INST 250 (Final Control Elements), section 3

Lab

Split-range control valves: *Questions 91 and 92*, **completed objectives due by the end of day 4, section 4**

Exam

Day 5 of next section

Specific objectives for the "mastery" exam:

- Build a circuit to sense either pressure or vacuum using a DP transmitter (question 93)
- Determine proper fail-safe mode for a control valve in a given process
- Calculate C_v rating of control valve for liquid (non-cavitating) service
- Calculate split-ranged valve positions given signal value and valve calibration ranges
- Solve for a specified variable in an algebraic formula
- Determine the possibility of suggested faults in a simple circuit given measured values (voltage, current), a schematic diagram, and reported symptoms
- INST240 Review: Calculate ranges for hydrostatic (DP) level-measuring instruments given physical dimensions and fluid densities
- INST263 Review: Determine effect of a fault in a selector or override control system

Recommended daily schedule

Day 1

Theory session topic: Valve positioners

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

Day 2

Theory session topic: Split-ranged control valves

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

Day 3

Theory session topic: Electric valve actuators and variable-speed pumps

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

Day 4

Theory session topic: Valve sizing

Questions 61 through 80; answer questions 61-70 in preparation for discussion (remainder for practice)

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

Course Syllabus

INSTRUCTOR CONTACT INFORMATION:

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DEPT/COURSE #: INST 250

CREDITS: 5 **Lecture Hours:** 22 **Lab Hours:** 70 **Work-based Hours:** 0

COURSE TITLE: Final Control Elements

COURSE OUTCOMES: Commission, analyze, and efficiently diagnose instrumented systems using industry-standard control valves as final control elements.

COURSE DESCRIPTION: In this course you will learn how to precisely control energy in process systems using fluid valves and motors. You will also learn how fluid power systems work, and how to efficiently troubleshoot final control elements. **Pre/Corequisite course:** INST 200 (Introduction to Instrumentation) **Prerequisite course:** MATH&141 (Precalculus 1)

COURSE OUTLINE: A course calendar in electronic format (Excel spreadsheet) resides on the Y: network drive, and also in printed paper format in classroom DMC130, for convenient student access. This calendar is updated to reflect schedule changes resulting from employer recruiting visits, interviews, and other impromptu events. Course worksheets provide comprehensive lists of all course assignments and activities, with the first page outlining the schedule and sequencing of topics and assignment due dates. These worksheets are available in PDF format at `http://openbookproject.net/books/socratic/sinst`

- INST250 Section 1 (Fluid system principles): 4 days theory and labwork
- INST250 Section 2 (Control valve basics): 4 days theory and labwork + 1 day for mastery/proportional Exams
- INST250 Section 3 (Valve positioners, MOVs): 4 days theory and labwork
- INST250 Section 4 (Valve sizing, characterization): 4 days theory and labwork + 1 day for mastery/proportional Exams

STUDENT PERFORMANCE OBJECTIVES:

- Without references or notes, within a limited time (3 hours total for each exam session), independently perform the following tasks. Multiple re-tries are allowed on mastery (100% accuracy) objectives, each with a different set of problems:
  → Build a circuit to energize an electromechanical relay given a switch and relay both randomly selected by the instructor, with 100% accuracy (mastery)
  → Build a circuit to sense either pressure or vacuum using a DP transmitter randomly selected by the instructor, with 100% accuracy (mastery)
  → Determine response of a pneumatic force-balance mechanism to different conditions, with 100% accuracy (mastery)
  → Determine the effect of a fault in a solenoid-controlled valve system with 100% accuracy (mastery)
  → Determine proper fail-safe mode for a control valve in a given process, with 100% accuracy (mastery)
  → Calculate C_v rating of control valve for liquid (non-cavitating) service, with 100% accuracy (mastery)
  → Calculate instrument input and output values given calibrated ranges, with 100% accuracy (mastery)
  → Calculate split-ranged valve positions given signal value and valve calibration ranges, with 100% accuracy (mastery)
  → Solve for specified variables in algebraic formulae, with 100% accuracy (mastery)
  → Determine the possibility of suggested faults in simple circuits given measured values (voltage, current), schematic diagrams, and reported symptoms, with 100% accuracy (mastery)
  → Predict the response of automatic process control systems to component faults and changes in process conditions, given pictorial and/or schematic illustrations
  → Sketch proper power and signal connections between individual instruments to fulfill specified control system functions, given pictorial and/or schematic illustrations of those instruments

- In a team environment and with full access to references, notes, and instructor assistance, perform the following tasks:
  → Demonstrate proper use of safety equipment and application of safe procedures while using power tools, and working on live systems
  → Communicate effectively with teammates to plan work, arrange for absences, and share responsibilities in completing all labwork
  → Completely rebuild a pneumatically-actuated control valve
  → Calibrate an I/P signal converter to specified accuracy using industry-standard calibration equipment
  → Construct and commission a working hand control "loop" consisting of a PID controller, signal wiring, and control valve with positioner
  → Calibrate a pair of split-ranged control valves using industry-standard calibration equipment
  → Generate accurate loop diagrams compliant with ISA standards documenting your team's hand control systems

- Independently perform the following tasks on a functioning hand control system with 100% accuracy (mastery). Multiple re-tries are allowed with different specifications/conditions each time):
  → Diagnose random faults placed in other teams' 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

METHODS OF INSTRUCTION: Course structure and methods are intentionally designed to develop critical-thinking and life-long learning abilities, continually placing the student in an active rather than a passive role.

- **Independent study:** daily worksheet questions specify *reading assignments*, *problems* to solve, and *experiments* to perform in preparation (before) classroom theory sessions. Open-note quizzes and work inspections ensure accountability for this essential preparatory work. The purpose of this is to convey information and basic concepts, so valuable class time isn't wasted transmitting bare facts, and also to foster the independent research ability necessary for self-directed learning in your career.
- **Classroom sessions:** a combination of *Socratic discussion*, short *lectures*, *small-group* problem-solving, and hands-on *demonstrations/experiments* review and illuminate concepts covered in the preparatory questions. The purpose of this is to develop problem-solving skills, strengthen conceptual understanding, and practice both quantitative and qualitative analysis techniques.
- **Lab activities:** an emphasis on constructing and documenting *working projects* (real instrumentation and control systems) to illuminate theoretical knowledge with practical contexts. Special projects off-campus or in different areas of campus (e.g. BTC's Fish Hatchery) are encouraged. Hands-on *troubleshooting exercises* build diagnostic skills.
- **Feedback questions:** sets of *practice problems* at the end of each course section challenge your knowledge and problem-solving ability in current as as well as first year (Electronics) subjects. These are optional assignments, counting neither for nor against your grade. Their purpose is to provide you and your instructor with direct feedback on what you have learned.
- **Tours and guest speakers:** quarterly *tours* of local industry and *guest speakers* on technical topics add breadth and additional context to the learning experience.

