meaning(s) of all *triangles* in these diagrams
- Identify the meaning(s) of all *boxes* in these diagrams
- Identify the meaning(s) of all *circles* in these diagrams
- Identify how directions of motion are indicated in each diagram (if at all)
- Identify how sources of energy are indicated in each diagram (if at all)

file i02683

Question 60

This pictorial diagram shows the wiring connections for a simple pressure control loop, where a loop-powered 4-20 mA pressure transmitter sends a signal to a Honeywell controller, which in turn sends another 4-20 mA signal to a control valve:



Suppose the operator informs you that the control valve refuses to open, no matter what value she sets the output of the controller in manual mode. Your job now is to diagnose the problem in this control loop using only basic test equipment (e.g. digital multimeter, hand tools).

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

Diagnostic test	**Yes**	**No**
Place controller in automatic mode		
Measure V_{AB} with controller output set to 100% (manual mode)		
Measure V_{5-4} with controller output set to 100% (manual mode)		
Measure V_{8-7} with controller output set to 50% (manual mode)		
"Crack" open tube fitting at the "S" port on the I/P transducer		
"Crack" open tube fitting at the "O" port on the I/P transducer		
Press the I/P transducer's flapper closer to its nozzle		
Pull the I/P transducer's flapper away from its nozzle		
Tighten the nuts compressing the control valve's stem packing		
Loosen the nuts compressing the control valve's stem packing		
Measure the output voltage of the DC power supply		
Measure voltage across the pressure transmitter terminals		
Measure voltage across the I/P transducer terminals		

file i01298

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.

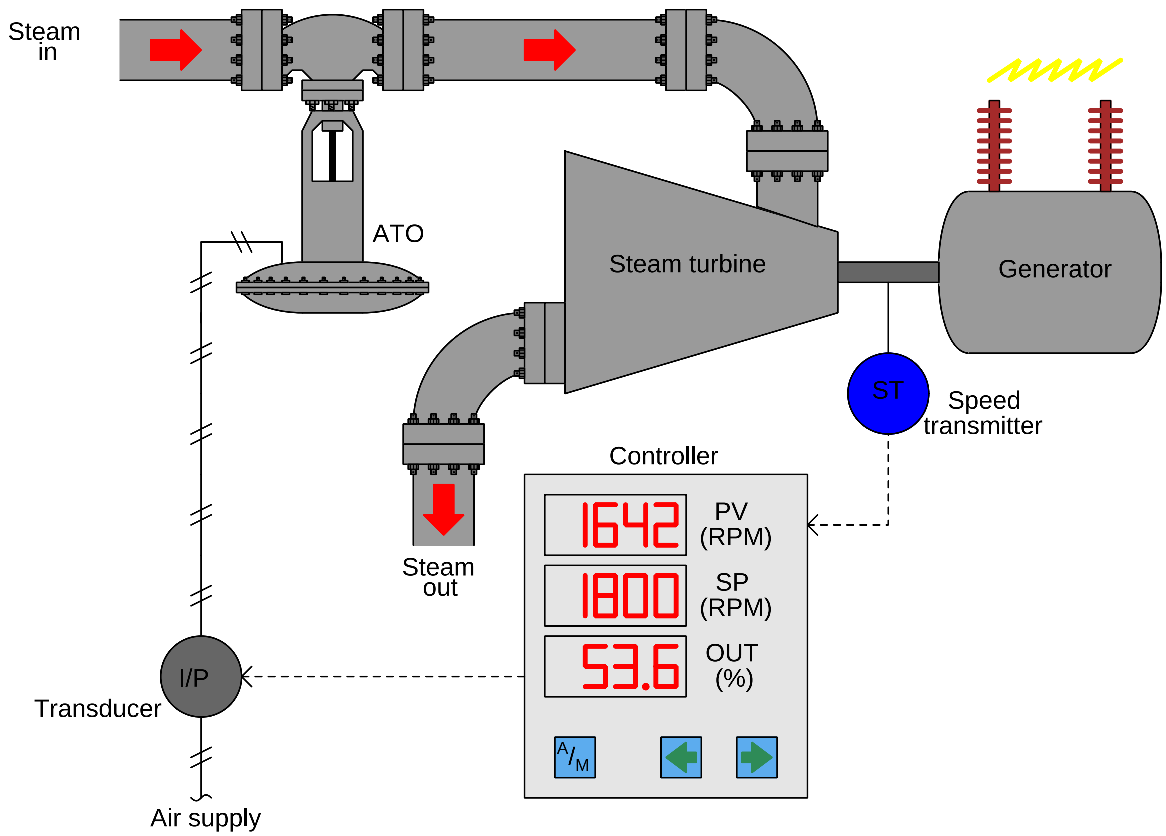
file i00999

Question 62

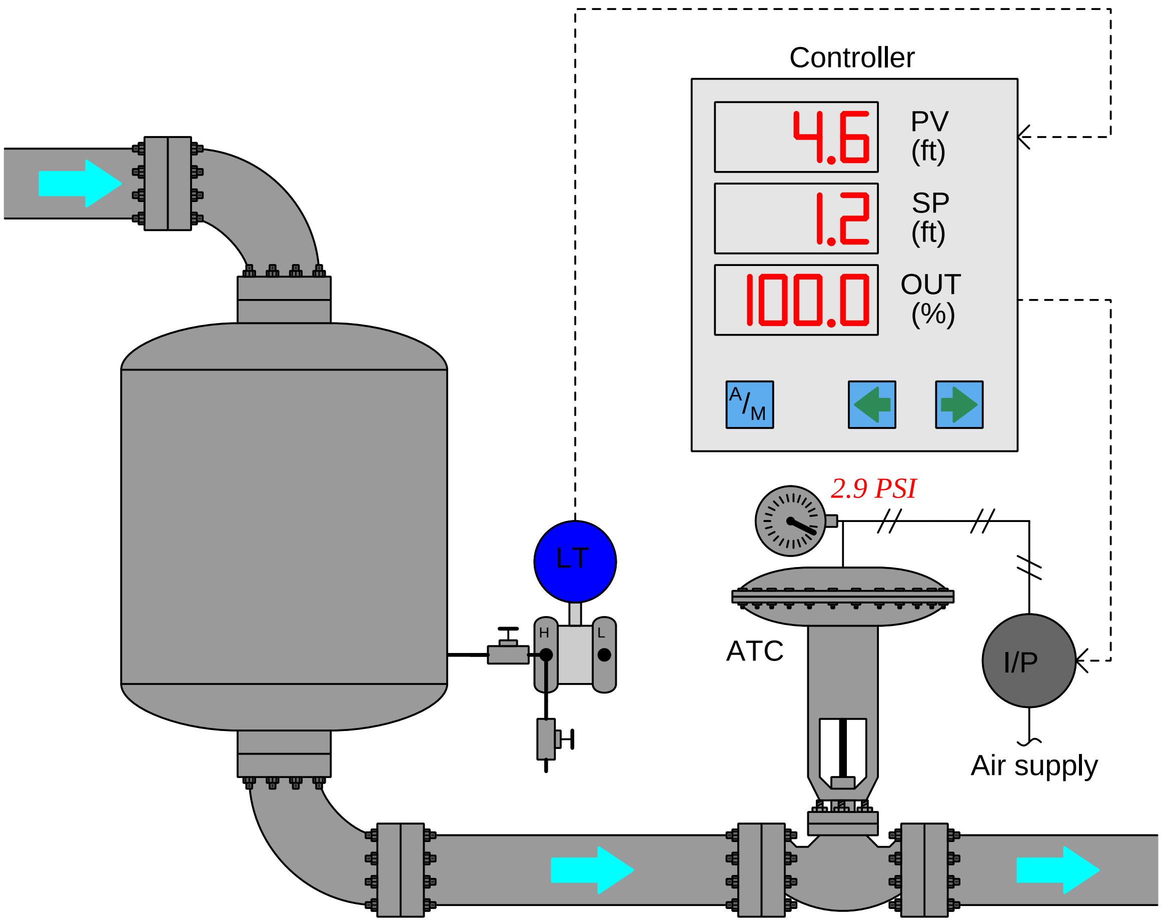
The following processes all have some problem, which may be diagnosed by careful observation of the controller's faceplate display (PV, SP, and Output values) and/or indications given by gauges in the field. Examine each control system and determine the fault in each one from the information given.

Assume that the conditions shown have existed for quite some time (long enough for the control system to have brought the process variable back to setpoint if everything were operating correctly):

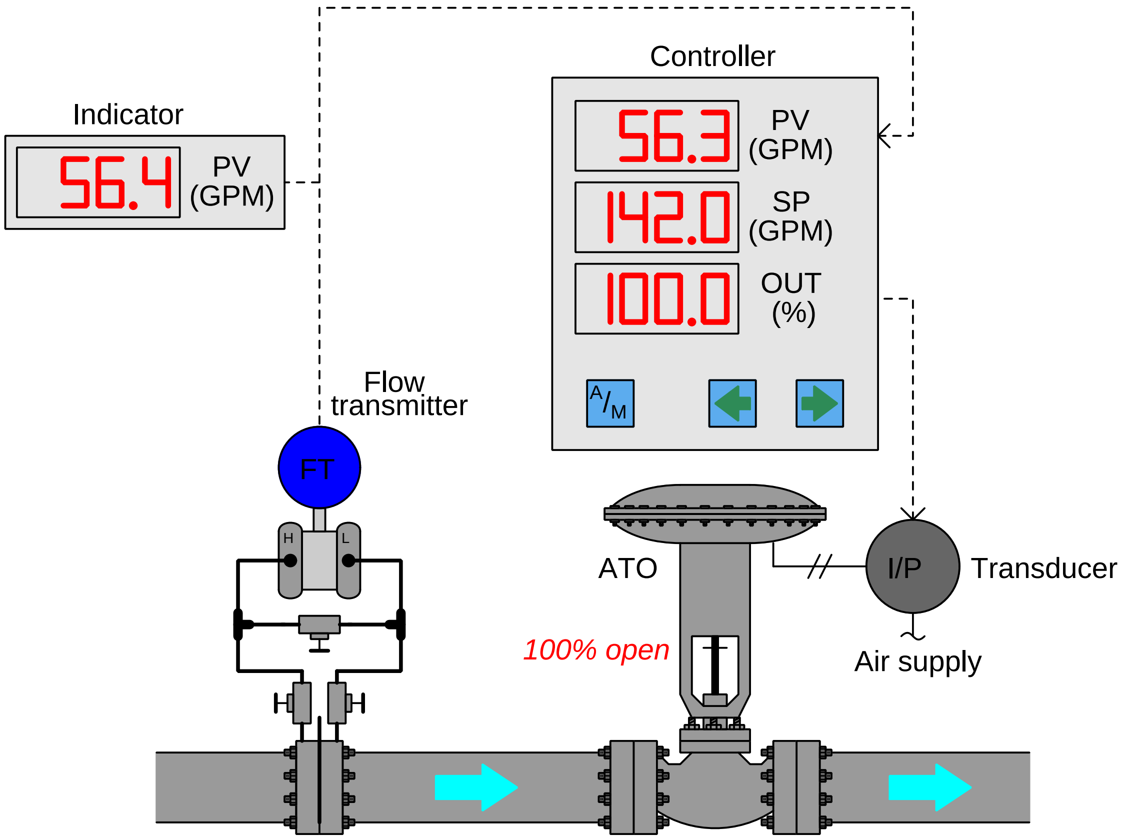
Example 1:



Example 2:


Controller
4.6
PV
(ft)
1.2
SP
(ft)
100.0
OUT
(%)
A/M
2.9 PSI
LT
H
L
ATC
I/P
Air supply

Example 3:



Suggestions for Socratic discussion

- A valuable principle to apply in a diagnostic scenario such as this is *correspondence*: identifying which values agree with each other. Explain how a check of correspondence tells us which instrument is at fault in any of these control loops.
- For each of these scenarios, determine what your next diagnostic test might be to further pinpoint the location and nature of the problem.

file i00643

Question 63

Site visit!

As part of today's inverted theory session, you will meet your instructor at a site containing real process equipment, where you will apply your knowledge of control valves and fluid systems to various processes there. Prepare yourself to do the following while on site:

- Measure vessel dimensions (length, diameter)
- Calculate surface areas of vessels and the amount of force generated by fluid pressure on those surfaces
- Identify different control valve types and applications
- Select appropriate control valve fail-safe mode for a given process, and then select the necessary controller action (e.g. direct or reverse) to properly control that valve
- Sketch diagrams showing how to install 3-way solenoid valves to override pneumatic control valve actuators
- Wear safety glasses and sturdy (closed-toed) shoes

file i01739

Question 64

Read selected portions of the "Fisher Type 1098-EGR and 1098H-EGR Pilot-Operated Regulators" product bulletin (document 71.2:1098-EGR), and answer the following questions:

Page 4 shows excellent illustrations of the regulator body and actuator assemblies, as well as internal views of the pilot mechanism. Identify the type of valve trim used to throttle process fluid (stem-guided, cage-guided, port-guided), and also whether the valve body is *direct* or *reverse* acting. Additionally, explain how the valve plug position may be monitored while the regulator is in service.

The purpose of the *pilot* is to provide a *loading pressure* to the actuator of the 1098 pressure regulator. Page 6 explains how the pilot provides this loading pressure to the main actuator. Explain what this "loading pressure" does to the main regulator mechanism, and also how the regulator self-adjusts to changes in the downstream pipe pressure. Also, identify the fluid used to actuate the regulator – it is *not* instrument air!

What type of *stem packing* do you see used in this valve? Explain why you think the valve is designed in this way.

Suggestions for Socratic discussion

- A powerful problem-solving technique is performing a *thought experiment* where you mentally simulate the response of a system to some imagined set of conditions. Describe a useful "thought experiment" for this system, and how the results of that thought experiment are helpful to answering the question.
- Fisher's *Fundamentals of Gas Pressure Regulation* (Technical Monograph 27) by Floyd D. Jury gives a fairly comprehensive explanation of pressure regulators, including pilot-operated regulators. No photographs in this document, but a good amount of simple illustrations are provided. If you have lingering questions after reading the Fisher 1098 product bulletin, peruse this monograph.

file i00783

Question 65

Read the National Transportation Safety Board's pipeline accident brief (DCA-97-FP-002) of the 1996 diesel pipeline rupture in Murfreesboro, Tennessee, and answer the following questions.

Identify the physical cause(s) of the pipeline rupture: what exactly caused the pipeline pressure to rise to the point where it ruptured the line?

One of the factors contributing to this accident was an incorrect schematic on the SCADA system display screen for the Murfreesboro pumping station. Describe what was incorrect about this schematic, and how this error mis-led the human operator monitoring it.

Why did the electric block valve at the Murfreesboro station refuse to open when the operator commanded it to open at 9:35:02 AM? Based on your knowledge of different control valve types, explain why a valve such as this would be affected in this manner.

A technician called to inspect the electric block valve and its associated control equipment at the Murfreesboro pumping station reported there "were no problems." What do you think of this assessment, given what you know about the valve and why it was not opening? Did the technician thoroughly check the valve, in your estimation?

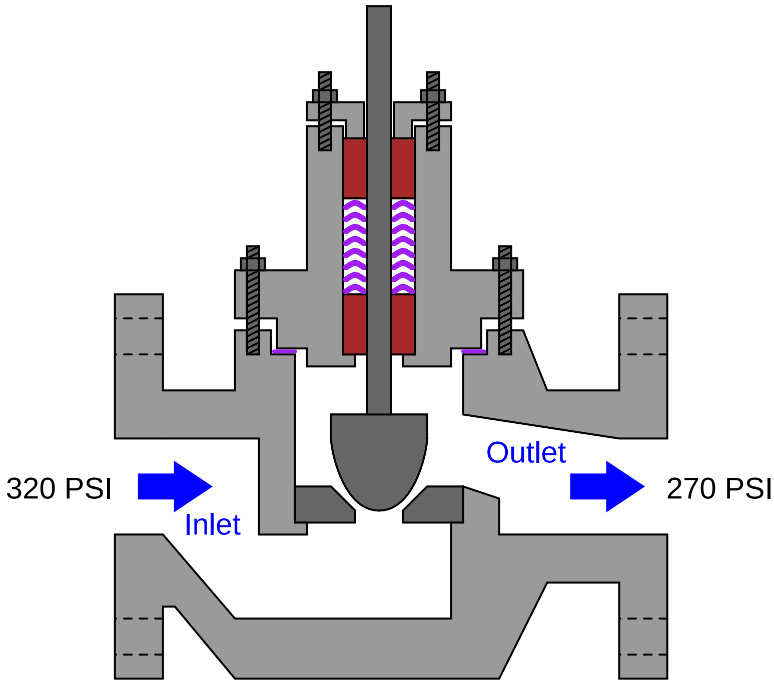
Suggestions for Socratic discussion

- Page 3 of the report mentions a "depressurization wave" taking 74 seconds to travel through the pipeline from the rupture site to Coalmont. What do you think a "depressurization wave" is, and how does this relate to Pascal's Principle?
- Identify ways an instrument technician could have helped to prevent this pipeline rupture.

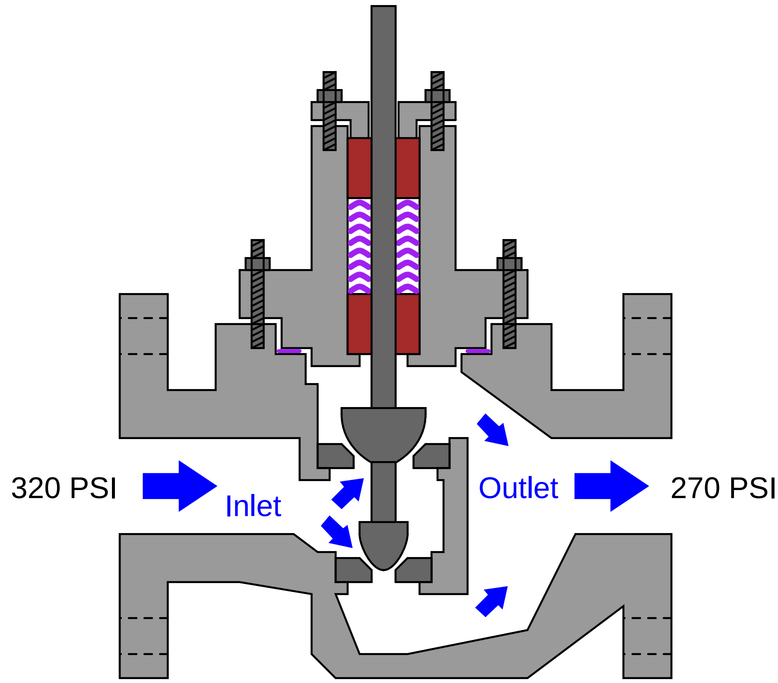
file i00785

Question 66

Suppose we had a single-ported globe valve such as this controlling fluid flow, with inlet and outlet pressures as shown in the illustration. If the plug has a cross-sectional area of 3 square inches, how much force will be exerted on the plug by the fluid? In which direction will this force be exerted?



Now suppose we replace the single-ported globe valve with a *double-ported* globe valve of similar operating characteristics. Given the same inlet and outlet pressures, how much (net) force will be exerted on the plugs by the fluid? Assume the upper plug has a cross-sectional area of 3 square inches, and the lower plug a cross-sectional area of 2 square inches:



Which of these two control valves will be easier to position (i.e. require less actuating force), all other factors being equal?

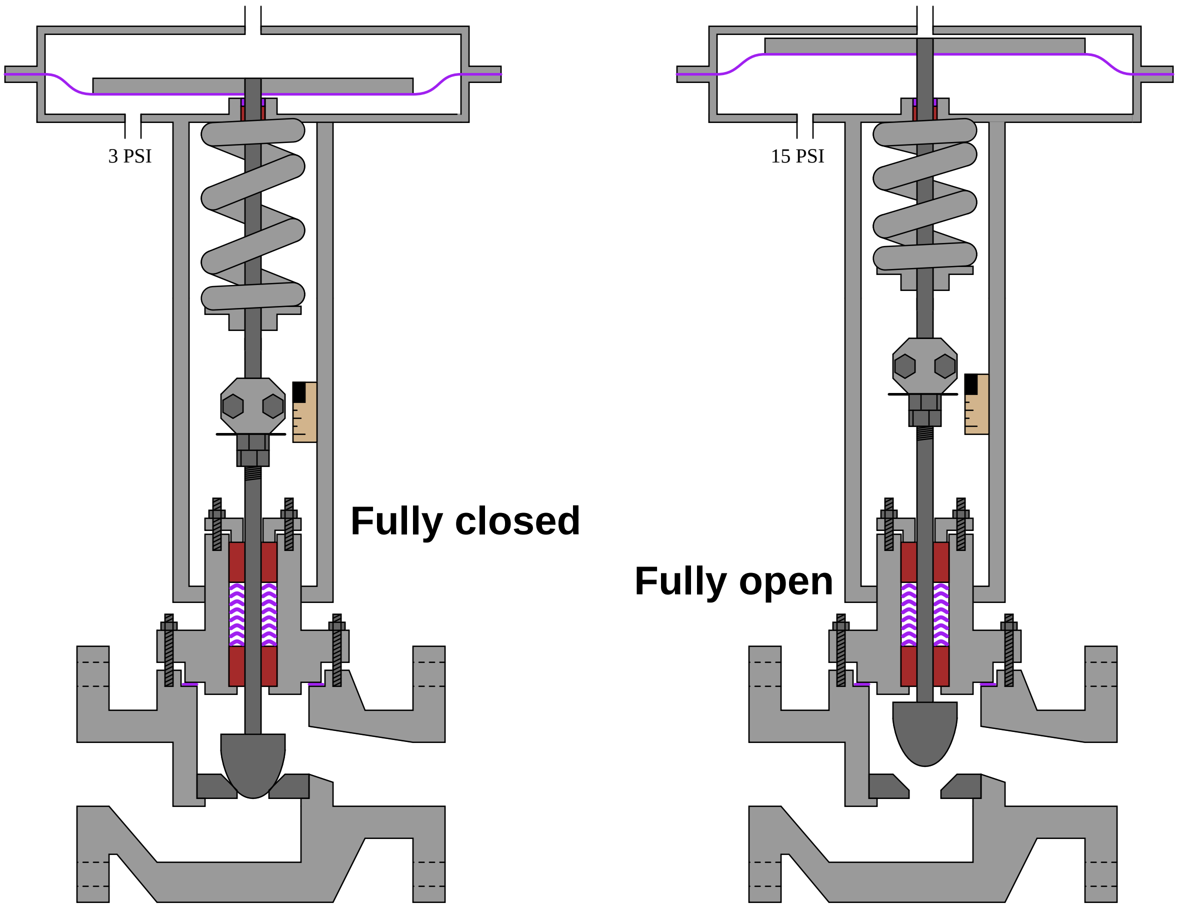
Suggestions for Socratic discussion

- For the valve requiring less actuating force, are there any disadvantages to the design? Clearly, lower actuating force is a good thing, so there must be some drawback to this design or else *all* control valves would be manufactured this way!
- Is the direction of flow arbitrary for this control valve, or is there a reason why the flow should be passing *up* past the plug rather than *down* past it?
- Does the packing of a double-ported control valve need to be different than the packing of a single-ported valve? Why or why not?

file i00772

Question 67

This pneumatically-actuated globe valve assembly is comprised of a pneumatic actuator joined to a globe control valve. It is very important for proper valve operation to correctly set the "travel" on the valve, so the plug moves exactly as far as the travel indicator's range, no more and no less. The control valve assembly below has properly set stem travel – full travel exactly matches the 0% and 100% marks on the travel indicator.



Explain *in detail* what could cause a control valve assembly to have too little stem travel, and identify what operational problem(s) may result from insufficient travel.

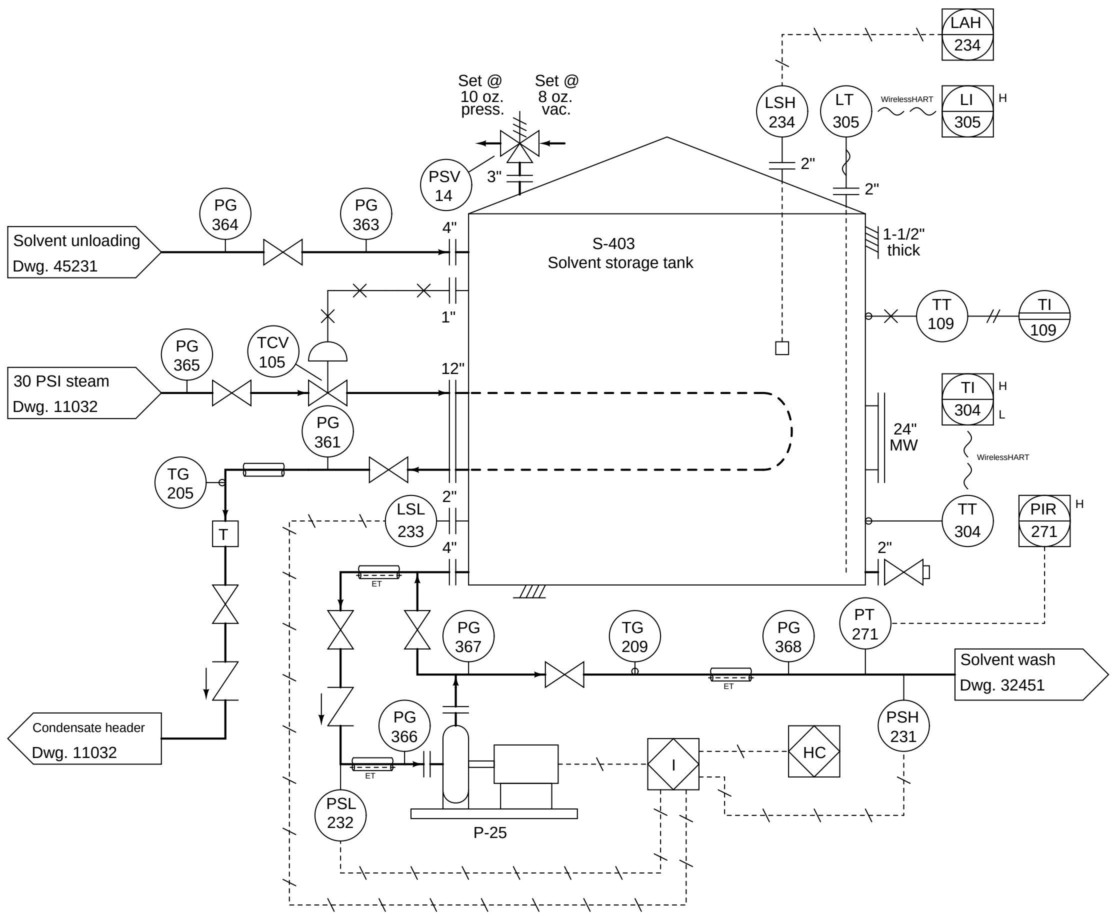
Suggestions for Socratic discussion

- Identify in the illustrations exactly where the valve stem's motion will be "blocked" from being able to move freely, given the cause you identify for insufficient stem travel.

file i01631

Question 68

This solvent storage tank is kept heated to 95 degrees F by a steam heat exchanger inside the tank. Steam is admitted to the exchanger "loop" through temperature control valve TCV-105, and exits the loop through a steam trap:



The tank's temperature control system is interesting, in that there is neither a temperature transmitter nor a temperature controller, just a self-actuated temperature control valve. The line connecting TCV-105's actuator with the tank (the one with the "X" symbols along its length) is a *capillary tube* filled with a liquid that expands with temperature. The far end of this tube (inside the tank) terminates in a sealed metal bulb, so there is no way the fluid inside the tube can escape.

First, explain how this temperature control system functions during normal operation.

Next, identify what you would have to mechanically adjust on TCV-105 in order to raise the temperature setpoint for the storage tank.

Finally, identify the fail-safe state of this temperature control valve.

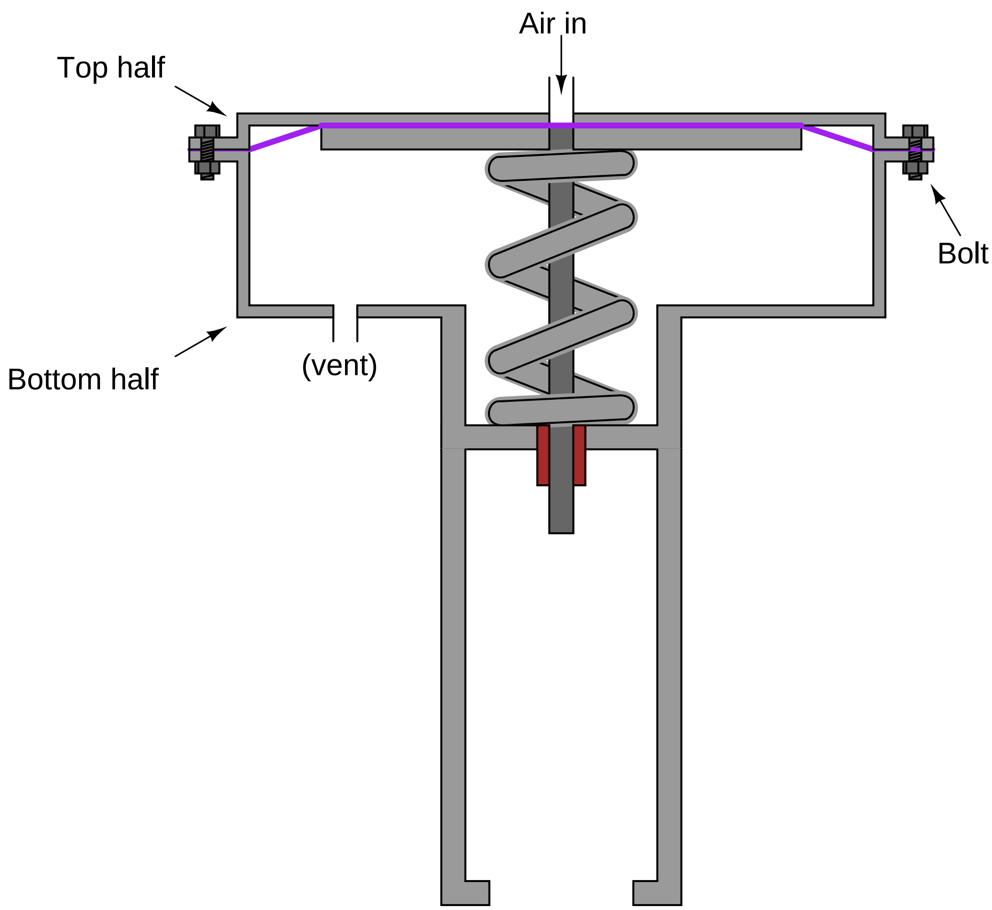
Suggestions for Socratic discussion

- Identify the meaning of the dashed line inside the solvent storage tank. Does this mean the same thing as the dashed lines outside of the tank? How can we tell one way or the other?

file i03444

Question 69

Pneumatic diaphragm and piston actuators are usually equipped with powerful springs to ensure a particular fail mode. Take for instance this illustration for a pneumatic diaphragm actuator:



A series of nuts and bolts hold the upper and lower halves of the actuator together. These same bolts hold back the spring's force, which makes them potentially dangerous to remove! If one was to simply remove all the bolts at once, the top half of the actuator would fly off from the bottom half, possibly causing injury or equipment damage.

How, then, can we safely disassemble the actuator? How may we relieve the tension from the large spring safely *before* we completely separate the top half of the actuator from the bottom half?

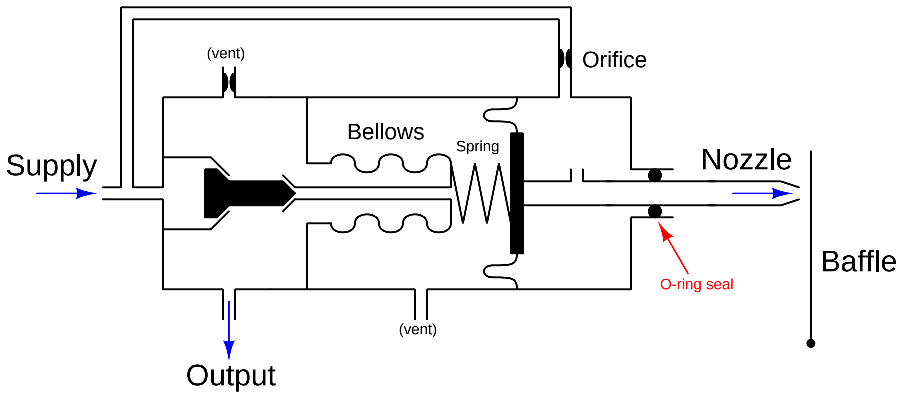
Suggestions for Socratic discussion

- Is this a *direct* or *reverse* acting actuator?
- Does the spring operate in a mode of *tension* or of *compression*?
- If this actuator were connected to a *direct-acting* control valve body, would the resulting valve assembly be *air-to-open* or *air-to-close*?
- If this actuator were connected to a *reverse-acting* control valve body, would the resulting valve assembly be *fail-open* or *fail-close*?

file i00789

Question 70

Analyze the operation of this pneumatic mechanism, identifying whether you think it is *force-balance* or *motion-balance* in nature:



Suggestions for Socratic discussion

- Explain how an *O-ring seal* functions, based on its representation in this diagram. What, exactly, is it sealing? Does it permit motion, or it is a stationary component?
- A powerful problem-solving technique is performing a *thought experiment* where you mentally simulate the response of a system to some imagined set of conditions. Describe a useful "thought experiment" for this system, and how the results of that thought experiment are helpful to answering the question.
- Identify how you could alter the *bias* (or *zero*) of this pneumatic mechanism. What components, if any, would need to be replaced?
- Identify how you could alter the *gain* (or *span*) of this pneumatic mechanism. What components, if any, would need to be replaced?

file i00880

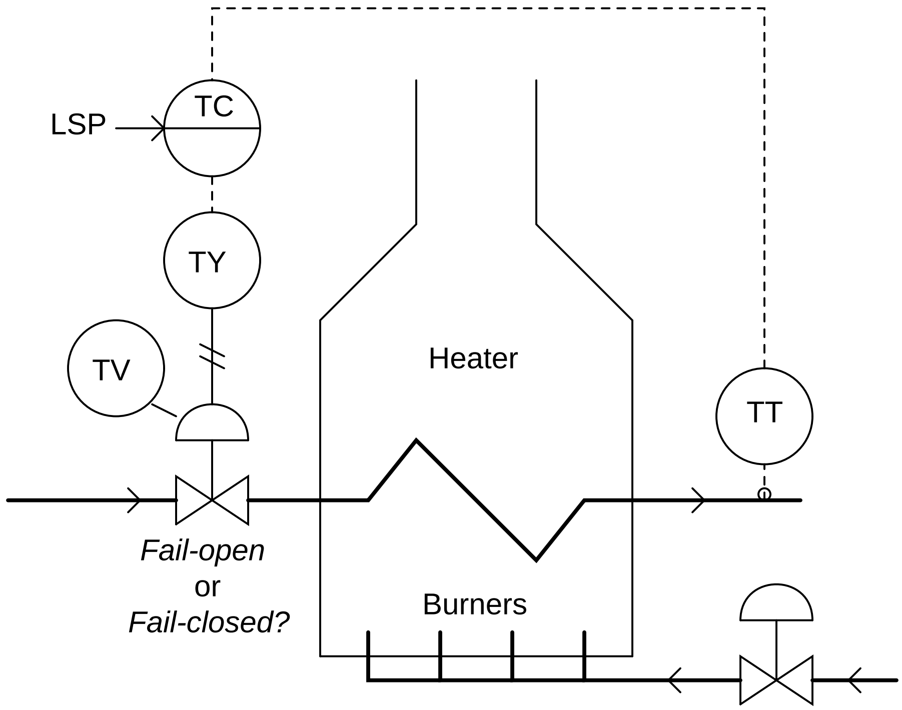
Question 71

Define *fugitive emission* as it applies to valves, and explain how these emissions may be mitigated through proper valve selection and maintenance.

file i00876

Question 72

Suppose we are using a control valve to throttle the flow of crude oil through a heater, fired by natural gas burners:



The flow is normally controlled on the basis of the crude oil's exiting temperature from the heater. In this particular application, should we choose a fail-closed or a fail-open valve? Why? Also, if the valve in question is actuated by a pneumatic spring-and-diaphragm assembly, will this be an air-to-close or an air-to-open valve?

Finally, once you have determined the proper failure mode for the valve, determine the proper control action (direct or reverse) for the controller.

Suggestions for Socratic discussion

- Articulate a strategy for analyzing such systems step-by-step, so that you *know* you have arrived at the correct answer(s).
- For those who have studied thermocouple temperature transmitters, determine whether the TT should be configured for *upscale* or *downscale* burnout.

file i00793

Question 73

Like all mechanical devices, control valves experience some mechanical friction in their movement. What effect will it have on a process if the control valve experiences significant friction?

Hint: if you are having difficulty visualizing the effects of valve friction on *control system performance*, imagine trying to drive a car with a lot of friction in the steering mechanism (making it very difficult to turn the steering wheel to new positions).

Suggestions for Socratic discussion

- Explain how you could empirically determine the amount of friction on the stem of a sliding-stem valve without disassembling the valve in any way.
- Note the suggested use of an *analogy* to help understand the effects of valve friction on control performance. While often helpful in explaining concepts, reasoning by analogy may lead to misunderstandings. Explain why this is so, and identify what situations analogies may be trusted for conceptual comprehension.

file i00786

Question 74

Two very popular valve packing materials are *graphite* and *Teflon*. Both materials possess inherent lubricating properties, which is a very good trait for a packing material in a control valve. However, there exist substantial differences in performance and application of these two packing materials. Elaborate on these differences, and identify processes where each would be applicable.

Also, explain what a *bellows seal* is, and how it is a completely different way to seal the stems of valves compared to either Teflon or graphite packing.