STUDENT ASSIGNMENTS/REQUIREMENTS: All assignments for this course are thoroughly documented in the following course worksheets located at:
`http://openbookproject.net/books/socratic/sinst/index.html`

- `INST250_sec1.pdf`
- `INST250_sec2.pdf`
- `INST250_sec3.pdf`
- `INST250_sec4.pdf`

EVALUATION AND GRADING STANDARDS: (out of 100% for the course grade)

- Mastery exams and mastery lab objectives = 50% of course grade
- Proportional exams = 40% (2 exams at 20% each)
- Lab questions = 10% (2 question sets at 5% each)
- Quiz penalty = -1% per failed quiz
- Tardiness penalty = -1% per incident (1 "free" tardy per course)
- Attendance penalty = -1% per hour (12 hours "sick time" per quarter)
- Repair bonus = +5% per repaired instrument (instrument's broken and repaired statuses must be verified by the instructor)

All grades are criterion-referenced (i.e. no grading on a "curve")

100% ≥ **A** ≥ 95%	95% > **A-** ≥ 90%		
90% > **B+** ≥ 86%	86% > **B** ≥ 83%	83% > **B-** ≥ 80%	
80% > **C+** ≥ 76%	76% > **C** ≥ 73%	73% > **C-** ≥ 70% (minimum passing course grade)	
70% > **D+** ≥ 66%	66% > **D** ≥ 63%	63% > **D-** ≥ 60%	60% > **F**

Graded quizzes at the start of each classroom session gauge your independent learning. If absent or late, you may receive credit by passing a comparable quiz afterward or by having your preparatory work (reading outlines, work done answering questions) thoroughly reviewed prior to the absence.

Absence on a scheduled exam day will result in a 0% score for the proportional exam unless you provide documented evidence of an unavoidable emergency.

Failing a mastery exam will result in a 10% deduction from the proportional exam score, and you must still pass the mastery exam before the next scheduled course exam date. Multiple re-tries on new versions of the mastery exam are allowed with no further grade deduction. Failure to pass the mastery exam by the due date will result in a failing grade (F) for the course.

If any other "mastery" objectives are not completed by their specified deadlines, your overall grade for the course will be capped at 70% (C- grade), and you will have one more school day to complete the unfinished objectives. Failure to complete those mastery objectives by the end of that extra day (except in the case of documented, unavoidable emergencies) will result in a failing grade (F) for the course.

"Lab questions" are assessed by individual questioning, at any date after the respective lab objective (mastery) has been completed by your team. These questions serve to guide your completion of each lab exercise and confirm participation of each individual student. Grading is as follows: full credit for thorough, correct answers; half credit for partially correct answers; and zero credit for major conceptual errors. All lab questions must be answered by the due date of the lab exercise.

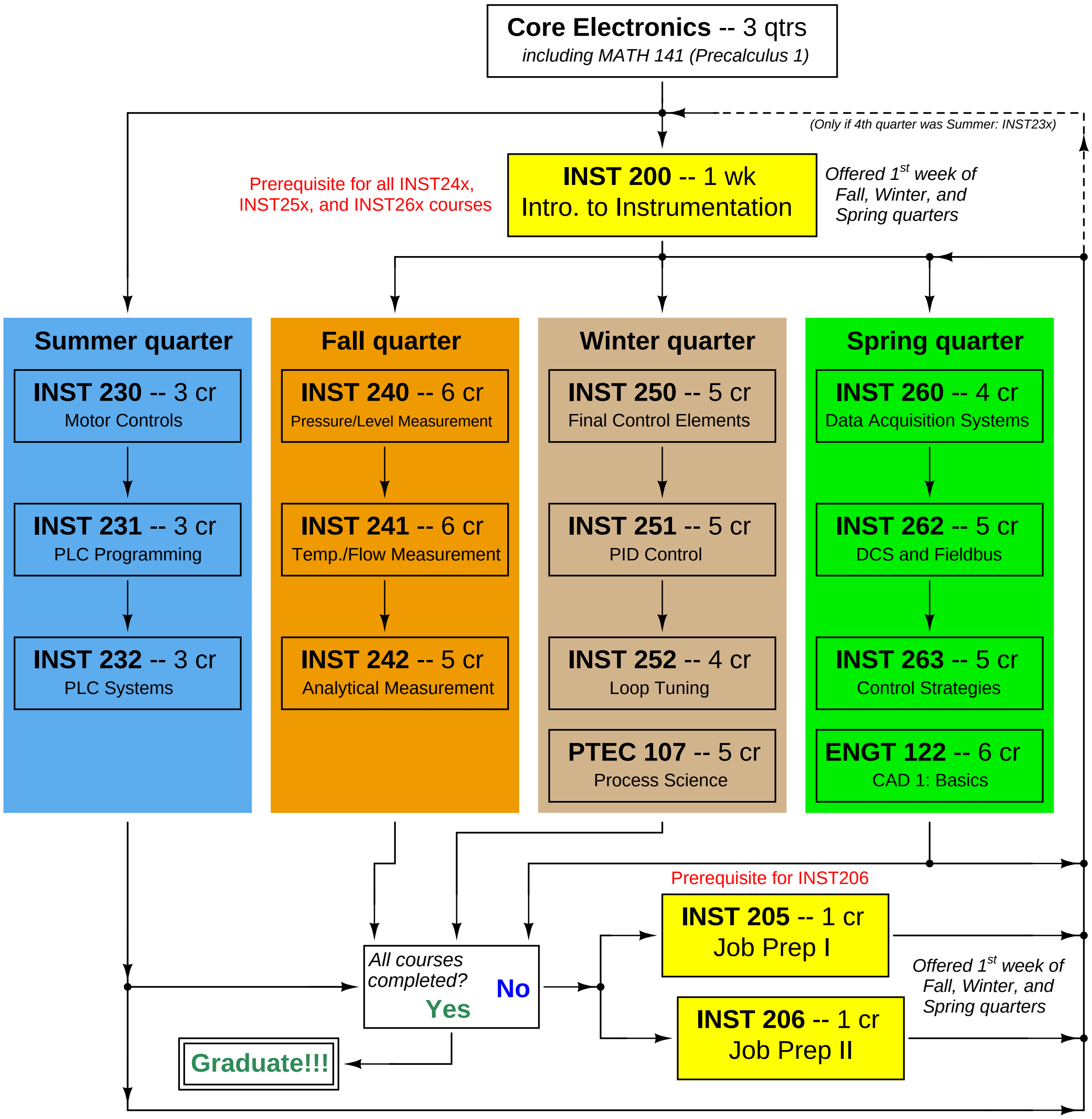
REQUIRED STUDENT SUPPLIES AND MATERIALS:

- Course worksheets available for download in PDF format
- *Lessons in Industrial Instrumentation* textbook, available for download in PDF format
  → Access worksheets and book at: `http://openbookproject.net/books/socratic/sinst`
- Spiral-bound notebook for reading annotation, homework documentation, and note-taking.
- Instrumentation reference CD-ROM (free, from instructor). This disk contains many tutorials and datasheets in PDF format to supplement your textbook(s).
- Tool kit (see detailed list)
- Simple scientific calculator (non-programmable, non-graphing, no unit conversions, no numeration system conversions), TI-30Xa or TI-30XIIS recommended

ADDITIONAL INSTRUCTIONAL RESOURCES:

- *Control Valve Handbook*, by Emerson Process Management (Fisher Controls International). This book is hard to find in print, but it may be obtained in electronic (PDF) format from Emerson's website, and is also included on the reference CD-ROM.
- The BTC Library hosts a substantial collection of textbooks and references on the subject of Instrumentation, as well as links in its online catalog to free Instrumentation e-book resources available on the Internet.
- "BTCInstrumentation" channel on YouTube (`http://www.youtube.com/BTCInstrumentation`), hosts a variety of short video tutorials and demonstrations on instrumentation.
- ISA Student Section at BTC meets regularly to set up industry tours, raise funds for scholarships, and serve as a general resource for Instrumentation students. Membership in the ISA is $10 per year, payable to the national ISA organization. Membership includes a complementary subscription to *InTech* magazine.
- ISA website (`http://www.isa.org`) provides all of its standards in electronic format, many of which are freely available to ISA members.
- *Instrument Engineer's Handbook, Volume 2: Process Control and Optimization*, edited by Béla Lipták, published by CRC Press. 4th edition ISBN-10: 0849310814 ; ISBN-13: 978-0849310812.
- *Purdy's Instrument Handbook*, by Ralph Dewey. ISBN-10: 1-880215-26-8. A pocket-sized field reference on basic measurement and control.
- *Cad Standard* (CadStd) or similar AutoCAD-like drafting software (useful for sketching loop and wiring diagrams). Cad Standard is a simplified clone of AutoCAD, and is freely available at: `http://www.cadstd.com`
- To receive classroom accommodations, registration with Disability Support Services (DSS) is required. Call 360-752-8450, email `mgerard@btc.ctc.edu`, or visit the DSS office in the Counseling and Career Center (room 106, College Services building).

file `INST250syllabus`


Core Electronics -- 3 qtrs
including MATH 141 (Precalculus 1)
(Only if 4th quarter was Summer: INST23x)
Prerequisite for all INST24x, INST25x, and INST26x courses
INST 200 -- 1 wk
Intro. to Instrumentation
Offered 1st week of Fall, Winter, and Spring quarters
Summer quarter
INST 230 -- 3 cr
Motor Controls
INST 231 -- 3 cr
PLC Programming
INST 232 -- 3 cr
PLC Systems
Fall quarter
INST 240 -- 6 cr
Pressure/Level Measurement
INST 241 -- 6 cr
Temp./Flow Measurement
INST 242 -- 5 cr
Analytical Measurement
Winter quarter
INST 250 -- 5 cr
Final Control Elements
INST 251 -- 5 cr
PID Control
INST 252 -- 4 cr
Loop Tuning
PTEC 107 -- 5 cr
Process Science
Spring quarter
INST 260 -- 4 cr
Data Acquisition Systems
INST 262 -- 5 cr
DCS and Fieldbus
INST 263 -- 5 cr
Control Strategies
ENGT 122 -- 6 cr
CAD 1: Basics
Prerequisite for INST206
INST 205 -- 1 cr
Job Prep I
INST 206 -- 1 cr
Job Prep II
Offered 1st week of Fall, Winter, and Spring quarters
All courses completed?
No
Yes
Graduate!!!

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

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

file sequence

General student expectations

Your future employer expects you to: show up for work on time, prepared, every day; to work safely, efficiently, conscientiously, and with a clear mind; to seek help when you need it; to follow through on all commitments; and to take responsibility for all your actions and for the consequences of those actions. Instrument technicians work on highly complex, mission-critical measurement and control systems, where incompetence and/or lack of integrity invites disaster. This is also why employers check legal records and social networking websites for signs of irresponsibility when considering a student for hire. Substance abuse is particularly noteworthy it impairs your ability to reason, and this is first and foremost a "thinking" career.

(Mastery) You are expected to master the fundamentals of your chosen craft. Accordingly, you will be challenged with "mastery" assessments ensuring 100% competence in specific knowledge and skill areas (with multiple opportunities to re-try if necessary). Failure to pass any mastery assessment by the deadline results in your grade for that course being capped at a C-, with one more day given to demonstrate mastery. Failure to pass the mastery assessment during that extra day results in a failing grade for the course.

(Punctuality and Attendance) You are expected to arrive on time, every day, and attend all day, just as you would for a job. If a session begins at 12:00 noon, 12:00:01 is considered late. Each student has 12 "sick hours" per quarter applicable to absences not verifiably employment-related, school-related, weather-related, or required by law. Each student must confer with the instructor to apply "sick hours" to any missed time – this is not done automatically for the student. Students may donate unused "sick hours" to whomever they specifically choose. You must contact your instructor and team members immediately if you know you will be late or absent, and it is your responsibility to catch up on all missed activities. Absence on an exam day will result in a zero score for that exam, unless due to a documented emergency.

(Independent study) Industry advisors and successful graduates have consistently identified the ability to independently learn new concepts and technologies as the most important skill for this career. You will build this vital skill by studying new facts and concepts *before* class begins, and you will be held accountable every day for this preparatory learning and for your problem-solving during class time. It is your responsibility to check the course schedule (given on the front page of every worksheet) to identify assignments and due dates. Most students find 2 hours per day the *absolute minimum* time commitment for adequate study. Question 0 (included in every worksheet) lists practical tips for independent learning and problem-solving.