Suggestions for Socratic discussion

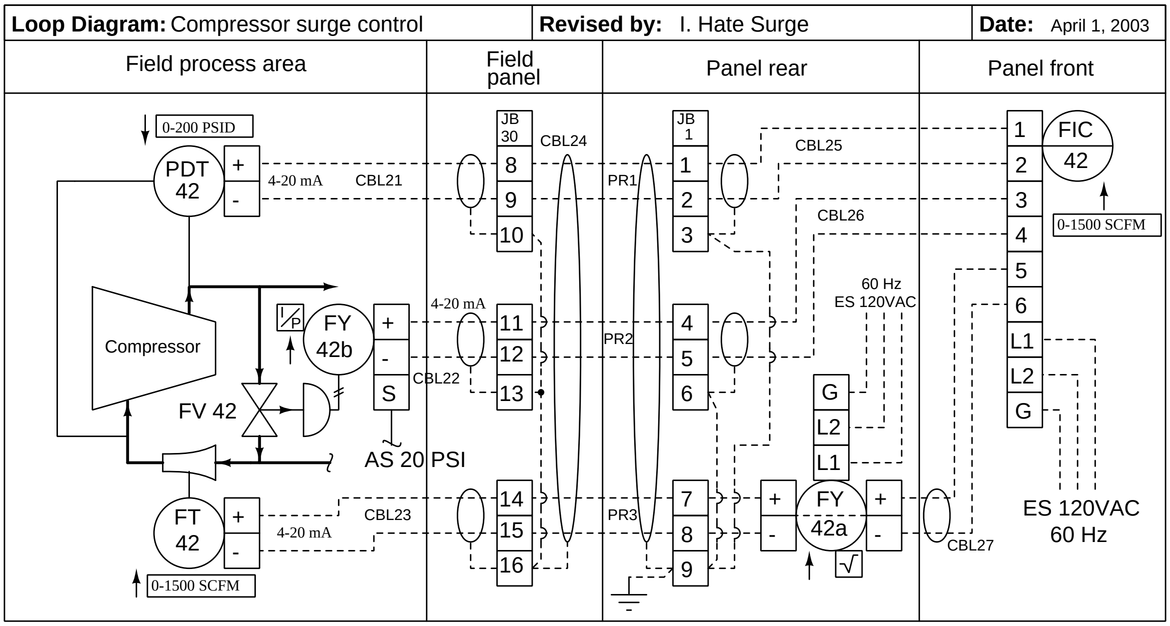
- Bellows seals exhibit some wonderful advantages over friction-type packings, but they suffer some major disadvantages as well. Identify some of the major limitations of bellows seals when used to seal control valve stems.

file i00878

Question 75

Fail-safe control system design does not end with the control valve, although it does begin with it. In order to maximize the safety of the control system in critical applications, the designer should choose a configuration for *each instrument in the loop* that leads to the exact same (safest) failure mode.

Closely examine the following loop diagram for a compressor surge control system, designed to open bypass valve FV-42 in the event that differential pressure across the compressor becomes too great and/or flow through the compressor becomes too little. When valve FV-42 opens, it shunts gas flow from the outlet to the inlet of the compressor, both increasing compressor gas flow and decreasing differential pressure:



Take special note of the up or down arrows next to each instrument's calibrated range in the diagram. These arrows indicate the *action* of the instrument, either direct or reverse. An up arrow (↑) near the instrument indicates direct action: the instrument's output increases as its input increases. A down arrow (↓) near the instrument indicates a reverse-action instrument: one whose output decreases as its input increases.

Perform a series of "thought experiments" whereby you analyze the action of the control system (to bypass the compressor or not to bypass the compressor) in the event of *any* break in *any* cable. Explain how the system responds in each case, step by step, resulting in the safest condition every time.

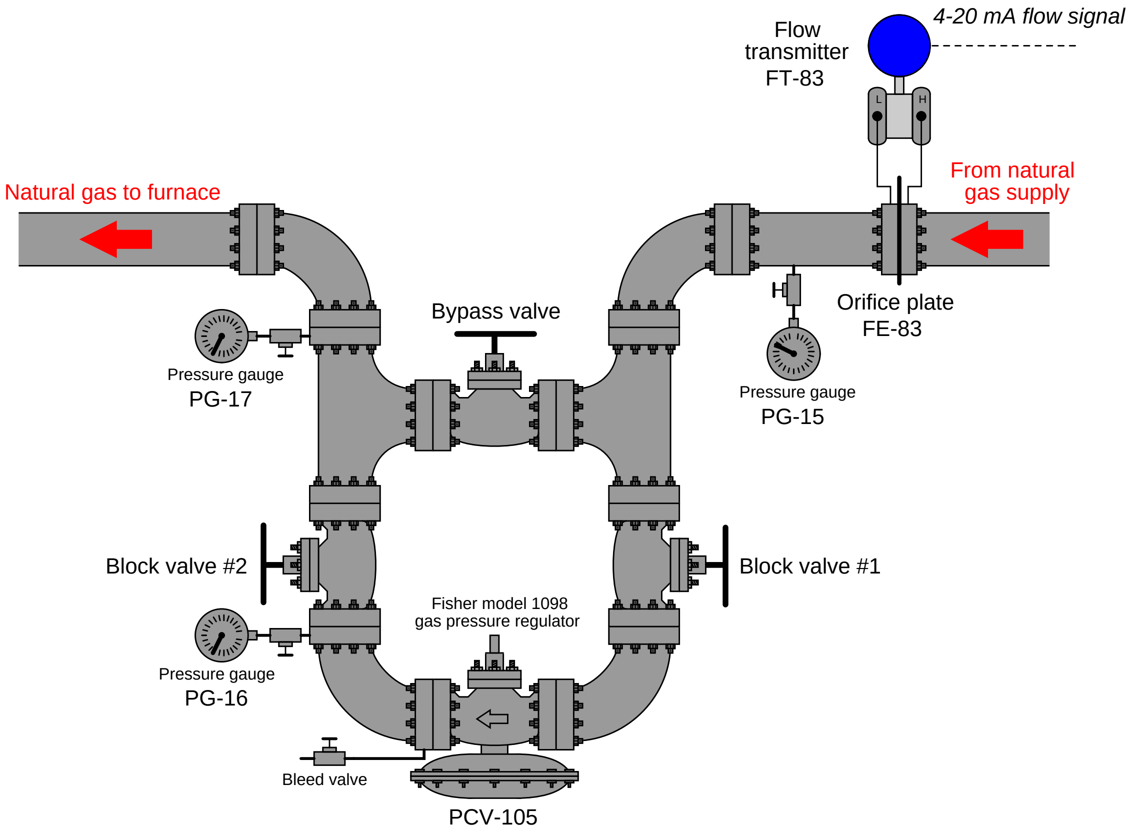
Suggestions for Socratic discussion

- Explain why the shield conductor of each cable is grounded only at one end, not at both ends.
- Explain why such "thought experiments" are useful techniques for analyzing control systems, and why you as a technician should become comfortable with applying this problem-solving technique on the job.

file i00794

Question 76

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 77

Question 78

Question 79

Question 80

Question 81

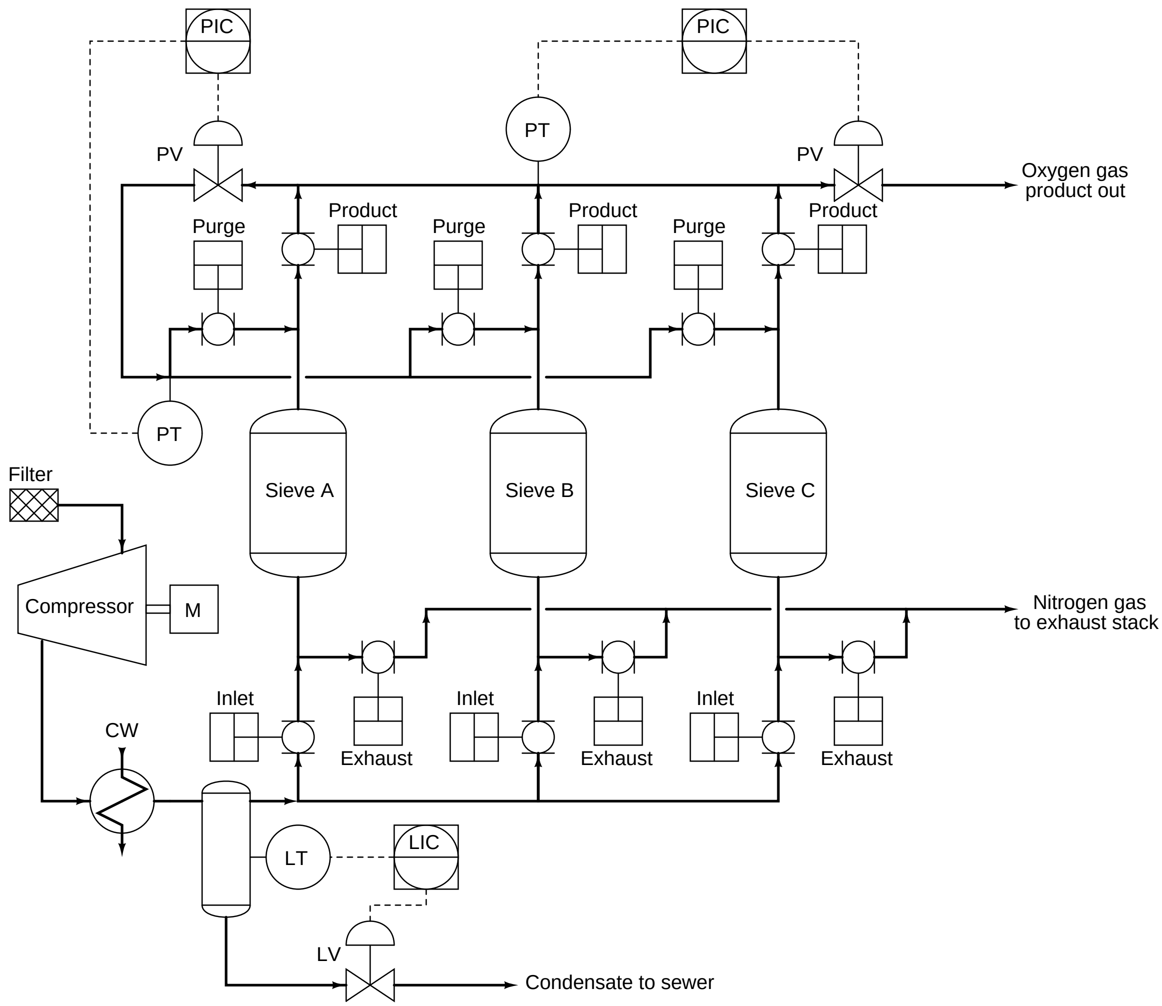
Complete the following table of equivalent pressures:

Atm	PSIG	bar (gauge)	kPa (absolute)
23			
	-2		
		16	
			0
		-0.4	
			72.5
	580		
0.81			

file i00055

Question 82

The *Pressure Swing Adsorption* (PSA) process uses a set of extremely fine filter elements called *molecular sieves* to "strain" nitrogen molecules from air, allowing oxygen and lighter gases to pass through:



A control system sequences the ball valves such that one vessel adsorbs (filters out nitrogen from air) while the other two regenerate (backflush with oxygen gas to purge out all the trapped nitrogen).

Identify which valves are open and which valves are closed during the portion of the cycle where vessel A is adsorbing, and vessels B and C are both regenerating. Trace the flow of air, oxygen, and (backwashed) nitrogen through all process lines.

file i00056

Question 83

An electric-to-pneumatic signal transducer has an input range of 4-20 mA and an output range of 3-15 PSI. Complete the following table of values, assuming zero calibration error. Show the equations used to calculate all values given the percentage of span (x):

Input current (mA)	Percent of span (%)	Output pressure (PSI)
6.6		
		8.5
	71	
		4.7

Equations used:

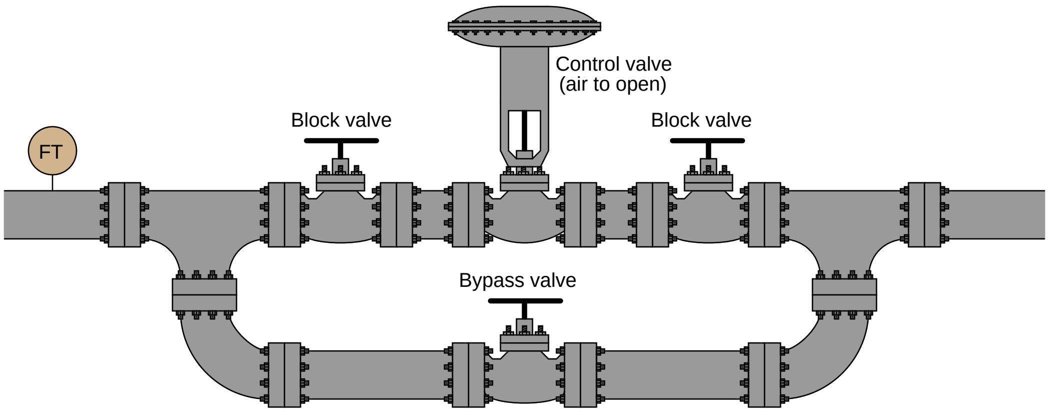
Input current =

Output pressure =

file i00057

Question 84

A flow transmitter measuring process liquid flow through this valve array registers 5 GPM (out of a 0-1800 GPM measurement range) when the control valve is fully closed. An operator shows you this, declaring the control valve to be leaking (internally).



An instrument technician called out to investigate decides to shut the upstream block valve as a diagnostic test. After doing this, the flow transmitter still registers 5 GPM.

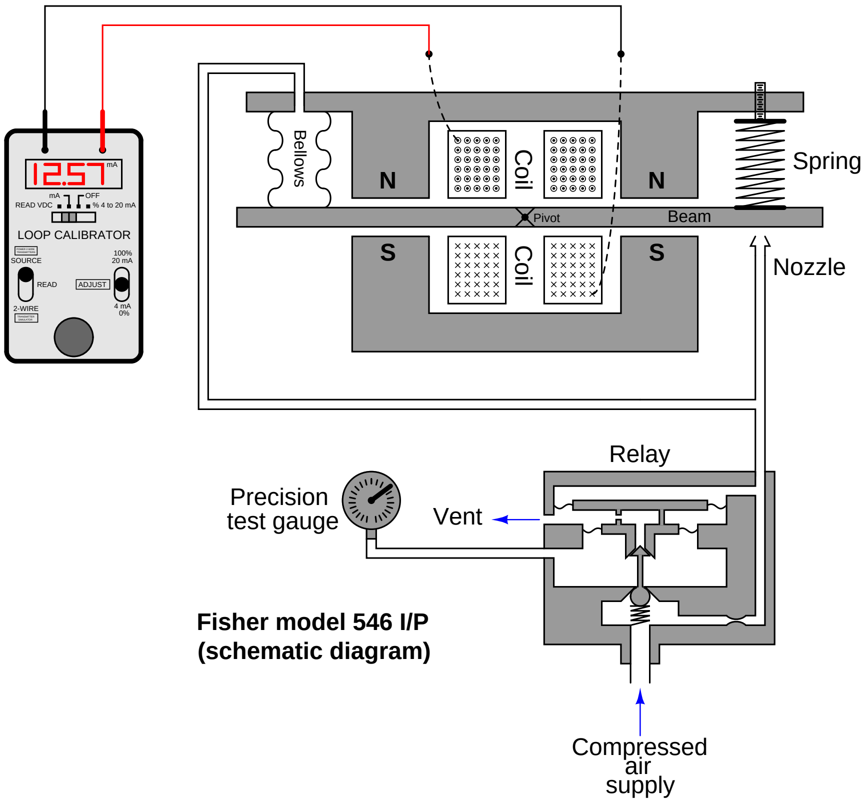
Identify the likelihood of each possible fault in this list by checking boxes in the table – whether the fault is "probable" (worth considering as a cause of this system's trouble) or is "unlikely" (either completely ruled out as a cause, or just not worth considering at this point in the diagnosis) – following the results of the technician's test:

Fault	**Probable**	**Unlikely**
Control valve trim leaking		
Downstream block valve leaking		
Bypass valve leaking by		
Low supply air pressure to control valve		
Bypass valve plugged		
Air leak in control valve diaphragm		
Improper control valve bench-set		
4-20 mA loop wiring failed shorted		
Flow transmitter out of calibration		

file i00058

Question 85

Suppose a Fisher model 586 I/P converter is set up on a bench for a calibration test:



The "As-Found" calibration table for this converter tests as follows:

Input current	Output pressure
4.00 mA	2.97 PSI
8.00 mA	5.98 PSI
12.00 mA	9.00 PSI
16.00 mA	11.37 PSI
20.00 mA	11.37 PSI

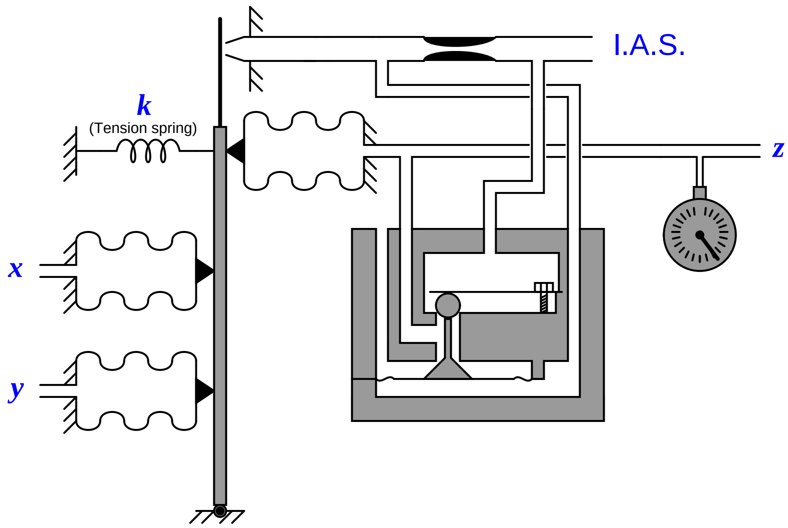
Two fellow instrument technicians observing this test disagree as to the causes of the 75% and 100% errors. One says this transducer has a *span* error and may be corrected by adjusting the span screw, while the other one says the problem cannot be corrected by any calibration (zero or span) adjustment.

What is your assessment of this instrument's problem? Identify at least one realistic cause, and propose a remedy to correct the error.

file i00059

Question 86

Identify which mathematical formula best describes the function of this pneumatic relay mechanism, assuming the positions of all bellows are drawn to scale:



$$z = \frac{x+y}{2} - 3k$$

$$z = \frac{x-y}{3} + 2k$$

$$z = 2y + x + \frac{k}{3}$$

$$z = \frac{y}{3} + \frac{2x}{3} - k$$

$$z = 2k + x - 3y$$

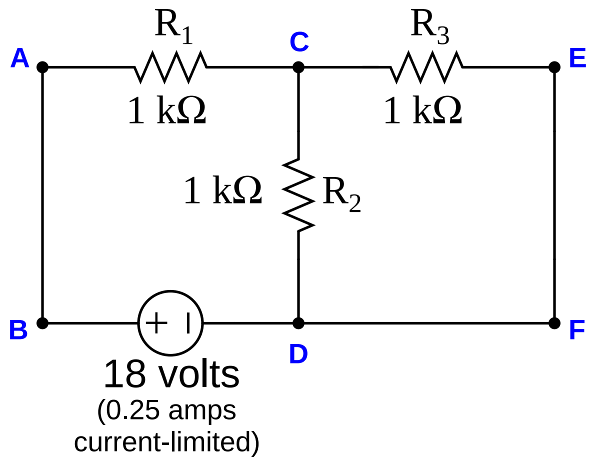
$$z = 2(y - x) - 3k$$

Also, identify whether this mechanism is *force balance* or *motion balance*.

file i00939

Question 87

Suppose a voltmeter registers 0 volts between test points **C** and **B** in this series-parallel circuit:



First, calculate the voltage which *should* appear between points **C** and **B** in a healthy circuit. Then, identify the likelihood of each specified fault for this circuit given the symptom of 0 volts between those test points. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this circuit.