(Safety) You are expected to work safely in the lab just as you will be on the job. This includes wearing proper attire (safety glasses when working with tools producing chips or dust, no open-toed shoes in the lab), implementing lock-out/tag-out procedures when working on circuits over 24 volts, using ladders to reach high places rather than standing on tables or chairs, and maintaining an orderly work environment.

(Teamwork) You will work in instructor-assigned teams to complete lab assignments, just as you will work in teams to complete complex assignments on the job. As part of a team, you must keep your teammates informed of your whereabouts in the event you must step away from the lab or cannot attend for any reason. Any student regularly compromising team performance through absence, tardiness, disrespect, unsafe work, or other disruptive behavior(s) will be expelled from their team and required to complete all labwork independently for the remainder of the quarter.

(Responsibility for actions) If you lose or damage college property (e.g. lab equipment), you must find, repair, or help replace it. If your actions strain the relationship between the program and an employer (e.g. poor behavior during a tour or an internship), you must make amends. The general rule here is this: *"If you break it, you fix it!"*

(Disciplinary action) The Student Code of Conduct (Washington Administrative Codes `WAC 495B-120`) explicitly authorizes disciplinary action against misconduct including: academic dishonesty (e.g. cheating, plagiarism), dangerous or lewd behavior, theft, harassment, intoxication, destruction of property, or disruption of the learning environment.

file `expectations`

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: *when turning a bolt, nut, or tube fitting with a hexagonal body, the preferred ranking of hand tools to use (from first to last) is box-end wrench or socket, open-end wrench, and finally adjustable wrench. Pliers should never be used to turn the head of a fitting or fastener unless it is absolutely unavoidable!*

Pliers

- Needle-nose pliers
- Tongue-and-groove pliers (sometimes called "Channel-lock" 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)

Measurement tools

- Tape measure. 12 feet minimum
- *Optional:* Vernier calipers
- *Optional:* Bubble level

Electrical

- Multimeter, Fluke model 87-IV or better
- Wire strippers/terminal crimpers with a range including 10 AWG to 18 AWG wire
- Soldering iron, 10 to 25 watt
- Rosin-core solder
- Package of compression-style fork terminals (e.g. Thomas & Betts "Sta-Kon" part number 14RB-10F, 14 to 18 AWG wire size, #10 stud size)

Safety

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

Miscellaneous

- Simple scientific calculator (non-programmable, non-graphing, no unit conversions, no numeration system conversions), TI-30Xa or TI-30XIIS recommended. Required for some exams!
- Teflon pipe tape
- Utility knife
- *Optional:* Flashlight

An inexpensive source of high-quality tools is your local pawn shop. Look for name-brand tools with unlimited lifetime guarantees (e.g. *Sears* "Craftsman" brand, *Snap-On*, etc.). Some local tool suppliers give BTC student discounts as well!

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*.

Theory

In the theory portion of each course, students independently research subjects *prior* to entering the classroom for discussion. This means working through all the day's assigned questions as completely as possible. This usually requires a fair amount of technical reading, and may also require setting up and running simple experiments. At the start of the classroom session, the instructor will check each student's preparation with a quiz. Students then spend the rest of the classroom time working in groups and directly with the instructor to *thoroughly* answer all questions assigned for that day, articulate problem-solving strategies, and to approach the questions from multiple perspectives. To put it simply: fact-gathering happens outside of class and is the individual responsibility of each student, so that class time may be devoted to the more complex tasks of critical thinking and problem solving where the instructor's attention is best applied.

Classroom theory sessions usually begin with either a brief Q&A discussion or with a "Virtual Troubleshooting" session where the instructor shows one of the day's diagnostic question diagrams while students propose diagnostic tests and the instructor tells those students what the test results would be given some imagined ("virtual") fault scenario, writing the test results on the board where all can see. The students then attempt to identify the nature and location of the fault, based on the test results.

Each student is free to leave the classroom when they have completely worked through all problems and have answered a "summary" quiz designed to gauge their learning during the theory session. If a student finishes ahead of time, they are free to leave, or may help tutor classmates who need extra help.

The express goal of this "inverted classroom" teaching methodology is to help each student cultivate critical-thinking and problem-solving skills, and to sharpen their abilities as independent learners. While this approach may be very new to you, it is more realistic and beneficial to the type of work done in instrumentation, where critical thinking, problem-solving, and independent learning are "must-have" skills.

Lab

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 eight-day period typically allotted 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)
(One day) Connect instrument(s) into a complete loop
(One day) Each team member drafts their own loop documentation, inspection done as a team (with instructor)
(One or two days) Each team member calibrates/configures the instrument(s)
(Remaining days, up to last) Each team member troubleshoots the instrument loop

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

Troubleshooting assessments must meet the following guidelines:

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

file `instructional`

Distance delivery methods

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

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

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

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

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

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

file `distance`

General advice for successful learning

Focus on principles, not procedures

- Effective problem-solvers don't bother trying to memorize procedures for problem-solving because procedures are too specific to the type of problem. Rather, they internalize *general principles* applicable to a wide variety of problems.
- When asking questions about some new subject, concentrate on *"why"* rather than "how" or "what."

Cultivate meta-cognitive skills (the ability to monitor your own thinking on a subject)!

- Whenever you get "stuck" trying to understand a concept, clearly identify where you are getting stuck, and where things stop making sense.
- When you think you understand a concept, test your understanding by explaining it in your own words. You can do this by trying to explain it to a willing classmate, or by imagining yourself trying to explain it to someone. *If you cannot clearly explain a concept to someone else, you do not understand it well enough yourself!*
- The technique of trying to explain a concept also works well to identify where you are stuck. The point at which you find yourself unable to clearly articulate the concept is very likely the exact point of your misconception or confusion.

Join or create a study group with like-minded classmates!

- Read the textbook assignments together.
- Solve assigned problems together.
- Collectively identify difficult concepts and areas needing clarification, to bring up later during class.
- Take turns trying to explain complicated concepts to each other, then critiquing those explanations.

Eliminate distractions in your life!

- Time-wasting technologies: televisions, internet, video games, mobile phones, etc.
- Unhelpful friends, unhealthy relationships, etc.

Make use of "wasted" time to study!

- Carefully plan your lab sessions with your teammates to reserve a portion of each day's lab time for study.
- Bring a meal to school every day and use your one-hour lunch break for study instead of eating out. This will not just save you time, but also money!
- Plan to arrive at school at least a half-hour early (the doors unlock at 7:00 AM) and use the time to study as opposed to studying late at night. This also helps guard against tardiness in the event of unexpected delays, and ensures you a better parking space!

Take responsibility for your learning and your life!

- *Do not procrastinate*, waiting until the last minute to do something.
- Obtain all the required books, and any supplementary study materials available to you. If the books cost too much, look on the internet for used texts (`www.amazon.com`, `www.half.com`, etc.) and use the money from the sale of your television and video games to buy them!
- Make an honest attempt to solve problems before asking someone else to help you. Being able to problem-solve is a skill that will improve only if you continue to work at it.
- If you detect trouble understanding a basic concept, address it immediately. Never ignore an area of confusion, believing you will pick up on it later. Later may be too late!
- Do not wait for others to do things for you. No one is going to make extra effort purely on your behalf.

. . . And the number one tip for success . . .

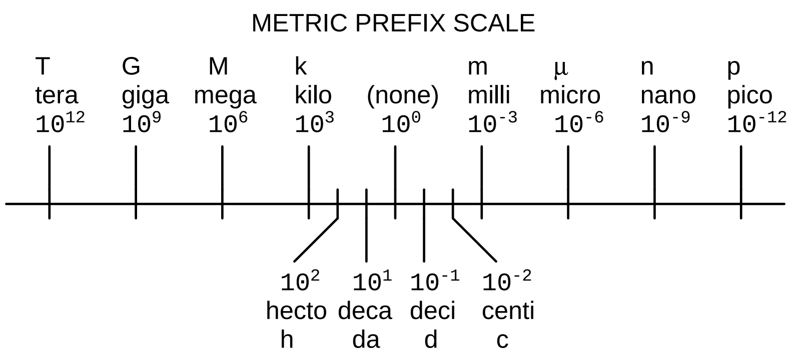
- *Realize that there are no shortcuts to learning. Every time you seek a shortcut, you are actually cheating yourself out of a learning opportunity!!*

file `studytips`

file license

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) = 1.05506×10^{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·^{o}C = 1 BTU/lb·^{o}F = 4.1869 Joules/g·^{o}C

Specific heat of ice ≈ 0.5 calories/g·^{o}C

Specific heat of steam ≈ 0.48 calories/g·^{o}C

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

Question 0

How to read actively:

- Avoid shallow annotation methods such as underlining and highlighting. Instead, express your own interpretation of the text in a notebook or in the margins of the text. A suggestion is one sentence of your own thoughts per paragraph in the text. *Expressing your own thoughts as you read is a far more effective way to digest the information than simply emphasizing portions of the text!* If you do wish to emphasize some portion of the text that either makes perfect sense to you or causes confusion, write that portion verbatim and include a page number reference in your notes so you may reference it during class.
- Identify as clearly as possible which concepts or points confuse you the most. This is the first and most important step to overcoming confusion. *The more specific you are, the better your instructor and classmates will be able to help you overcome the confusion!*
- If the text demonstrates a mathematical calculation, such as how to apply a new equation to solving a problem, *pick up your calculator and work through the example as you read!* Applications of math are an ideal opportunity to *actively* read a technical book.
- Maintain a notebook where you express your understanding of *general principles* applicable to the subject(s) you are studying, including mathematical formulae (a formula is really just a precise expression of a principle) with brief definitions of terms.
- Imagine trying to explain what you've just read to an intelligent child – someone with the capacity to understand but without the experience to immediately relate. This forces you to distill each concept to its essence. Your first attempt will rarely be right, but subsequent attempts will get better and better. Once you have an explanation that satisfies you, *write it out* using the fewest words possible.

Problem-solving tips:

- Always begin by identifying which general principles you've learned apply to the problem, then identify how the goal of the problem (i.e. what it is you're asked to solve) and the "given" information fits with those principles.
- Sketch a diagram to organize all "given" information and show where the answer will fit.
- Perform "thought experiments" to visualize the effects of different conditions.
- Work "backward" from a hypothetical solution to a new set of given conditions.
- Change the problem to make it simpler, and then solve the simplified problem (e.g. change quantitative to qualitative, or visa-versa; substitute different numerical values to make them easier to work with; eliminate confusing details; add details to eliminate unknowns; consider limiting cases that are easier to grasp; put the problem into a more familiar context, or analogy).
- Specifically identify which portion(s) of the question you find most confusing and need help with. The more specifically you are able to express your point(s) of confusion, the better.

Above all, cultivate persistence in your studies. Persistent effort is necessary for mastery of anything non-trivial. The keys to persistence are (1) having the desire to achieve that mastery, and (2) knowing that 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, and that "easier" methods usually substitute memorization for understanding!

file `question0`

Questions

Question 1

Read and outline the introduction to the "Valve Positioners" section of the "Control Valves" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04207

Question 2

Read and outline the "Force-Balance Pneumatic Positioners" subsection of the "Valve Positioners" section of the "Control Valves" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i01363