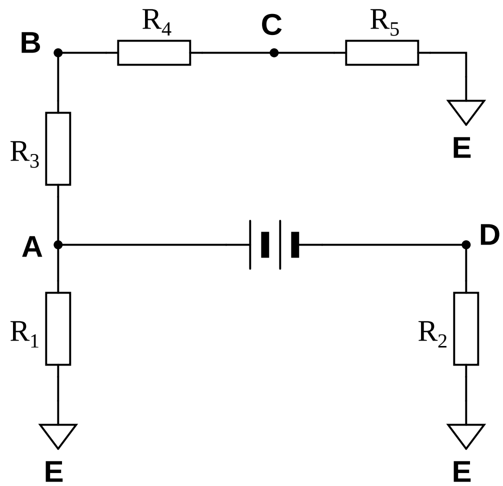
Fault	**Possible**	**Impossible**
R_1 failed open		
R_2 failed open		
R_3 failed open		
R_1 failed shorted		
R_2 failed shorted		
R_3 failed shorted		
Voltage source dead		

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 i03157

Question 88

Determine what will happen to the following voltage drops (between specified test points in the circuit) if the resistance of resistor R_3 happens to decrease:

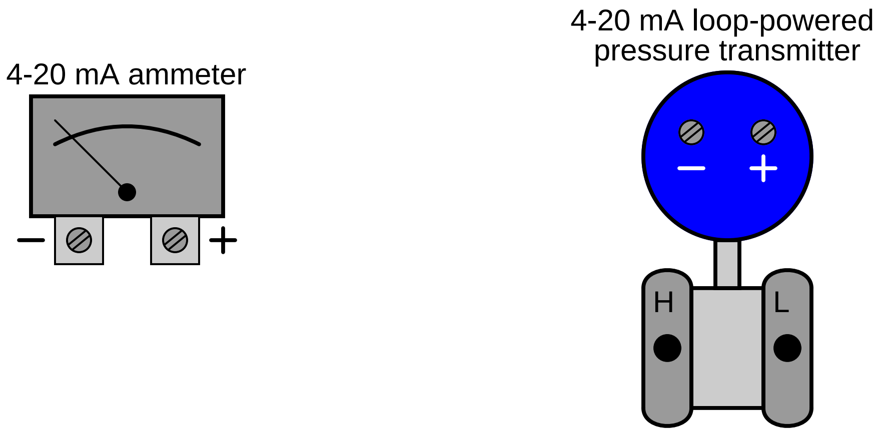


- V_{AC} = (*increase*, *decrease*, or *stay the same*)
- V_{BE} = (*increase*, *decrease*, or *stay the same*)
- V_{AD} = (*increase*, *decrease*, or *stay the same*)
- V_{CD} = (*increase*, *decrease*, or *stay the same*)

file i02914

Question 89

Sketch a circuit whereby this loop-powered pressure transmitter sends a signal to an analog current meter (acting as a remote pressure gauge). Include any necessary power sources in your completed circuit:

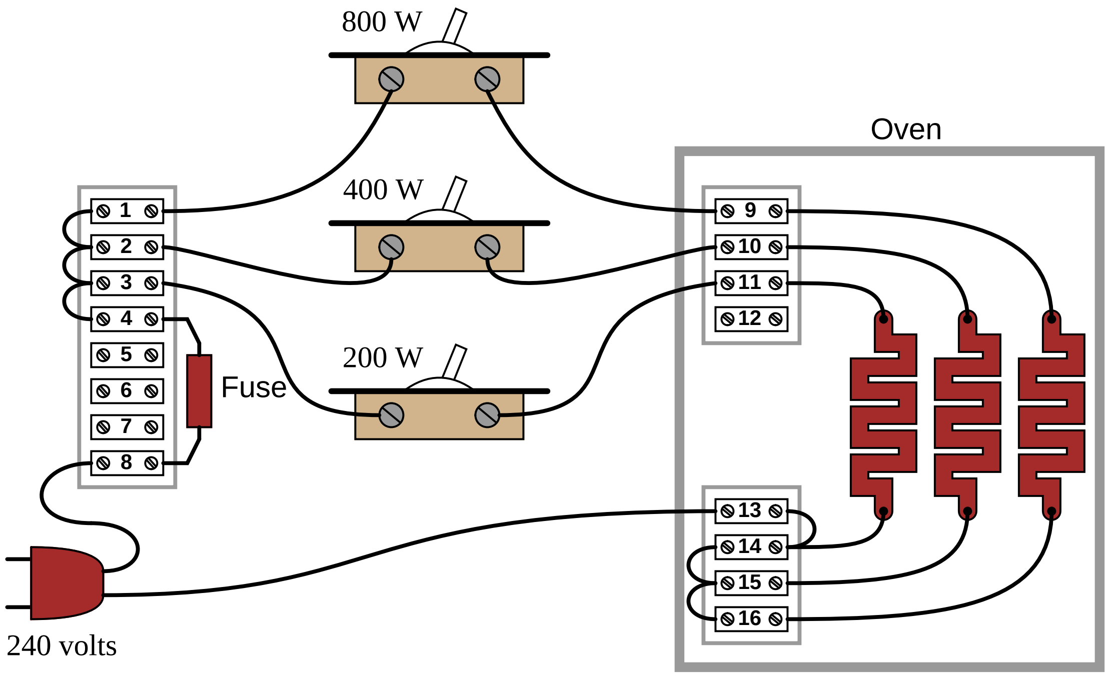


Also, identify each component in the circuit as being either a *Source* or a *Load* and annotate the direction of each component's current using an arrow pointing in the direction of conventional flow.

file i03202

Question 90

The following electric heater seems to have a problem: it heats up slower than usual with all three switches turned "on."



With three differently-sized heating elements (200 watt, 400 watt, and 800 watt), the oven operator can set the power in seven discrete steps by turning on specific combinations of switches: 200 watts, 400 watts, 600 watts, 800 watts, 1000 watts, 1200 watts, and 1400 watts.

You are summoned to diagnose this oven's problem *without turning it off*. You are allowed to turn off any single switch for a few seconds at most, but otherwise you need to leave all three heaters on because the oven needs to heat up as fast as it can! The idea is to figure out where the problem might be, then gather together any parts necessary for repairs while the oven is still being used, and fix the oven as fast as possible when you finally get the chance to turn it off completely.

Using a magnetic "clamp-on" ammeter to measure current without breaking the circuit, you read 4.9 amps through the wire between the power plug and terminal 13 with all three switches in the "on" position. Then, you momentarily turn the "800 watt" switch off and on, watching the current fall from 4.9 amps to 1.7 amps and then return to 4.9 amps.

Based on this data, identify two things:

- Two components or wires in the oven circuit that you know must be in good working condition.

- Two independent components or wires in the oven circuit that could possibly be bad (and thus cause the slow heating problem), including the type of fault (open or short) you suspect.

file i03163

Question 91

Lab Exercise – introduction

Your task is to completely disassemble, reassemble, and bench-set a pneumatically actuated control valve, preferably a Fisher (Emerson) E-body globe valve. Also, you will build a control loop to actuate that valve with an electronic 4-20 mA signal, using an I/P transducer as the signal converter between the electronic controller and the pneumatic valve. The controller will be a "Hand Indicating Controller" (HIC), and all other instruments in the loop shall have "Hand" (H) as the process variable designator, since this will be a manually controlled valve with no transmitter or sensing element.

Objective completion table:

Performance objective	**Grading**	**1**	**2**	**3**	**4**	**Team**
Team meeting and prototype sketch	mastery	–	–	–	–	
Control valve disassembly	mastery	–	–	–	–	
Valve component identification	mastery					– – – –
Torque wrench usage	mastery					– – – –
Proper stroke length and bench-set	mastery	–	–	–	–	
I/P calibration (with As-Found/As-Left)	mastery	–	–	–	–	
Circuit design challenge	mastery					– – – –
Final loop diagram and system inspection	mastery					– – – –
Demonstration of working system	mastery	–	–	–	–	
Safety and professionalism	deduction					
Lab percentage score	proportional					– – – –
Decommission and lab clean-up	(ungraded)	–	–	–	–	

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

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

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

Lab Exercise – objectives and expectations

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

Team meeting and prototype sketch

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

Control valve disassembly

Disassemble a control valve down to the last fastener, being sure to first "discharge" all stored energy in the valve's spring.

Valve component identification

Correctly identify valve components randomly selected by the instructor, accurately describing their function and placement in the valve assembly.

Torque wrench usage

Use a torque wrench to apply the necessary amount of torque to fasteners while assembling the control valve, particularly the nuts holding the diaphragm casing halves together.

Proper stroke length and bench-set

Follow the valve manufacturer's instructions precisely to ensure the valve stem operates with the correct stroke length and applied air pressures.

I/P calibration

Adjust the "zero" and "span" of the I/P converter so that it outputs the correct air pressures over the 4-20 mA input signal range. Complete both As-Found and As-Left calibration tables, and tag when complete.

Circuit design challenge

Build a circuit with a HART differential pressure transmitter responding properly to applied pressure/vacuum, using an analog multimeter to register the transmitter's analog signal and a digital oscilloscope to register the transmitter's digital (HART) signal.

Final loop diagram and system inspection

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

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.

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.

For example, if a team member lacks experience disassembling and reassembling mechanical devices, this lab exercise is an excellent opportunity to gain those skills. It is *strongly* recommended that those team members with the least mechanical experience be the people to disassemble the valve while those with more experience merely supervise. The team may work together in a more balanced fashion during re-assembly.

Remember, the purpose of this lab exercise is not to complete it in the least amount of time, but rather for every team member to gain new knowledge and skill. This is why tasks should not necessarily be assigned with *maximum efficiency* in mind as they would at a workplace, but rather with *maximum learning* in mind because this is a school.

An absolutely essential step in completing this lab exercise is to work together as a team to **sketch a prototype diagram** showing what you intend to build. This usually takes the form of a simple electrical schematic and/or loop diagram showing all electrical connections between components, as well as any tubing or piping for fluids. This prototype sketch need not be exhaustive in detail, but it does need to show enough detail for the instructor to determine if all components will be correctly connected for their safe function.

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

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

Your first step should be identifying the model of control valve assigned to you, then finding appropriate documentation for it. The Emerson website contains manuals for all the Fisher valves they sell, so your best resource is the Internet (and/or your Instrumentation Reference where a variety of instrument manuals have been downloaded for you). Use this documentation to locate diagrams of the valve assembly as well as assembly instructions.

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

Lab Exercise – disassembling and re-assembling the valve

The *Lessons In Industrial Instrumentation* textbook has an Appendix section documenting the complete tear-down of a Fisher "E-body" sliding-stem globe valve, which you may find helpful. Additionally, every control valve manufacturer publishes manuals for their products showing cross-sectional illustrations which are useful for understanding how the valve is assembled and disassembled. Feel free to take your own digital photographs as you disassemble the valve, to better aid in your understanding of its function and to serve as a re-assembly guide.

A safety tip for disassembly is to make releasing spring tension your *first* step. Back off the spring adjuster until it spins loosely, and then there should be no stored energy in the actuator spring to hurt you during disassembly. If ever you are loosening a nut or bolt on the valve assembly and it seems to be "stiff" during most of the loosening process, you may very well have stored spring tension inside the valve that should be relieved before any further loosening is attempted.

You and your teammates should disassemble the control valve down to the last nut and bolt. Use a coffee can or other container to place small items such as nuts, bolts, screws, brackets, clips, and O-rings. Use a larger bucket or tub to hold major valve components during the disassembly and re-assembly processes.

After disassembling the valve, each team member must properly identify a few key components of the valve as well as their respective functions and placement within the valve, as prompted by the instructor.

When all team members have successfully passed the component identification test, the team is cleared to re-assemble the valve. Be careful when doing so – if components don't seem to fit smoothly, and/or require substantial force to put together, you are likely doing something incorrect. Stop and re-evaluate your actions before you break something!

A helpful precaution to take when reassembling the valve body is to periodically move the valve stem by hand to ensure it continues to more freely and with full stroke (the stem should actually move just a bit *farther* than the rated stroke length, so long as the actuator remains unattached). If the stem exhibits any sign of limited travel or binding, it is a sign something is wrong with the assembly, and you should disassemble it again to check your work.

Be sure to *cross-torque* all nuts and bolts arranged in a circular pattern (e.g. nuts on bonnet studs, diaphragm casing nuts and bolts): this means alternating sides when choosing the next nut/bolt to tighten. Use a torque wrench to apply the amount of torque specified in the manufacturer's instruction manual, individually demonstrating this tool usage to the instructor. Proper execution of the torque sequence will ensure the assembly will not be warped by uneven bolt stress.

Common mistakes:

- The most-mechanically-minded students doing all the work, when they should let their lesser-mechanically-inclined teammates do most of the disassembly.
- Failing to consult documentation, especially with regard to the proper assembly of the stem packing.
- Not organizing parts in containers.
- Trying to hoist heavy valve components by yourself – improper lifting techniques and lack of teamwork.
- Using tools improperly: e.g. using adjustable wrenches when combination wrenches will do, using slip-joint and tongue-and-groove pliers instead of wrenches, using metal tools (hammer heads) to tap metal components out of place instead of softer tools such as the wooden handle of a hammer.
- Not checking valve stem stroke periodically while reassembling valve body.

Thoroughly disassembling a control valve should take no more than one full lab session (3 hours) if the team is working efficiently! Identifying components and re-assembling the control valve may take more than one whole (3 hour) lab session.

Lab Exercise – setting stroke length and bench-set pressure

The most complex step in the re-assembly process is properly setting both the stem stroke length and the bench-set pressure. This step takes a bit of time to do, and it is easy to mis-understand, so be sure to budget plenty of time (at least an hour or two) to do it right. Be sure to involve all team members in this procedure, as it is easy to mis-understand.

In a sliding-stem control valve, the length of the valve stem's travel ("stroke") is determined by the coupling of the valve and actuator stems. A *stem connector* couples these two stems together at just the right total stem length so that the valve plug "bottoms out" on the seat when at the 0% position and the actuator "tops out" on the upper casing at the 100% position. In order to set the proper coupling point between the two stems, you will need some way to apply variable air pressures to the diaphragm actuator to move it between its extreme positions. A small air pressure regulator connected to a compressed air supply works well for this purpose, and need not be precision.

Consult the manufacturer's manual for your control valve's actuator to obtain step-by-step instructions for setting the valve spring tension ("bench set") and also properly installing the stem connector (coupling). The result, after correctly following the procedures, is that the valve's stem travel should exactly match what is shown on the travel indicator scale. Your instructor will judge your team's proper assembly as such: the valve stem should just begin to move at slightly above the lower bench-set pressure, and reach full stroke just shy of the upper bench-set pressure value. Decreasing the applied air pressure below the lower bench-set value or increasing the pressure above the upper bench-set value should produce no stem motion at all (i.e. the valve should mechanically "bottom out" and "top out" at these bench-set pressure values).

Stroke length and bench-set are both crucial parameters for efficient and safe control valve operation. Wrong stroke length can prevent the valve from fully opening (if the stems are coupled too far apart) and may even prevent it from fully closing (if the stems are coupled much too close together). Proper stroke length ensures the valve will exhibit the engineered flow characteristics throughout its range of movement. Improper bench set may result in insufficient seating pressure (if spring tension is too weak), causing the valve to pass fluid by when it should be fully closed.

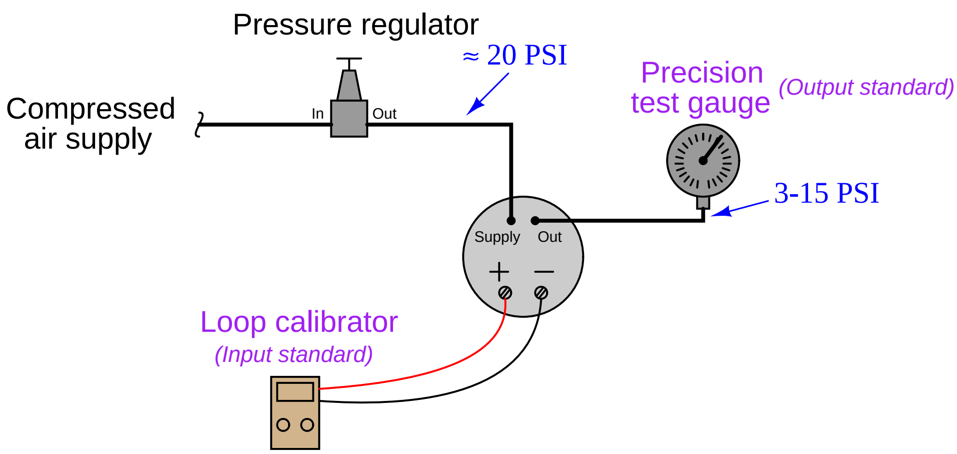
Common mistakes:

- Not following the manufacturer's instructions *precisely*.
- Referencing instructions for the wrong actuator type (e.g. direct-acting instead of reverse-acting).
- Incorrect valve assembly resulting in limited stem motion.
- Not paying attention to the travel indicator, which always shows the proper stroke length of the valve stem.
- Not paying attention to the bench set pressure values shown on the actuator's nameplate.

Lab Exercise – I/P calibration

Each team must calibrate their I/P transducer for a range appropriate to their control valve's actuator pressure range (usually 3-15 PSI). As in all cases where an instrument must be calibrated, you will need to check the instrument's response against one or more *standards*. In this case, the ideal standard to use for measuring the I/P output pressure is a *test gauge*, and the ideal standard to use for establishing the 4-20 mA current signal into the I/P is a *loop calibrator* set to "source" current.

Typical calibration setup for an I/P converter



Read the manufacturer's documentation on the I/P transducer for details on how to calibrate it. Like an analog measuring instrument, the procedure will involve trial-and-error applications of LRV and URV input signal values, adjusting the "zero" and "span" screws of the I/P until it tracks accurately at those two points. Note that the zero and span screw adjustments on most I/P converters are interactive: adjusting the span will affect the zero, necessitating a lot of back-and-forth applications of LRV and URV, zero screw turning and span screw turning.

Document the accuracy of your I/P's calibration before and after adjustment in these tables, at five different points throughout its sensing range. The "Applied" current is the amount of electric current you apply to the I/P's input using a loop calibrator, and the "Output" signal is the amount of air pressure output by the I/P (the 3-15 PSI range):

As-Found calibration table

Applied pressure	Output signal (actual)	Output signal (ideal)	Error (% of span)

As-Left calibration table

Applied pressure	Output signal (actual)	Output signal (ideal)	Error (% of span)

$$\text{Error as \% of span} = \left(\frac{\text{Actual} - \text{Ideal}}{\text{Span}} \right) (100\%)$$

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

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

CALIBRATED	**CALIBRATED**	**CALIBRATED**	**CALIBRATED**
By: ____ Date: ____	By: ____ Date: ____	By: ____ Date: ____	By: ____ Date: ____
Range: ________	Range: ________	Range: ________	Range: ________

The accuracy of your calibration will be checked by the instructor while installed in the loop, setting the hand controller's output to various levels and checking the valve stem position for correspondence. It should be noted that I/P transducers are not typically "precision" instruments like process transmitters, and as such you may find substantial variations in calibration resulting from modest changes in supply air pressure and/or mounting position.

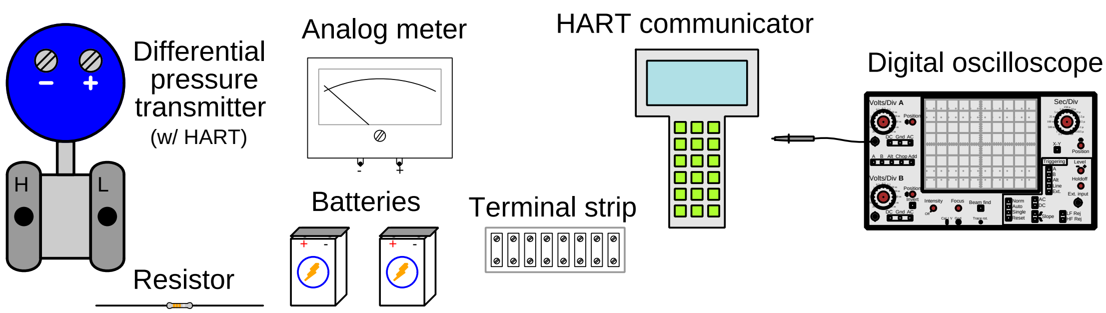
Common mistakes:

- Applying excessive force to I/P adjustments. This is a delicate mechanism! As such, it should *not* require forceful adjustment!! If you have to *force* something, you're probably doing it wrong.
- Improper supply air pressure to the converter (see the manual for supply air pressure specifications)
- Improper pipe/tube fitting installation (e.g. trying to thread tube fittings into pipe fittings and vice-versa).
- Ignoring the mathematical signs (+ or −) of error calculations.
- Neglecting to place a calibration tag on the I/P converter after calibrating it.

Lab Exercise – circuit design challenge

Connect a loop-powered "smart" differential pressure transmitter (4-20 mA output with HART communication ability) to a DC voltage source and an analog meter such that the meter will indicate a increasing signal when a certain stimulus is applied to the transmitter, setting the transmitter's pressure measurement range as specified by the instructor. Additionally, connect a digital oscilloscope to this circuit and use it to capture one of the digital messages communicated between the transmitter and the HART communicator. All electrical connections must be made using a terminal strip (no twisted wires, crimp splices, wire nuts, spring clips, etc.) "Alligator" clips are permitted for making connections to battery terminals only.

This exercise tests your ability to correctly identify pressure port functions on a differential pressure transmitter, to navigate a "smart" instrument's parameters using a communicator, to properly interpret terminal connections on a field instrument for signal and power, to use an analog multimeter to measure 4-20 mA loop current, to use a DMM to capture peak signal amplitude, to use a digital oscilloscope to capture FSK data, and to interpret that FSK-encoded digital data.



The following components and materials will be available to you: assorted 2-wire 4-20 mA HART differential pressure **transmitters** calibrated to ranges 0-30 PSI or less, equipped with Swagelok compression tube connectors at the "high" and "low" ports ; lengths of **plastic tube** with ferrules pre-swaged ; **terminal strips** ; lengths of **hook-up wire** ; 250 Ω (or approximate) **resistors** ; analog **meters** ; **batteries** ; **HART communicator** ; digital **oscilloscope**. You must provide your own tools and digital multimeter (DMM) as well as a copy of this page for your instructor to mark objectives.

SEQUENCE: (1) Instructor chooses criteria; (2) You build, power, and test circuit; (3) Instructor verifies all objectives satisfied.

Transmitter range (instructor chooses): LRV = __________ URV = __________

Meter options (instructor chooses): ____ Voltmeter (1-5 VDC) *or* ____ Ammeter (4-20 mA)

Signal increases with... (instructor chooses): ____ Positive pressure *or* ____ Vacuum (suction)

HART signal captured (instructor verifies): ____ (peak FSK signal voltage read on DMM)

HART signal captured (instructor verifies): ____ (correctly read FSK "0" and "1" bits on scope)

Study references: the "Analog Electronic Instrumentation" chapter of *Lessons In Industrial Instrumentation*, particularly the sections on loop-powered transmitters and current loop troubleshooting. Also, the "Basic Concept of HART" subsection of the "The HART Digital/Analog Hybrid Standard" section of the "Digital Data Acquisition and Networks" chapter of the same book. Your DMM manual will provide instructions on capturing peak signal values.

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 build a hand-control system for it. This will consist of a loop controller placed into "manual" mode to allow direct control over the valve's position. There will be no transmitter installed in this loop – just the valve and the I/P converter necessary to convert the controller's 4-20 mA output signal into a pneumatic signal to move the valve. 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 I/P (as documented in the I/P manual).

Your hand-control system needs to have a loop number, so all instruments within it may be properly labeled. This loop number needs to be unique, so that another team does not label their instruments and tubes the same as yours. One way to make your loop number unique is to use the equivalent resistor color-code value for your team's color in the loop number. For example, if you are the "Red" team, your loop number could be "2".

The controller itself should be labeled "HC-" because it is a "hand" controller, allowing a human operator manual control over the valve's position. Similarly, all other instruments in the loop should bear tag names beginning with "H" (e.g. HV = Hand Valve, HY = Hand Transducer, etc.) because this is a *manually controlled* system.

Common mistakes:

- Neglecting to consult the manufacturer's documentation for the I/P converter (e.g. how to connect pneumatic signal lines, how to calibrate it).
- Improper pipe/tube fitting installation (e.g. trying to thread tube fittings into pipe fittings and vice-versa).
- Applying Teflon tape to tube fitting threads; failing to apply Teflon tape to pipe fitting threads.
- Over-tightening tube fittings (remember, no more than 1-1/4 turns when installing a new ferrule set, and no more than "snug" when re-making the 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!

Lab Exercise – loop diagram and system inspection

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

Construction Standards

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

Documentation Standards

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

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

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

Common mistakes:

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

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

Lab Exercise – 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:

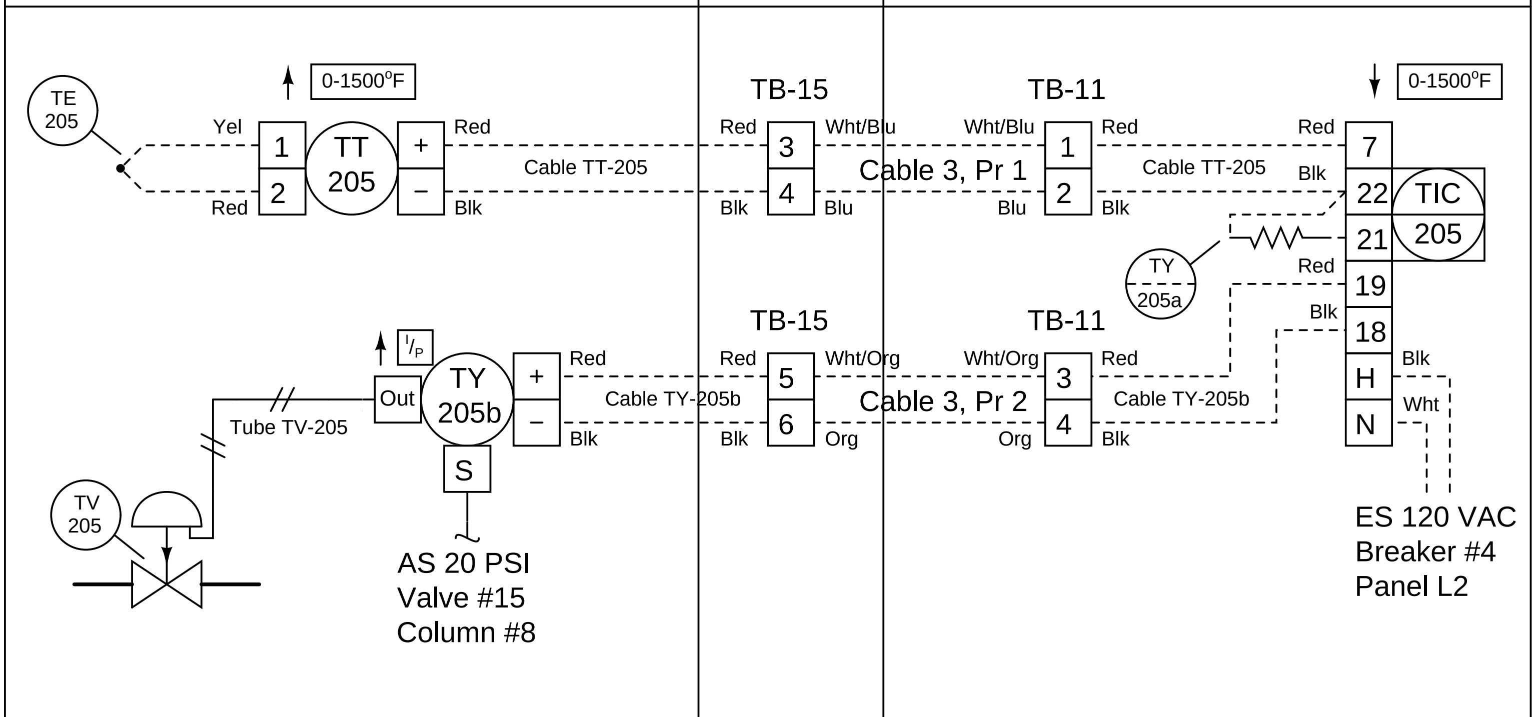
- Sensing elements (e.g. thermocouples, pH probes, etc.)
- Process transmitters
- "Jumper" cables used to connect terminal blocks within a single junction box
- Plastic tubing and tube fittings (disconnect compression-style tube fittings)
- Power cables and extension cords
- Adjustment (loading station) 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 i02865

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

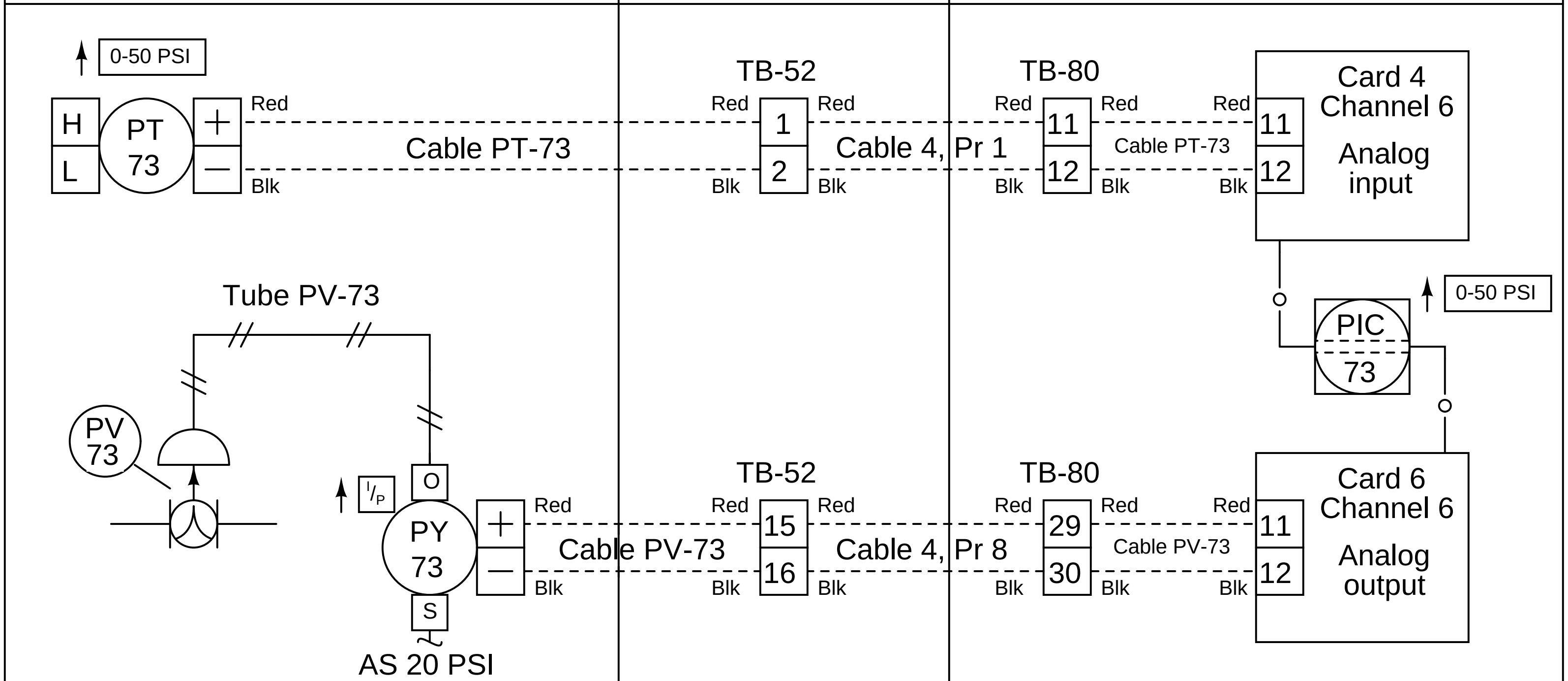
Process area	Field panel JB-12	Control room panel CP-1



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

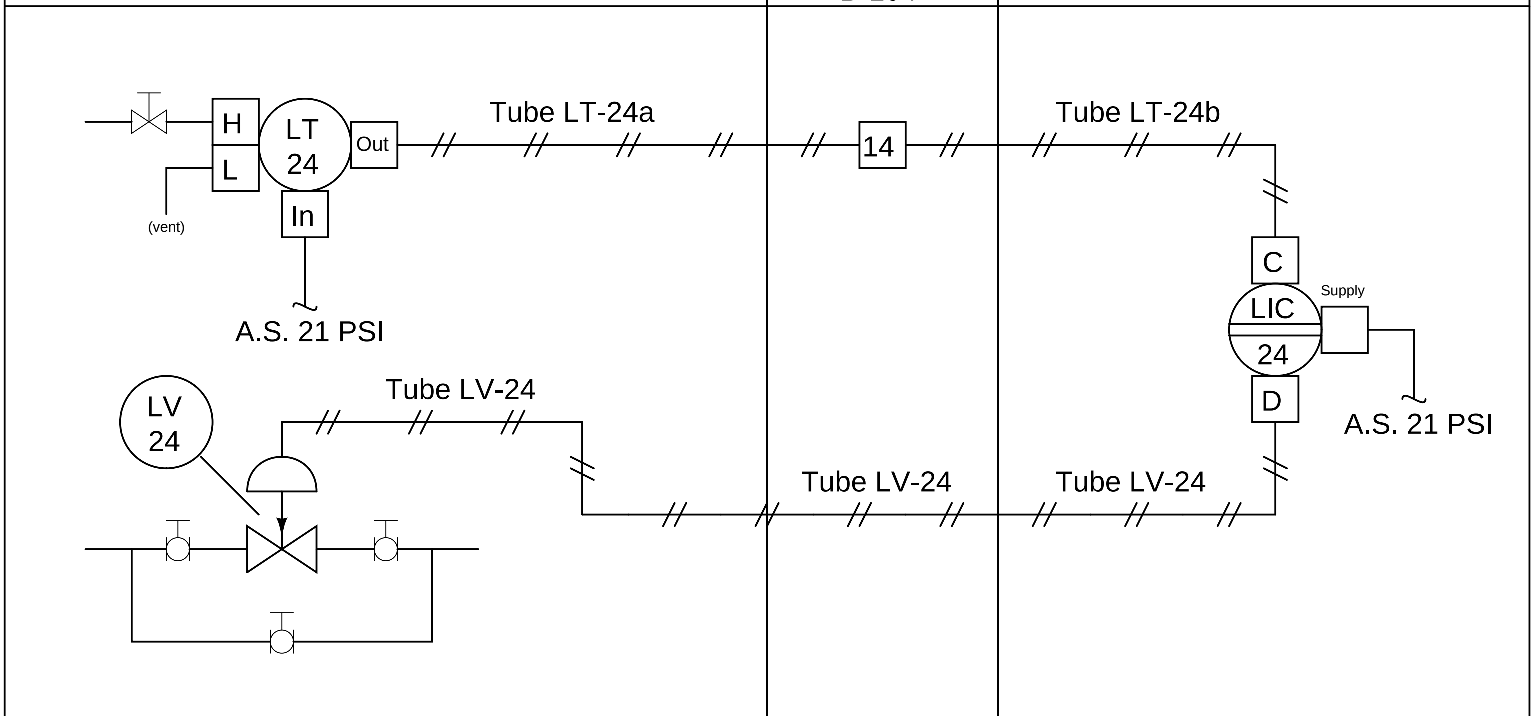
Loop Diagram: Blue team pressure loop | **Revised by:** Duncan D.V. | **Date:** April 1, 2009