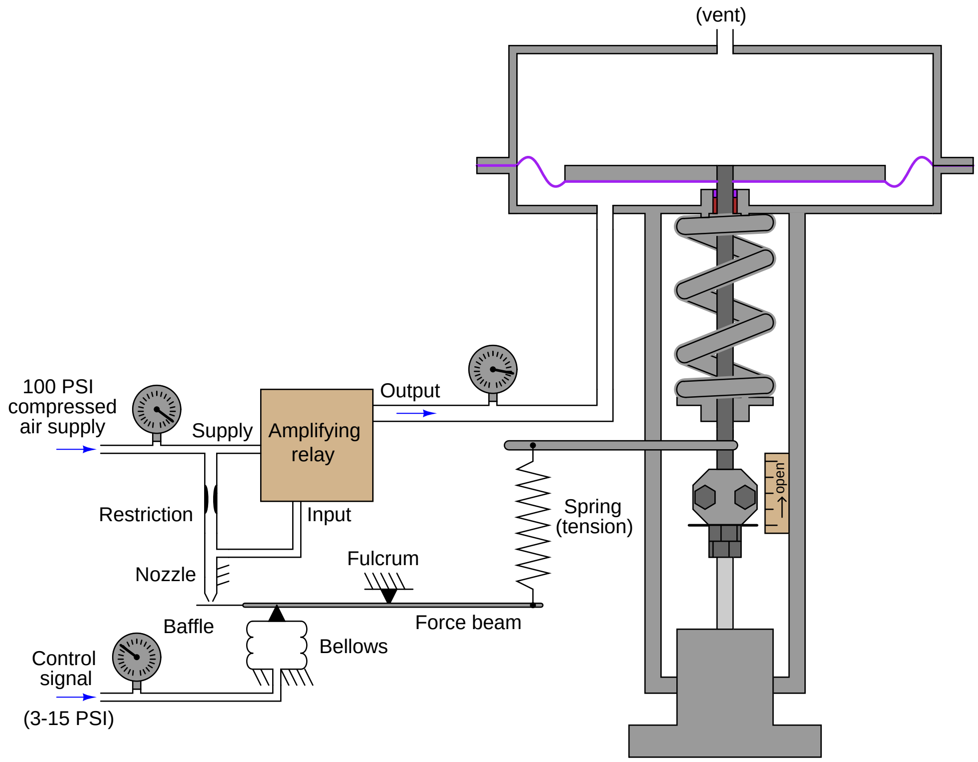
Question 3

Read and outline the "Motion-Balance Pneumatic Positioners" subsection of the "Valve Positioners" section of the "Control Valves" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i01364

Question 4

This valve positioner system has a problem. The valve remains at 100% (full open) for *any* applied control signal value:



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

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

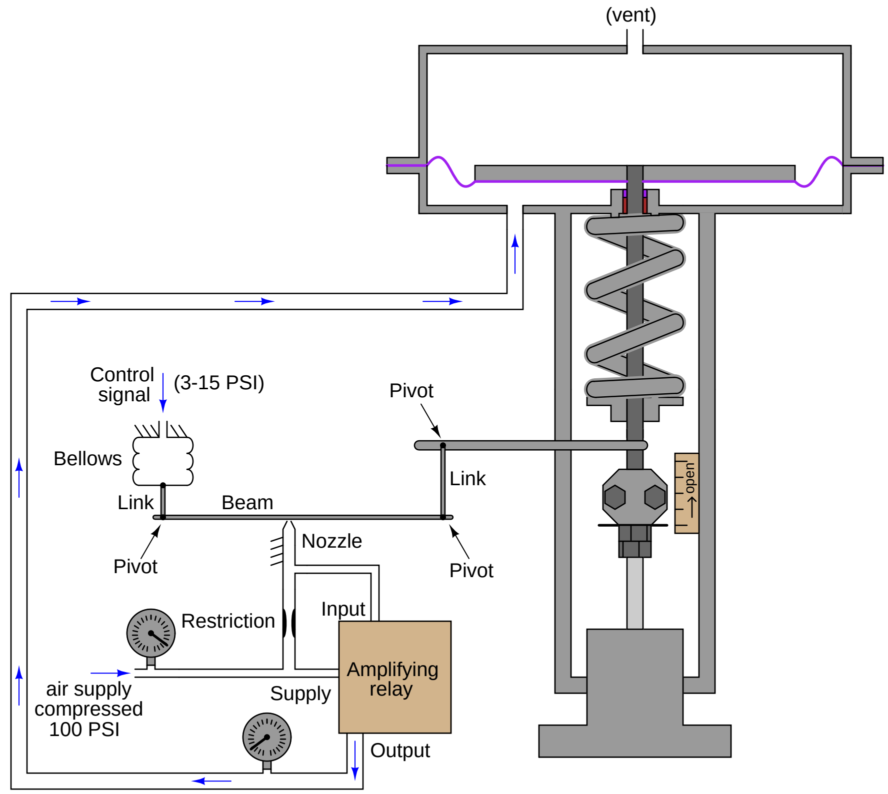
Fault	**Possible**	**Impossible**
Plugged restriction		
Plugged nozzle		
Broken spring		
Leak in bellows		
Leak in actuator diaphragm		
Air supply failure		

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

file i01361

Question 5

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



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

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

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

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

file i01362

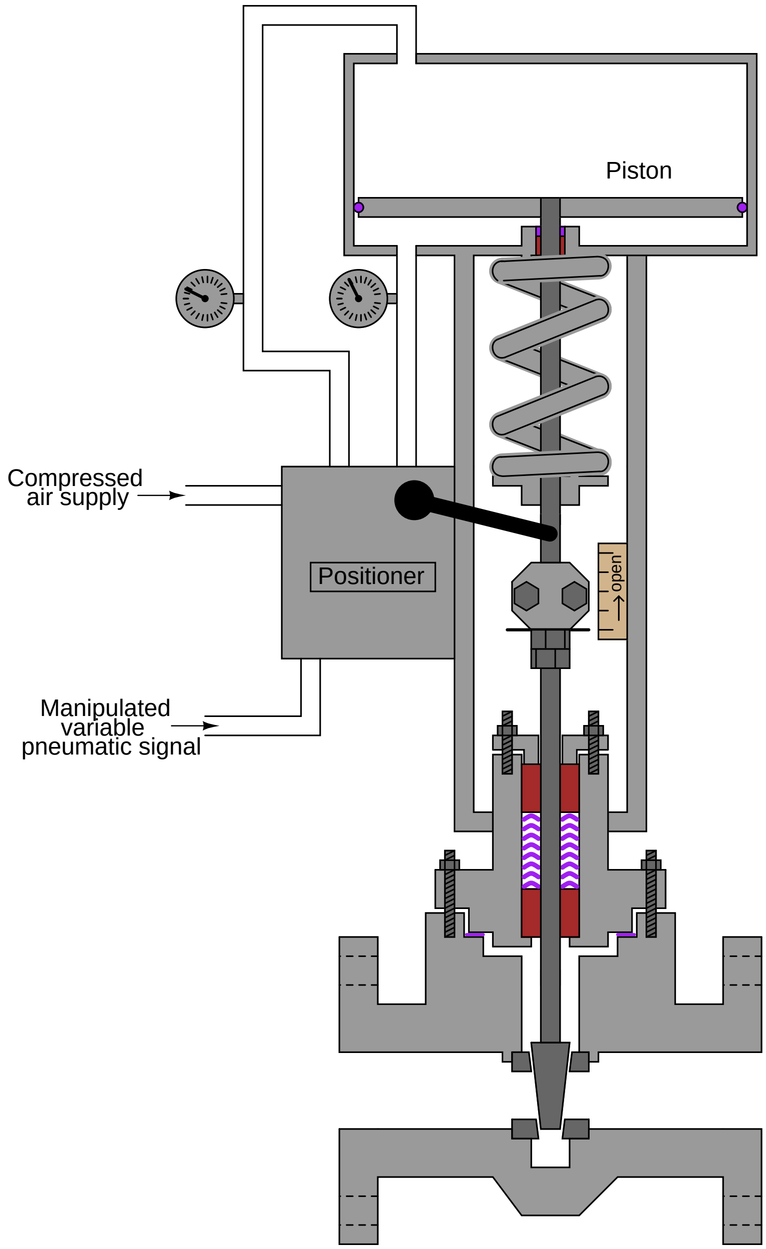
Question 6

Read and outline the "Electronic Positioners" subsection of the "Valve Positioners" section of the "Control Valves" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i01365