Field process area	Field panel JB-25	DCS cabinet



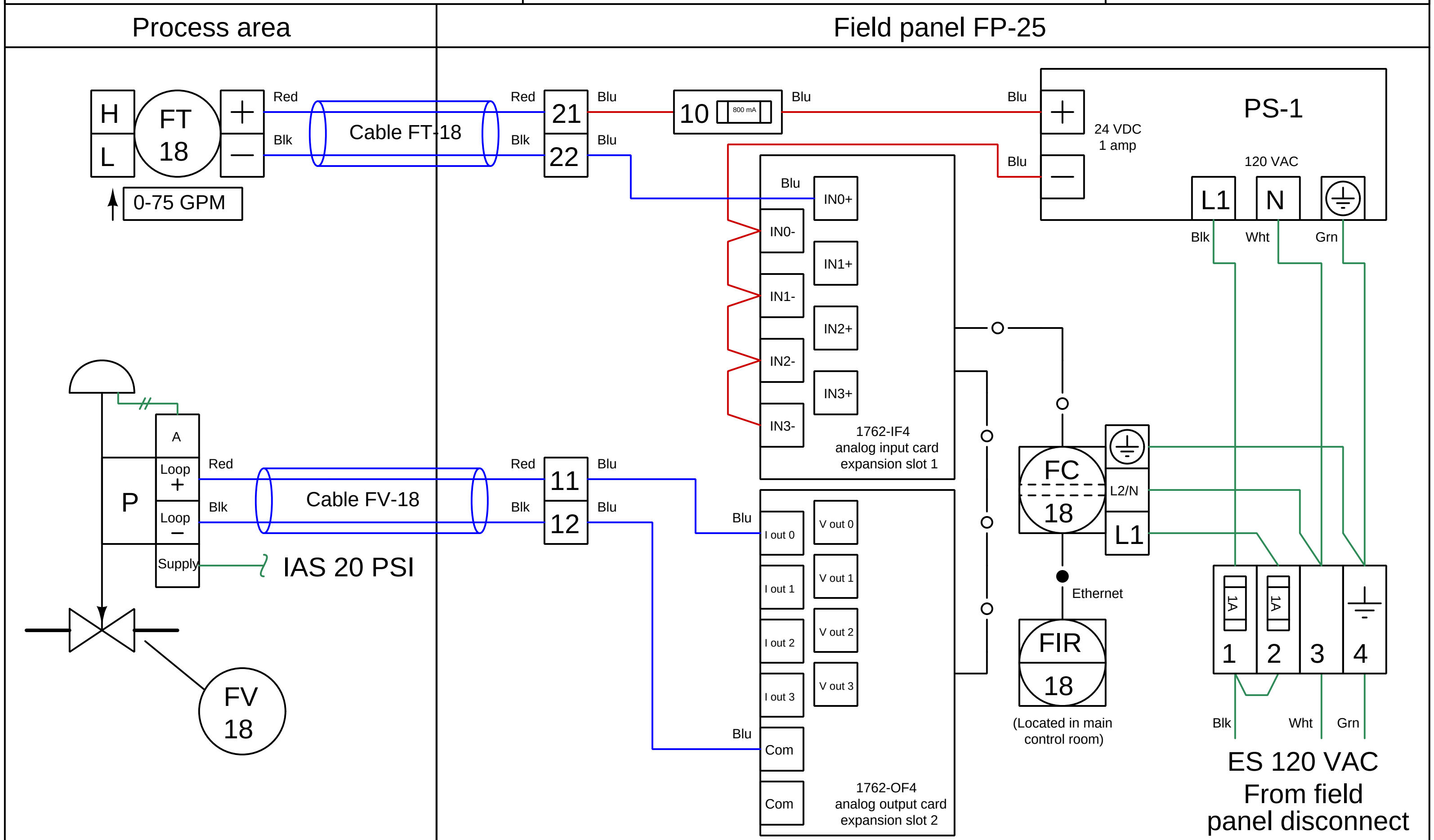
Tag #	Description	Manufacturer	Model	Input range	Output range	Notes
PT-73	Pressure transmitter	Rosemount	3051CD	0-50 PSI	4-20 mA	
PIC-73	Controller	Emerson	DeltaV	4-20 mA	4-20 mA	HART-enabled input Direct-acting control
PY-73	I/P transducer	Fisher	846	4-20 mA	3-15 PSI	
PV-73	Control valve	Fisher	Vee-ball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

Loop Diagram: Sludge tank level control	**Revised by:** I. Leaky	**Date:** April 1, 2008
Process area	Bulkhead panel B-104	Control panel CP-11



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

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



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

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file i00654

Answer 1

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

Answer 2

Answer 3

Part of Harold Black's patent application reads,

> The invention is applicable to any kind of wave transmission such as electrical, mechanical, or acoustical, and thus far in the description the terms used have been generic to all such systems. The invention will be disclosed herein, however, as specifically applied to electrical systems, it being understood that the principles involved are equally applicable to other types of wave transmission and that the generic claims are intended to include electrical and other than electrical wave systems and apparatus.

Black's patent application gives a very easy-to-understand description of *positive feedback* which leads a system into oscillation, and also describes how negative feedback had been used in radio engineering (in the "prior art") to counter-act positive feedback for the purpose of eliminating oscillations. Black's patent, however goes further than this by using greater amounts of negative feedback to stabilize the amplifier's performance rather than merely prevent oscillation. In his own words:

> Applicant has discovered how to use larger amounts of negative feedback than were contemplated by prior art workers with a new and important kind of improvement in tube operation. One improvement is in lowered distortion arising in the amplifier. Another improvement is greater constancy of operation, in particular a more nearly constant gain despite variable factors such as ordinarily would influence the gain. Various other operating characteristics of the circuit are likewise rendered more nearly constant. Applicant has discovered that these improvements are attained in proportion to the sacrifice that is made in amplifier gain, and that by constructing a circuit with excess gain and reducing the gain by negative feedback, any desired degree of linearity between output and input and any desired degree of constancy or stability of operating characteristics can be realized, the limiting factor being in the amount of gain that can be attained rather than any limitation in the method of improvement provided by the invention.

Answer 4

First example: $V_{out} = 6.8$ volts ; $P_{out} = 6.8$ PSI ; force-balance.

Second example: $V_{out} = 10.2$ volts ; $P_{out} = 10.2$ PSI ; motion-balance.

Answer 5

Partial answer:

With a larger bellows in place, the system becomes less sensitive. The nozzle pressure indicated by the gauge will be *less* for the same amount of hand force. Another way to say this is that the *gain* of this pneumatic system is less with a larger bellows. Once again, the baffle will hardly move at all.

Answer 6

- (1) Force-balance
- (2) Motion-balance
- (3) Force-balance
- (4) Force-balance
- (5) Motion-balance
- (6) Motion-balance
- (7) Force-balance
- (8) Motion-balance
- (9) Force-balance

The general principle to keep in mind here is that motion-balance instruments generate a *motion* to counteract an input motion in order to maintain a constant detector (flapper/nozzle) gap, while force-balance instruments generate a *force* to counteract an input force in order to maintain a constant detector (flapper/nozzle) gap.

Example number 9 is tricky, because one might argue it is *motion-balance* by virtue of the lower bellows' stretching motion as output pressure increases. However, the fact that the two bellows' forces oppose each other to ensure the flapper remains *stationary* in order to hold a constant flapper/nozzle gap is a defining characteristic of any force-balance mechanism. Also, the degree of spring stiffness has no effect whatsoever on the gain of this mechanism, which it would if it were motion-balance (i.e. if the amount of motion generated per unit increase in output pressure were related at all to the amount of input pressure increase). The two bellows' *forces* will cancel each other to achieve equilibrium regardless of how much or how little the spring must compress in the process of achieving that balance. If this were a true motion-balance mechanism, weakening the spring (making it less stiff) would result in a decrease of output pressure because less pressure would be required to move as far as before. Here, a weakened spring would indeed result in the lower bellows expanding a greater distance than before to balance the same amount of input pressure, but this would actually be the same output pressure as before, meaning the change in required motion has no effect on the gain.

Answer 7

Answer 8

Answer 9

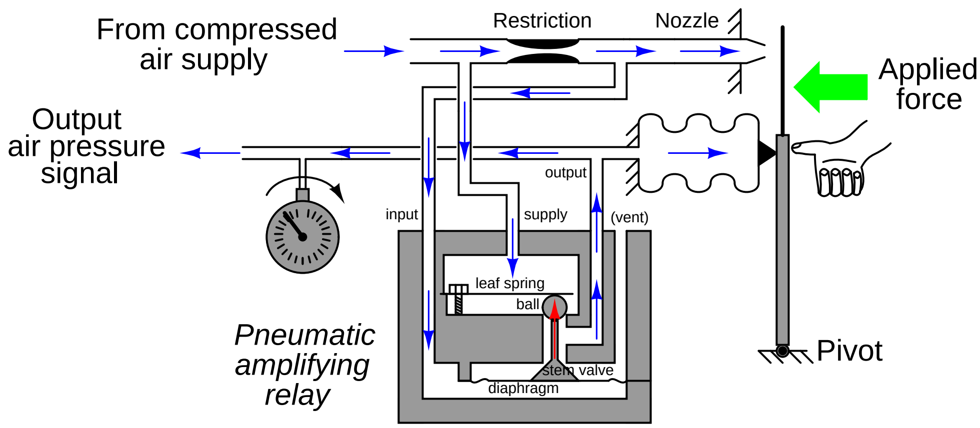
Answer 10

Partial answer:

The model 610F has a bias adjustment screw, whereas the other relay models are strictly 1:1 (output pressure = input pressure).

Answer 11

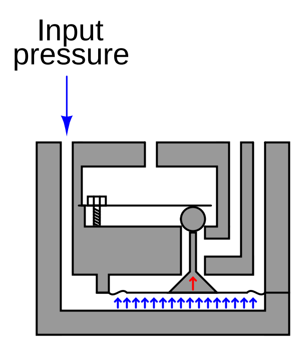
The particular pneumatic amplifying relay shown is the one typically used in Foxboro pneumatic instruments. It is not the only type of amplifying relay design, but a very common one.



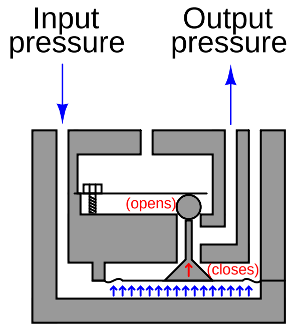
If the lever is pushed toward the nozzle by an external force, the following will happen:

- Pressure upstream of the nozzle will increase, as the nozzle becomes more restricted by the flapper.
- This pressure, going to the relay through the "input" port, will push *up* on the relay diaphragm.
- The relay diaphragm lifts up, pushing the stem valve closer to its seat, and lifting the ball off of its seat.
- As the ball lifts off its seat, more supply air is allowed to go into the area between the ball and stem.
- As the stem closes on its seat, the passage from this middle area to the vent port becomes more restrictive.
- As a result of the previous two factors, the output air pressure to the bellows will increase dramatically.
- The bellows will expand, pushing to the right on the lever.
- As the flapper will move to the right until a condition of equilibrium is reached with the force from the thumb.

The operation of the pneumatic relay might require a bit more explanation for full understanding. The "input" pressure sent to the relay from the nozzle tube pushes against the full area of the diaphragm, creating an upward force. Since the area above the diaphragm is vented (at atmospheric pressure), there can be no substantial pressure buildup on the top side of the diaphragm, and thus no downward force generated by the diaphragm to counter the input pressure's upward force:



This force acts to lift the "ball" valve off its seat and also close the cone-shaped "stem valve," adding more pressure to the output chamber by opening the passage for supply air to enter and closing the passage for air to vent, respectively:



The only force opposing the diaphragm's upward motion is a small leaf spring pressing down against the ball. This spring is not very strong, meaning that small changes in input pressure result in large changes in output pressure. In other words, the pneumatic amplifying relay has a very large *gain*.

Pneumatic relays such as this serve the same purpose as operational amplifiers in electronic circuits: amplifiers with extremely high gains, used within negative feedback loops to achieve some lesser amount of amplification that is very nearly linear. In this particular example, the final result (flapper, nozzle, lever, relay, and bellows) is a force-balance system that aggressively responds to any external force applied to the lever, such as the force exerted by someone's thumb. In a real pneumatic instrument, this external force would represent some signal or process variable, and the balancing pressure at the bellows would be the instrument's pneumatic output signal.

The presence or absence of the pneumatic amplifying relay does *not* alter the pressure/force relationship of this mechanism. The relay merely increases sensitivity to small changes in force, and increases the speed of response.

Answer to challenge question: although narrowing the restriction would decrease nozzle air flow, this would have no effect on the pressure/force relationship of this mechanism. It is *still* a force-balance system where bellows force must equal applied force to reach a state of equilibrium, and this bellows force is strictly a function of nozzle pressure ($F = PA$) not nozzle flow rate.

It should be noted that the actual gain of the pneumatic amplifier ($\frac{\Delta P_{out}}{\Delta P_{in}}$) is irrelevant, so long as it is arbitrarily large. This is analogous to the open-loop voltage gain of an operational amplifier being largely irrelevant to the overall voltage gain of a negative-feedback circuit. In other words, the presence of this amplifying relay does not alter the input force / output pressure relationship of this pneumatic mechanism.

In order to alter the pressure/force relationship of this mechanism, one would have to alter the feedback components: either change the effective area of the bellows, or the moment arm through which it acts to counteract the applied force.

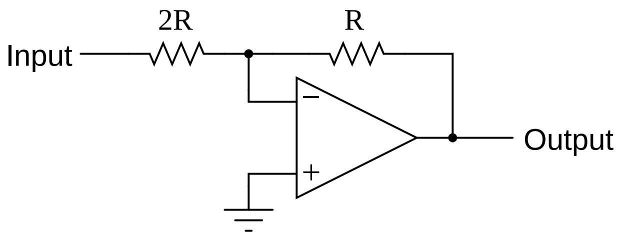
Answer 12

- Clogged nozzle: *output pressure saturates high*
- Clogged restriction: *output pressure saturates low*
- Clogged tube at supply port of amplifying relay: *output pressure saturates low*
- Broken leaf spring inside amplifying relay: *output pressure may saturate high or possibly oscillate*
- Major hole or tear in diaphragm inside amplifying relay: *System responds very little to applied force*

Answer 13

The input pressure range is the greater of the two (6-30 PSI), and the output is the lesser of the two (3-15 PSI).

Follow-up question: explain how the following op-amp circuit is similar to the pneumatic system shown in the question.



Answer 14

The output pressure will not rise as much, with the same force applied to a point closer to the pivot.

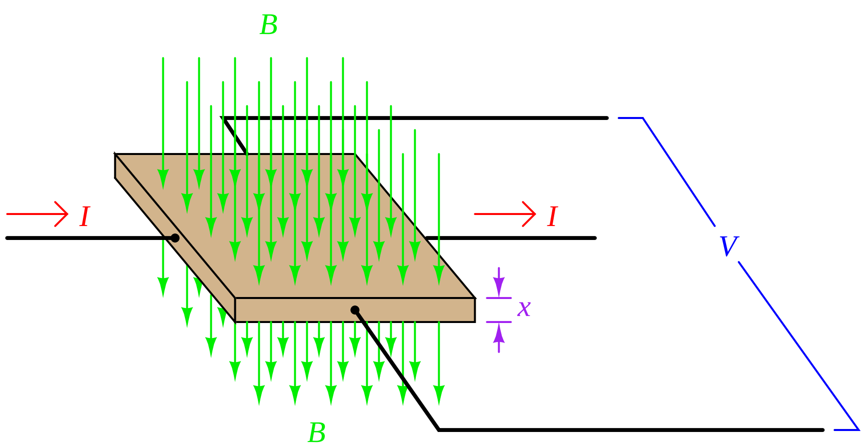
Answer 15

Partial answer:

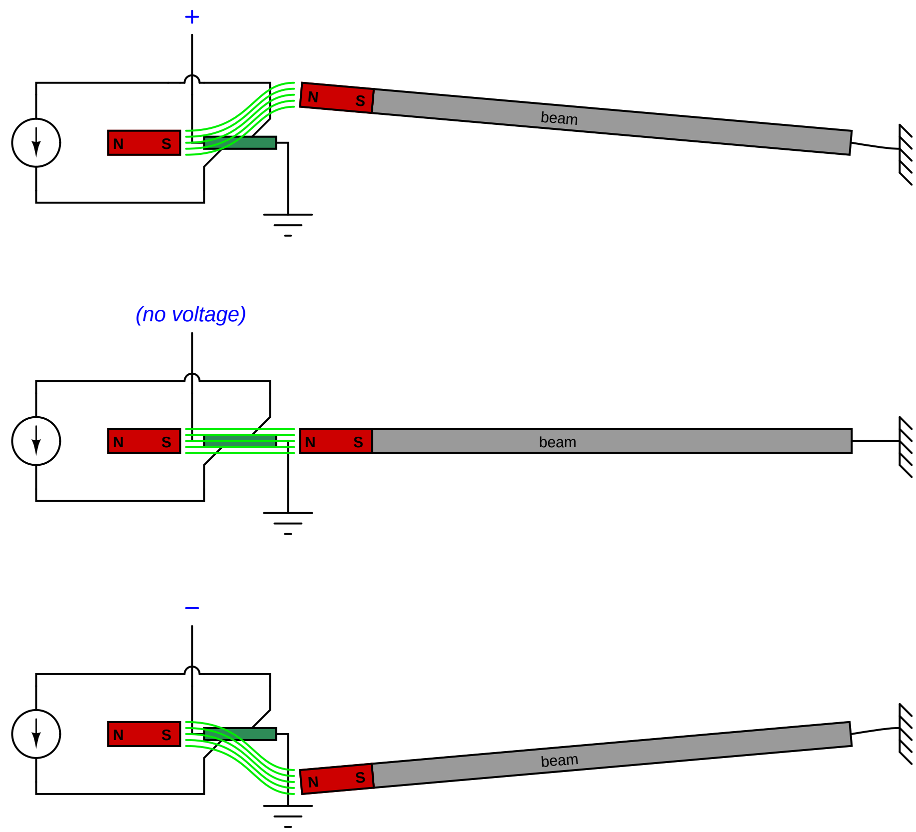
A *flexure* is a thin strip of springy material, usually spring steel, designed to act as a frictionless fulcrum and/or a pivoting link. Unlike bearings, flexures are usually not able to handle a lot of angular motion.

Hall Effect sensors are used to detect magnetic fields. They generate a DC voltage proportional to the magnitude and polarity of an applied magnetic field and the magnitude and direction of a perpendicular DC current:

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



The operation of the Hall Effect sensor may not be clear to all readers. It is oriented such that the magnetic field is parallel to the Hall Voltage axis and not perpendicular to it, when the beam is exactly level. When the beam tips up or down, however, the magnetic flux lines passing from the "North" tip of the beam's magnet to the "South" tip of the stationary magnet to the left of the Hall Effect sensor will angle, passing through the Hall Effect sensor with a definite direction, either up or down, depending on which way the beam tips:



Thus, any output voltage from the Hall Effect sensor indicates an out-of-balance condition between the diaphragm and force motor.

Answer 16

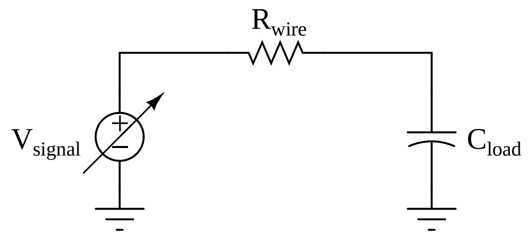
Port "A" is the "high" pressure port on this transmitter, and port "B" is the "low" pressure port. Remember: an increasing pressure applied to the "high" port causes an increasing signal out of the transmitter. Conversely, an increasing pressure applied to the "low" port causes a decreasing signal out of the transmitter.

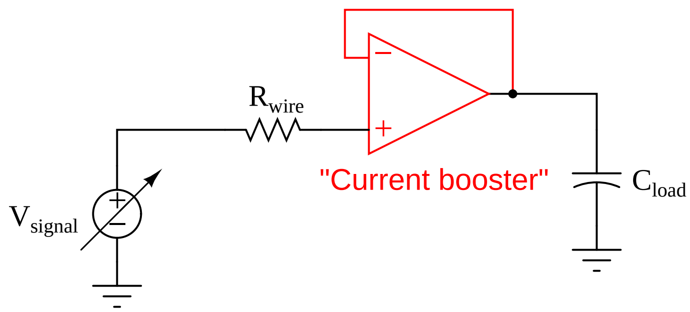
Answer 17

The feedback loop in this I/P design is electronic, not mechanical.

Answer 18

A volume booster installed at the end of a *long* pneumatic tube run will significantly improve the valve's response time to any changes in controller output. Examine the following electrical analogy for a better understanding, where electric charge is the analogue to pneumatic volume:





The tubing's inherent friction to air flow (and the controller's internal restrictions) are analogous to electrical resistance, while the valve actuator's volume is analogous to electrical capacitance. The two combined form an equivalent RC time constant.

By placing the booster at the end of the tubing run, the controller need not fill or empty such a large volume (the valve actuator) anymore. The only volume it must control air pressure in now is the volume internal to the booster, which is extremely small. The booster now handles the pneumatic flow needs of the actuator, and through a much shorter (less restrictive) tubing length. This greatly decrease the "RC time constant" of the system, improving response.

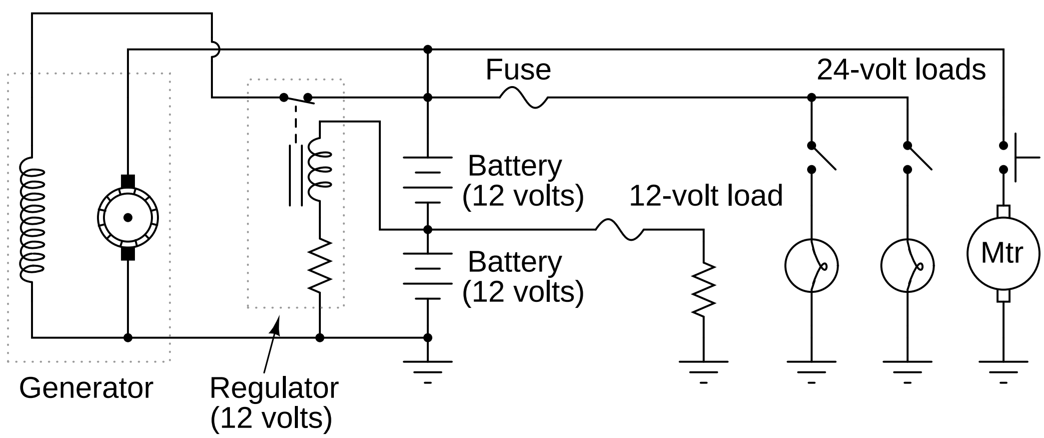
Answer 19

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

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

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

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



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

Answer 20

Answer 21

Answer 22

Answer 23

Answer 24

Answer 25

The design engineer made it so that air will pass to the process valve actuator during typical (good) operating conditions, holding the process valve open.

This is a 1oo2 to trip system, because the process valve will go to its "fail" position if either of the two solenoid valves trip (go to their abnormal operating states).

Answer 26

Answer 27

Answer 28

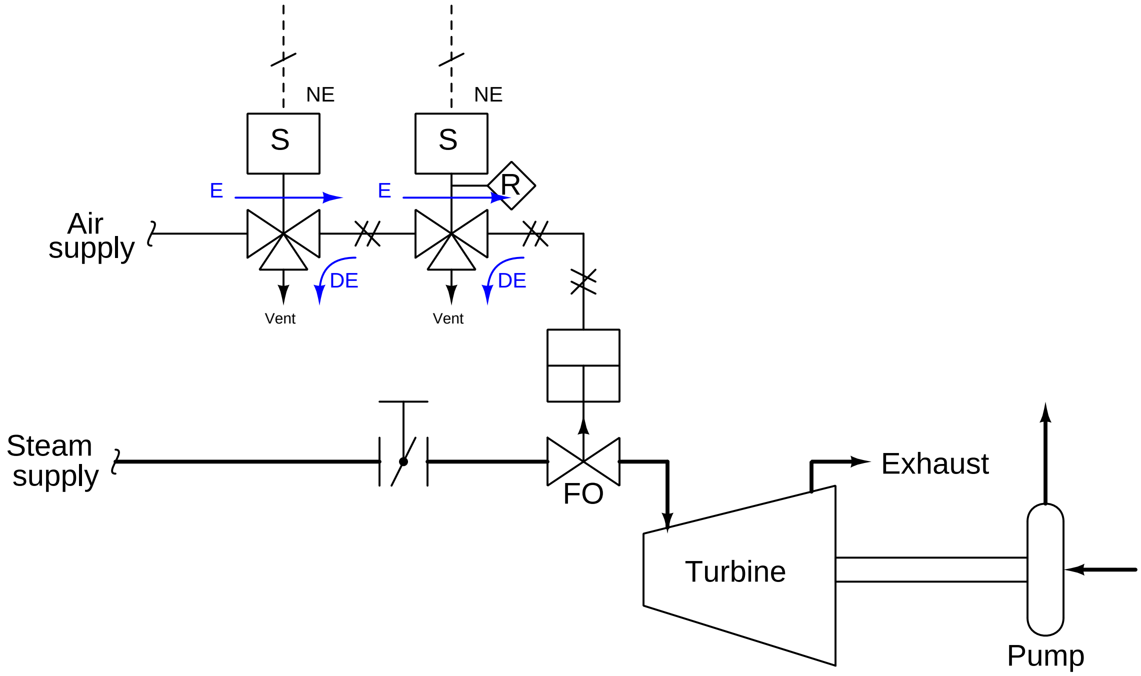
Fault	**Possible**	**Impossible**
Fuse F3 blown (failed open)		√
Solenoid stuck in "energized" position	√	
Solenoid stuck in "de-energized" position		√
Solenoid coil failed open		√
Solenoid coil failed shorted		√
Silencer plugged		√
Vent cap plugged		√
Wire open between terminals A and E		√
Wire open between terminals C and H		√
Wire open between terminals K and B		√
Valve V1 shut	√	
Valve V2 shut	√	

A plugged vent on the valve actuator, while in theory capable of limiting the control valve's upward motion, would not prevent any motion at all from occurring when full pressure is applied to the bottom of the diaphragm. This is why "Vent cap plugged" is checked as impossible rather than possible for this scenario.

A good "next test" would be to crack the fitting at port "C" of the solenoid valve. If there is pressure, it means the problem must lie past the solenoid (e.g. valve V1 shut, or a problem in the process control valve). If there is no pressure at that point, either the solenoid valve is stuck in the "energized" position or there is a lack of supply pressure to the solenoid.

Answer 29

If either solenoid loses electric power, it vents air pressure from the piston actuator of the fail-open steam valve, sending steam to the turbine to start it up:



Answer 30

Incidentally, this is a *1oo2* to trip system, because all it takes is for one of the solenoid valves to trip in order to start up the steam turbine:

Answer 31

Spring-and-diaphragm pneumatic actuators work by allowing pressurized air to push against a large, flexible diaphragm. The force created by the air pressure against the diaphragm's surface area works in opposition to the force produced by a compressed spring. The spring's compression must change to balance out new levels of air pressure, and this results in a change in position which is then used to move a valve mechanism.

Pneumatic piston actuators use a piston instead of a flexible diaphragm for compressed air to push against. Some piston actuators have springs to provide a "return" force (air pushes the piston one way, and the spring pushes it back), while other piston actuators are double-acting (compressed air on both sides of the piston).

Electromechanical actuators use an electric motor coupled to the valve stem or shaft via a gear mechanism. As the motor turns, the valve changes position. Often used for on-off control of valves (from full-open to full-closed and back), electric actuators may also be equipped with position sensors and servo drive electronics for proportioning control.

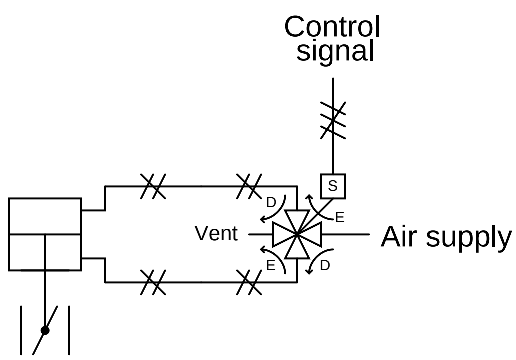
Solenoid (electromagnetic) valve actuators are simple open-closed devices, not used for throttling. They utilize an electromagnet coil to magnetically attract an armature, sometimes in opposition to a spring force.

Electrohydraulic actuators usually use an electric motor to turn a hydraulic pump, the fluid output of which moves a piston actuator.

Electromechanical actuators (where the valve is moved by the turning of an electric motor) inherently hold their positions under a loss-of-supply condition, as well as electrohydraulic actuators (where the valve is moved by a piston actuated by hydraulic pressure from a pump turned by an electric motor).

Any actuator with a return spring will inherently "fail" to a consistent position under a loss-of-supply condition. This includes pneumatic diaphragm and piston actuators, and solenoid actuators.

Answer 32



Answer 33

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

Answer 34

Net piston force = 890.936 pounds.

In this scenario, there are two pressures fighting against each other: the 850 PSI pressure is pressing downward on the piston while the 1000 PSI pressure is pressing upward. The resultant (differential) pressure is 150 PSI (1000 PSI - 850 PSI). This is the pressure figure to be used in the final force calculation.

Answer 35

Atm	PSIG	inches W.C. (G)	PSIA
3.5	36.75	1017.3	51.45
6.51	81	2242	95.7
22.71	319.1	8834	333.8
0	-14.7	-406.9	0
1.017	0.2572	7.12	14.96
25.03	353.3	9779.6	368
1.136	2	55.36	16.7
100	1455.3	40284	1470

Answer 36

The given pressure is in units of PSI *gauge* (PSIG), while the final unit (atmospheres) is an *absolute* pressure unit. In order for this conversion to be correct, there must somewhere be an offset (addition) in the calculation to account for the 14.7 PSI shift between gauge pressure and absolute pressure.

Here is the proper conversion technique:

$$\textbf{Step 1:}\ 65 \text{ PSIG} + 14.7 \text{ PSI} = 79.7 \text{ PSIA}$$

$$\textbf{Step 2:}\ \left(\frac{79.7 \text{ PSIA}}{1}\right)\left(\frac{1 \text{ atm}}{14.7 \text{ PSIA}}\right) = 5.422 \text{ atm}$$

Answer 37

This is perfectly legitimate, because in either case all the pressure units involved in each conversion are of the same type: either all gauge or all absolute. Where we encounter difficulties is if we try to mix different units in the same "unity fraction" conversion that do not share a common zero point.

A classic example of this mistake is trying to do a temperature conversion from degrees F to degrees C using unity fractions (e.g. 100^o C = 212^o F):

$$\left(\frac{60^o \text{ F}}{1}\right)\left(\frac{100^o \text{ C}}{212^o \text{ F}}\right) \neq 28.3^o \text{ C}$$

This cannot work because the technique of unity fractions is based on proportion, and there is no simple proportional relationship between degrees F and degrees C; rather, there is an *offset* of 32 degrees between the two temperature scales. The only way to properly manage this offset in the calculation is to include an appropriate addition or subtraction (as needed).

However, if there is no offset between the units involved in a conversion problem, there is no need to add or subtract anything, and we may perform the entire conversion using nothing but multiplication and division (unity fractions). Such is the case if we convert pressure units that are all gauge, or if we convert pressure units that are all absolute.

To summarize, it is perfectly acceptable to construct a unity fraction of $\frac{27.68 \text{ "W.C.}}{2.036 \text{ "Hg}}$ because 0 "W.C. is the same as 0 "Hg (i.e. they share the same zero point; there is no offset between units "W.C. and "Hg). Likewise, it is perfectly acceptable to construct a unity fraction of $\frac{27.68 \text{ "W.C.A}}{2.036 \text{ "HgA}}$ because 0 "W.C.A is the same as 0 "HgA (i.e. they share the same zero point; there is no offset between units "W.C.A and "HgA).

Answer 38

- This mechanism activates when the process pressure's rate of change **falls** quickly over time.
- To switch the direction of change, both the check valve and the spool valve's return spring would have to be reversed in direction.
- Identify the direction of air flow through the line leading to the "pneumatic control device" when the process pressure is not changing at all: **air flowing out to the pneumatic control device**.
- Identify one component that would have to be altered in this mechanism to make it *more sensitive* to rates of process gas pressure change over time, and precisely how that component would have to be altered (e.g. size, shape, etc.): either **narrow the restriction**, **increase the size of the capacity tank**, and/or **replace the spool valve spring with one that is "softer"**.

Answer 39

Fault	**Possible**	**Impossible**
Manual valve in "bypass" position	$\surd$	
Solenoid coil failed open		$\surd$
Solenoid coil failed shorted		$\surd$
Solenoid valve (UY-104) spool stuck	$\surd$	
Solenoid valve (UY-104) vent plugged	$\surd$	
Air supply to LY-104 failed		$\surd$
4-20 mA signal wiring to LY-104 failed open		$\surd$
4-20 mA signal wiring to LY-104 failed shorted		$\surd$
Control valve (LV-104) stuck		$\surd$

Answer 40

Partial answer:

Fault	Possible	Impossible
Dead power supply		$\surd$
Relay coil failed open		
Pushbutton switch failed open		
NO contact failed open		
NC contact failed open		$\surd$
Relay coil failed shorted		
Pushbutton switch failed shorted		
Break in wire between points A and G		$\surd$
Break in wire between points C and E		
Break in wire between point F and relay coil		

Many students may find themselves fooled by the 0 volt measurement, thinking this proves points C and E are continuous. The fallacy at work here is thinking 0 volts proves continuity, just because continuity *does* guarantee 0 volts. In fact, it *is* possible for there to be a break between C and E (and still have a 0 volt measurement) if something *else* is open within that loop. For example, the lower NO relay contact could be failed open!

If the same C-to-E measurement were taken with the pushbutton switch pressed, you would find a 24 volt measurement given a broken wire between those two points.

Answer 41

Partial answer:

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

Answer 42

Answer 43

When air supply pressure actuates the lock-up valve, the I/P transducer has full control over the process valve. If and when the air supply fails, the lock-up valve will go to its "lock" position, trapping compressed air inside the valve actuator and thereby causing the control valve to hold position.

Answer 44

Answer 45

Answer 46

Answer 47

Controller display	Controller current	I/P pressure	Valve stem position
77.5%	7.6 mA	5.7 PSI	77.5% open
13.1%	17.9 mA	13.43 PSI	13.1% open
89.3%	5.72 mA	4.29 PSI	89.3% open
64%	9.76 mA	7.32 PSI	64% open

Answer 48

Fault	Possible	Impossible
Fuse F3 blown (failed open)		$\surd$
Solenoid coil failed open		$\surd$
"Open" switch contacts (L to M) failed open		$\surd$
"Close" switch contacts (J to K) failed open		$\surd$
Relay coil failed open		$\surd$
Relay contact (G to P) failed open	$\surd$	
Relay contact (F to N) failed open		$\surd$
Wire open between terminals K and C		$\surd$
Valve V2 shut		$\surd$

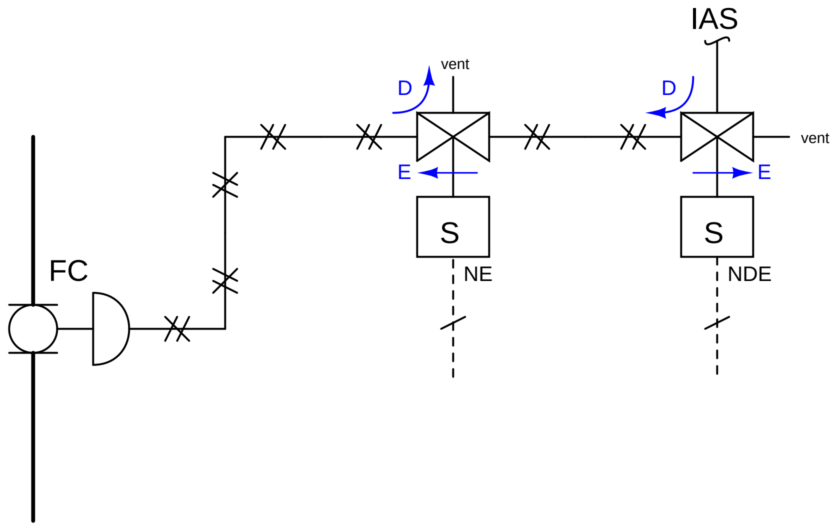
A good "next test" is a voltage measurement between **P** and **D**, to see whether or not AC power is available at that relay terminal (as it should be!). Another good "next test" would be to temporarily connect terminals **G** and **P** with a jumper wire and see if this makes the valve actuate.

Answer 49

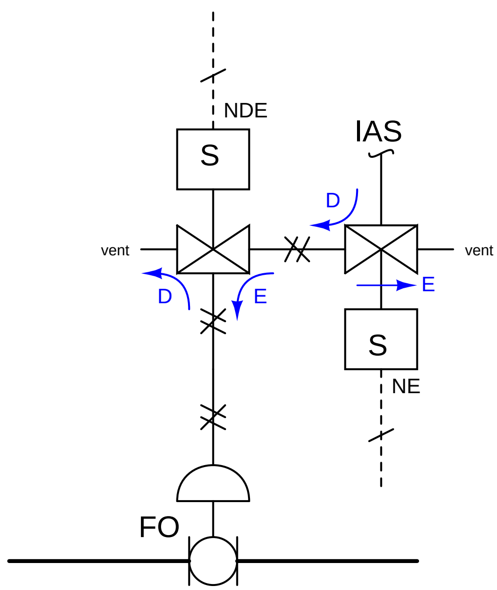
Partial answer:

- Packing flange: transfers force from nuts to the packing follower
- Packing follower: transfers force from flange to the packing assembly
- Lubrication port: lubricant is pumped in here
- Lantern ring: allows even distribution of lubricant around the stem
- Packing box ring: provides a flat surface at the bottom of the assembly for the upper components to rest against

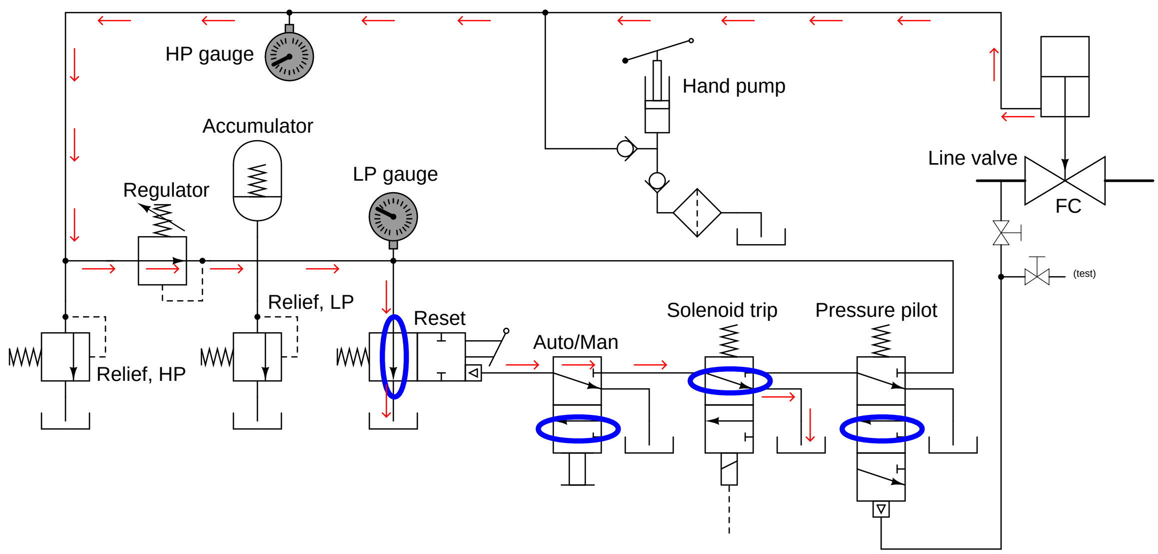
Answer 50



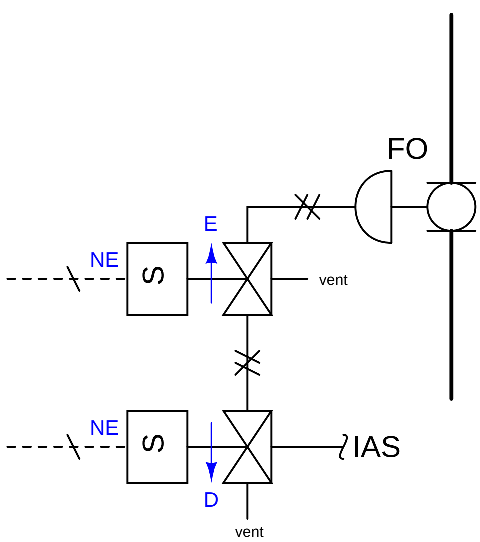
Answer 51



Answer 52

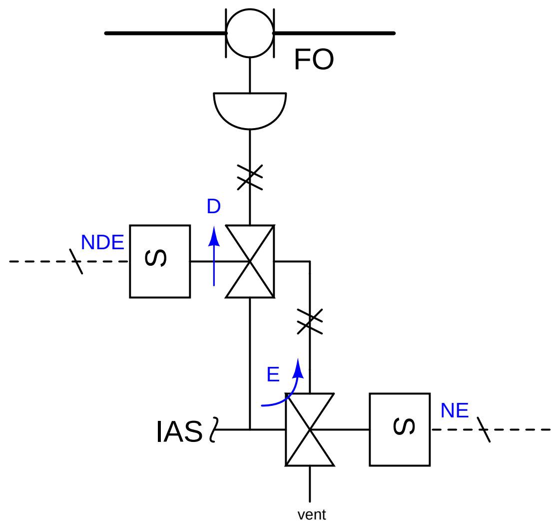


Answer 53



Answer 54

Both solenoid valves must trip to "fail" the process valve (i.e. 2oo2 to trip):



Possible faults:

- Instrument air supply dead
- Break in tubing between upper solenoid valve and ball valve actuator
- Large leak in ball valve actuator

Answer 55

- 71.5 PSIA = 56.8 PSIG
- 5.03 bar (gauge) = 148.5 "Hg
- 101 kPa = 29.35 PSIA
- 800 torr = 0.774 PSIG
- 41 "Hg = 557.4 "W.C.
- 2.2 feet Hg = 89.4 kPa
- 11 PSI vacuum = 191.3 torr
- 350 "W.C.G = 756.9 "W.C.A
- 66 cm W.C. = 1.911 "Hg
- 910 PSIG = 62.9 atm
- 35 "W.C. = 32.5 "HgA
- 125 PSIA = 760.5 kPa

Answer 56

Partial answer:

Applied differential pressure = 0.969 PSID = 0.0668 bar (differential)

Answer 57

P_{high} = 748 mmHgA = 0.9842 Atm = 14.468 PSIA
P_{low} = 0.15 Atm = 2.205 PSIA
ΔP = 14.468 PSIA − 2.205 PSIA = 12.263 PSID

Shut the block valve first, then open the bleed valve in order to remove the transmitter from service.

Prior to operating either the block or the bleed valve, the technician should first notify operations personnel that the transmitter will be taken out of service and therefore will *not* register any process vacuum in the near future. If the transmitter connects to a controller, that controller will need to be placed into manual mode. If the transmitter connects to any pressure alarms or (worse yet!) an emergency shutdown system, those alarms will have to be disabled and/or the shutdown function will have to be bypassed before taking the transmitter out of service.

Incidentally, the atmospheric pressure of 748 torr is equivalent to an altitude of 136 meters above sea level, which makes this a very realistic figure for an industrial application.

Answer 58

If pressure suddenly falls, the Rate Tank maintains gas pressure to the left-hand side of the Differential Pressure Pilot valve, while the (lesser) instantaneous line gas pressure is applied to the right-hand side. This causes the Pilot to actuate. When the left-hand and right-hand actuating pressures to the Pilot are equal, the Pilot's spring maintains it in the "normal" position (shown in the diagram).

Since the shutdown system signal goes to the "Close" 3-way valve only, and not to the "Open" 3-way valve, this system does *not* have the capability of automatically re-opening the gas pipeline valve.

When the Differential Pressure Pilot valve (part #120) actuates due to a sudden drop in line pressure, it bleeds signal pressure from the actuator of the Reversing Relay (part #25). When this Relay goes to its "normal" position, it passes signal pressure to actuator of the 3-way "Close" valve (part #5), sending signal pressure to the left-hand Gas/Hydraulic Tank (part #3), sending oil to the left-hand side of the Operator (part #1).

Answer 59

Answer 60

Diagnostic test	**Yes**	**No**
Place controller in automatic mode		$\surd$
Measure V_{AB} with controller output set to 100% (manual mode)		$\surd$
Measure V_{5-4} with controller output set to 100% (manual mode)	$\surd$	
Measure V_{8-7} with controller output set to 50% (manual mode)		$\surd$
"Crack" open tube fitting at the "S" port on the I/P transducer	$\surd$	
"Crack" open tube fitting at the "O" port on the I/P transducer	$\surd$	
Press the I/P transducer's flapper closer to its nozzle	$\surd$	
Pull the I/P transducer's flapper away from its nozzle		$\surd$
Tighten the nuts compressing the control valve's stem packing		$\surd$
Loosen the nuts compressing the control valve's stem packing		?
Measure the output voltage of the DC power supply		$\surd$
Measure voltage across the pressure transmitter terminals		$\surd$
Measure voltage across the I/P transducer terminals	$\surd$	

Loosening the nuts on the control valve's stem packing is a questionable test because control valve actuators generally exert sufficient force to overcome even the worst cases of stem packing friction. Thus, it is highly unlikely that stem packing friction is the cause of the valve's unresponsiveness, and as such this test should be avoided unless it is determined that the valve actuating diaphragm is indeed receiving full air pressure from the I/P.

Answer 61

Answer 62

Answer 63

Answer 64

The stem packing question is a "trick": there is no stem packing at all in this valve! The reason no packing is required is because any leakage past the stem will simply enter the diaphragm housing and then pass to the downstream side of the valve through the outlet pressure feedback tube, becoming part of the regulator's out-flow. These regulators normally operate in throttling mode, and tight shut-off is not critical.

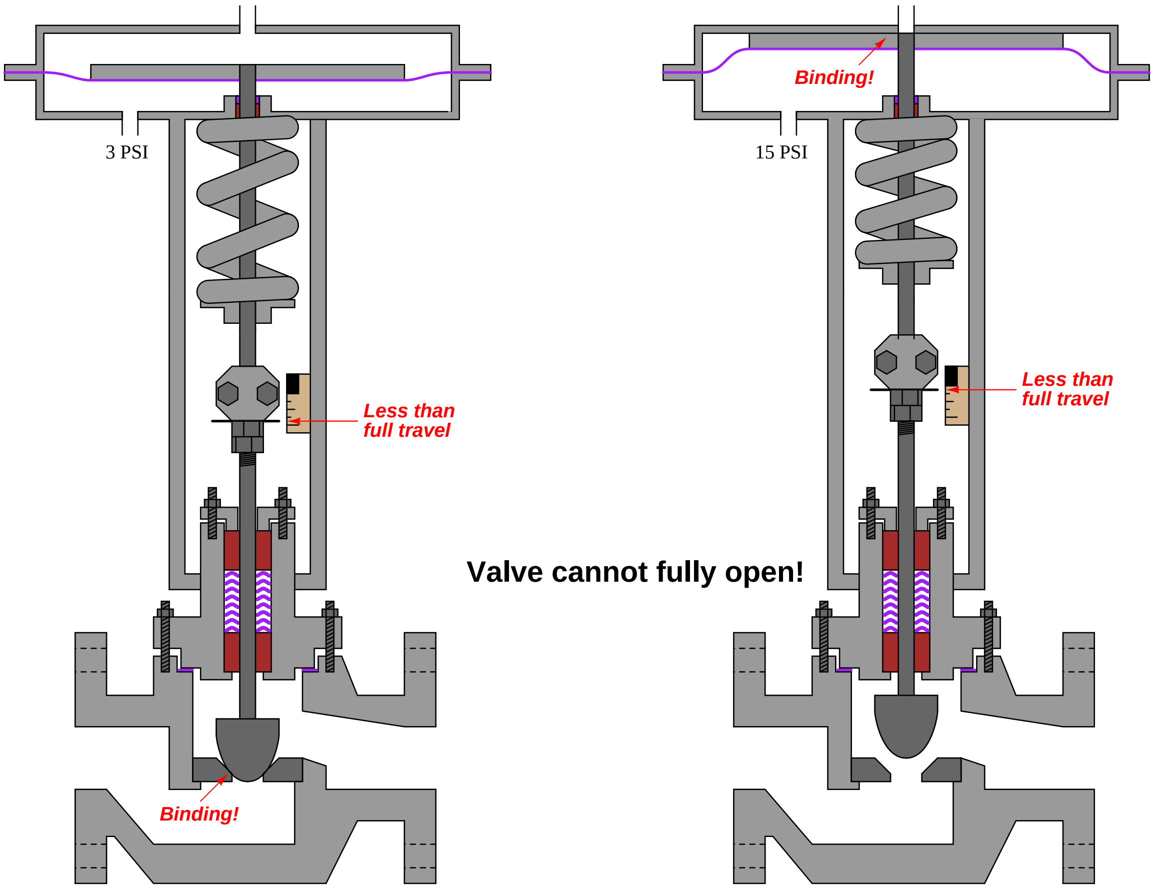
Answer 65

Answer 66

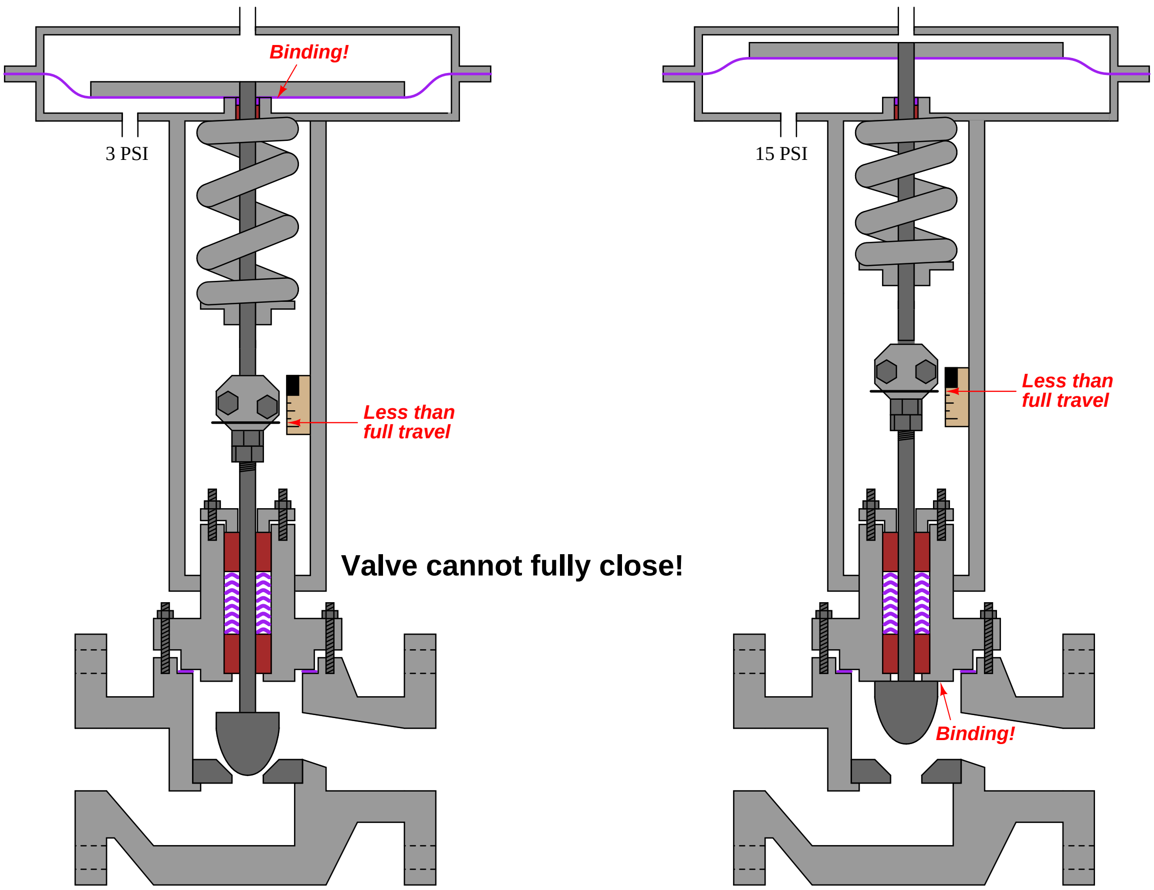
For the single-ported valve, the force will be 150 lbs in the upward direction. For the double-ported valve, the force will be only 50 lbs in the upward direction.

Answer 67

This is what happens when the valve and actuator stems are coupled too far apart (i.e. total stem length is excessive):



This is what happens when the valve and actuator stems are coupled too close together (i.e. total stem length is insufficient):



Answer 68

Pressure generated inside the sensing bulb due to temperature acting on the enclosed fluid presses against the valve's diaphragm to shut it off, thereby decreasing steam flow as vessel temperature increases.

The control valve's spring load adjustment would serve as the temperature setpoint, since this will "bias" the control valve to require different amounts of filled-system fluid pressure for any given % opening.

Given that increased bulb pressure shuts off this valve, a failure of this filled-bulb pressure will cause the steam valve to open wide, possibly overheating the vessel.

Answer 69

Remove every other bolt (half of the total number of bolts holding the actuator halves together), then replace those removed bolts with *longer* bolts and tighten down their nuts. Now, remove the remaining original bolts. Finally, begin to loosen the longer bolts previously installed. Their additional length will give the mechanism the displacement it needs to relieve spring pressure.

This procedure may be repeated more than once, using successively longer stages of bolts, if the spring's de-compression travel is longer than expected.

Answer 70

All components to the right of the spring are motion-balance, while all components to the left of the spring are force-balance. A good way to approach a problem like this is to run "thought experiments" on it, imagining the input pressure rising or falling to determine its response.

Answer 71

A "fugitive emission" is a leak of volatile organic substance from any non-point source (any source other than smokestack or other controlled vents, which are "point" sources).

According to Emerson's *Control Valve Handbook* (4th edition), fugitive emissions may account for over 400 million pounds of material lost in American industry per year!

Answer 72

We should choose a fail-open valve, which would be an air-to-close valve (if pneumatically actuated). If the valve were to fail closed, the heater tubes would overheat, causing a crude oil leak above the natural gas burners, thus causing a large fire. Failing the valve in the full-open position will actually cool down the heater tubes and prevent a rupture.

However, maximum flow through the heater tubes can cause other problems in the process as well, such as distillation tower flooding. An alternative solution is to use a fail-closed valve (air-to-open) equipped with minimum-flow stops that prevent the valve from ever going fully closed.

Another alternative plan is to install a manual *bypass* valve in parallel with the control valve, then chain-lock that manual valve at some low-flow setting. This way, when our fail-closed control valve goes fully closed, there is still some minimum amount of crude oil flow through the heater tubes. If operations personnel ever truly wish to halt flow, they can unlock the manual valve and shut it too.

If the transmitter wires break, the PV signal will fall below zero percent. This will drive the output of a reverse-acting controller *up*, which in this case will drive the control valve shut. This, clearly, is not the failure mode we intended when specifying an air-to-close valve.

The best fix for this is to configure the temperature transmitter for reverse action, and the controller for direct action. In other words, an increasing temperature will drive its 4-20 mA signal down. This way, an open fault in the transmitter wiring will look like a high temperature ($> 100\%$) to the controller, which being direct-acting will decrease its output and allow the valve to go to its resting (fail-safe) state.

Answer 73

Friction in a control valve is detrimental to stable control, because it makes it more difficult to quickly and precisely position the valve. Friction, in dissipating mechanical energy, makes valve motion slower. It also impedes precise positioning, especially when pneumatic actuators are used.

Valve friction may be empirically measured by applying variable air pressure to the actuating diaphragm and noting the difference in applied pressure necessary to make the valve move open versus making it move closed. That difference in pressure (ΔP), when multiplied by the diaphragm area will yield a difference in applied force $\Delta F = (\Delta P)(A)$. This ΔF value represents the static friction for upward movement *plus* the static friction for downward movement. If we assume the two friction values to be equal to each other, then the stem's static friction value will be $\Delta F \div 2$.

Answer 74

Teflon:

- Relatively narrow temperature range (-40^o F to 450^o F)
- Does not contribute to galvanic corrosion of valve stem
- Not suitable for nuclear service (radiation destroys PTFE)
- Minimal valve stem friction

Graphite:

- Wide temperature range (cryogenic to 1200^o F)
- Permits galvanic corrosion of valve stem
- Suitable for nuclear service
- More stem friction than Teflon

(Information gathered from Emerson's *Control Valve Handbook*, fourth edition.)

A *bellows seal* looks like a skinny accordion which fastens to the valve stem and to the bonnet, forming a leak-proof seal with very little friction.

Answer 75

For every cable break, the system responds by opening FV-42 to bypass the compressor: the safest possible condition.

For your information, compressor surge is a fluid dynamic phenomenon whereby the blades in a non-positive-displacement compressor (e.g. axial or centrifugal vane) "stall" just like the wings of an airplane flying too slowly and/or at too great an angle of attack. When the blades of a compressor stall, they lose "traction" on the compressed gas, unloading the mechanical driver (engine, motor, or turbine) and allowing the compressor to gain speed, then the blades will "un-stall" and re-load the driver, continuing the cycle.

The following passage is taken from Francis Shinskey's excellent treatise *Energy Conservation and Control*, published by Academic Press in 1978, describing compressor surge:

> "The most demanding aspect of controlling compressors is surge protection. The problem lies in being unable to determine with absolute certainty the degree of approach to surge. Once a compressor begins to surge, it will continue until corrective action is applied, so automatic protection is mandatory. A small centrifugal compressor may surge several times without damage, but a 100,000-hp axial could require reblading after a single incident."
>
> "When a compressor begins to surge, the suction flow falls to zero within a few milliseconds, reverses momentarily, and begins to recover in less than a half second. If the situation is not corrected, the cycle repeats immediately, resulting in a series of thunderclaps less than a second apart. The sudden fall in suction flow can be detected and used to open a recirculating valve, but not before at least one surge cycle is sustained. To prevent surge from developing at all requires a control system which skirts the unstable area altogether."

Answer 76

- 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.

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.