Question 7

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



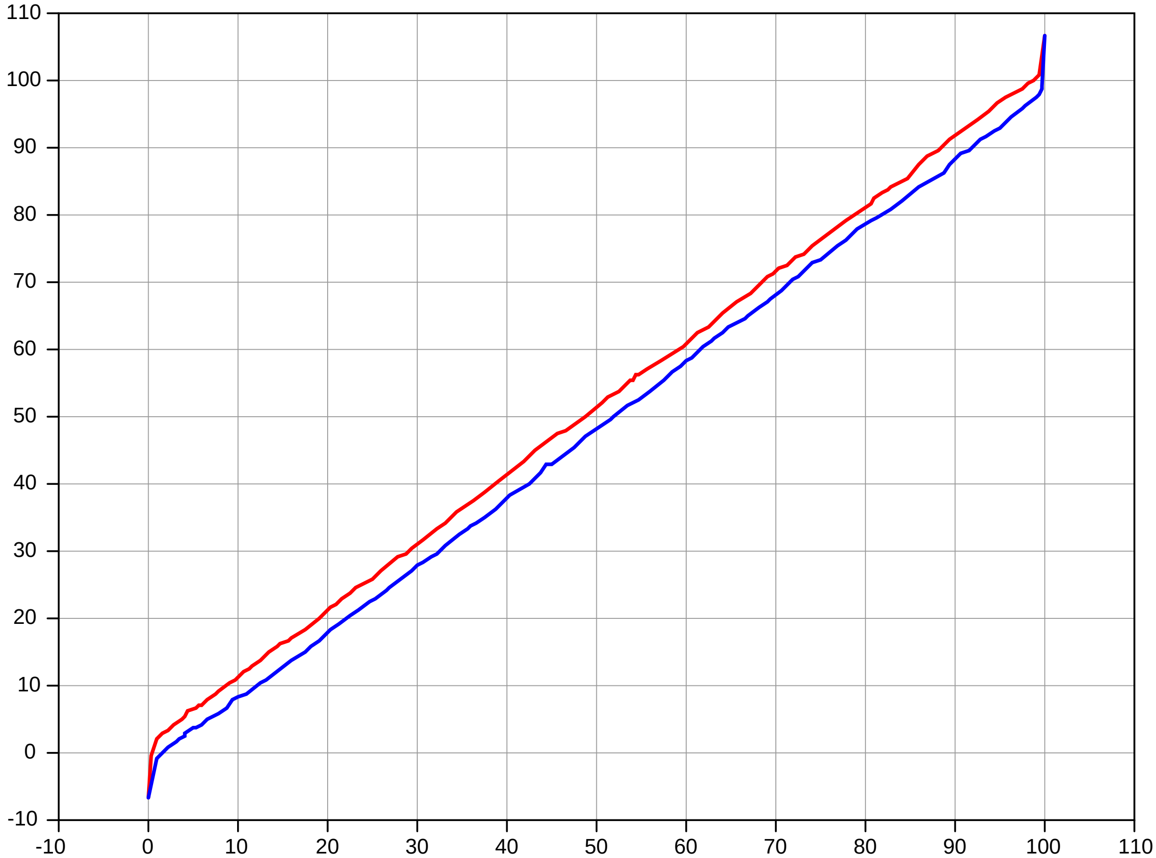
- Gauge readings at 0% (3 PSI) signal to the positioner
- Gauge readings at 50% (9 PSI) signal to the positioner
- Gauge readings at 100% (15 PSI) signal to the positioner

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

file i01401

Question 8

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



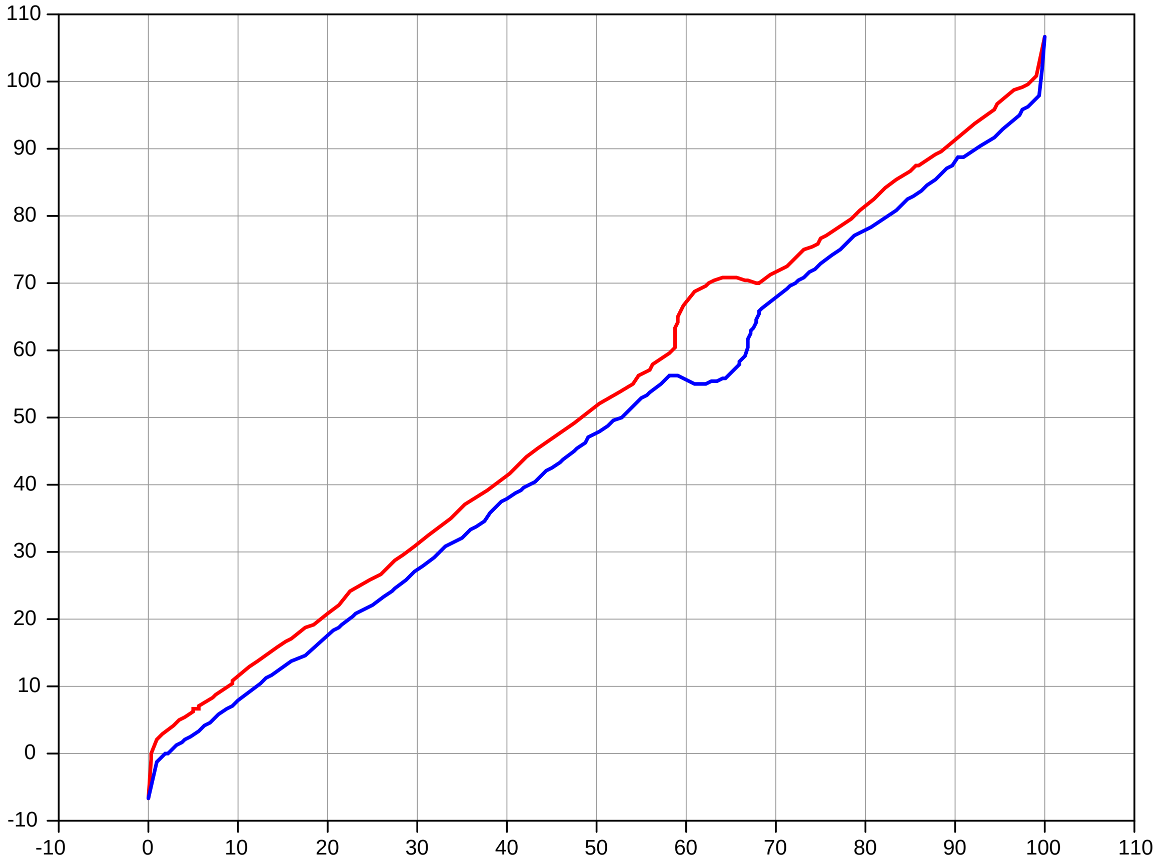
Closely examine this graph of stem position vs. actuator pressure, and answer the following questions:

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

file i04185

Question 9

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



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

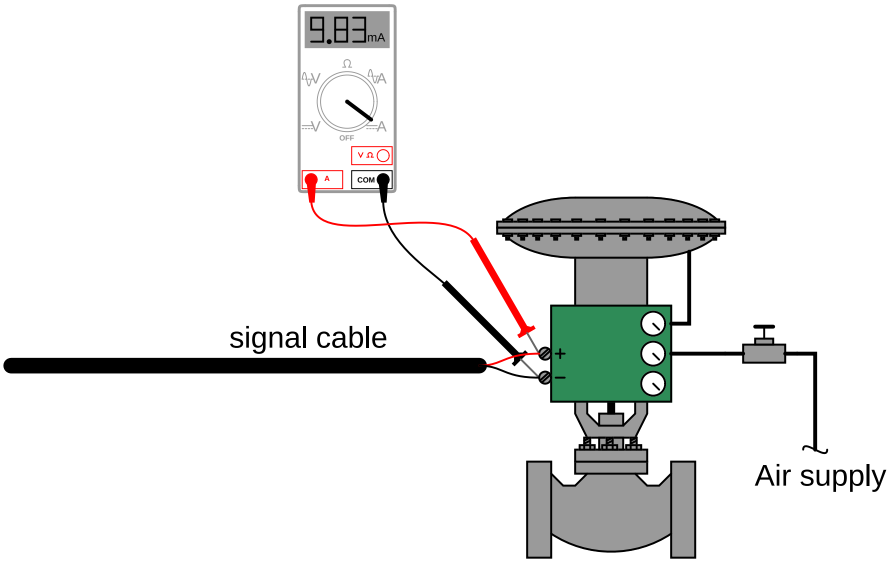
Suggestions for Socratic discussion

- A useful problem-solving technique to apply to any scenario with a graph is to let the graph "tell you" what is happening step-by-step in time as you follow it from one extreme to the other. Try doing this: starting at the lower-left corner, following the upper (red) trace step by step as though you are re-playing the opening of the valve over time, interpreting the graph in terms of stem position and actuator pressure (applied force). Describe what the graph "tells" you as you follow it from one end to the other.

file i00746

Question 10

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



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

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

Suggestions for Socratic discussion

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

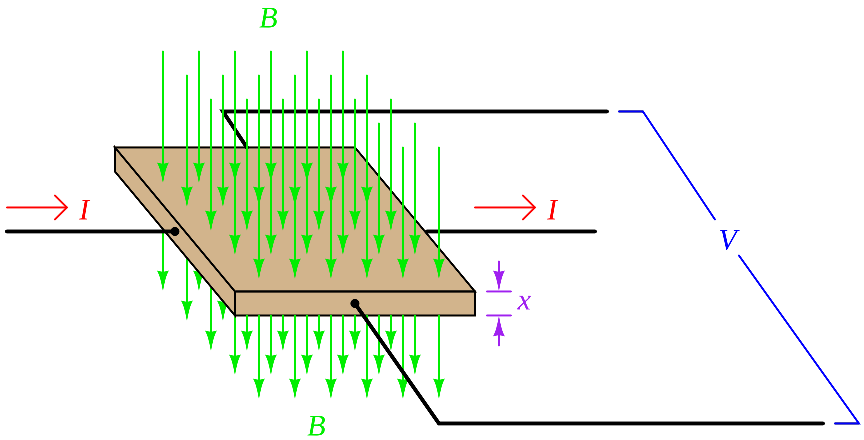
file i00748

Question 11

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

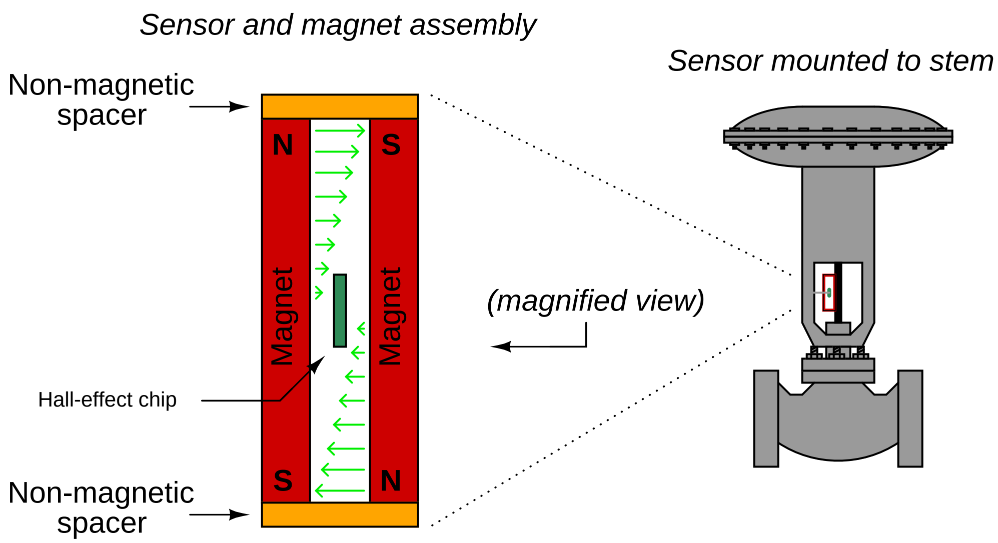
The Hall Effect is the generation of a (small) voltage in relative proportion to an electric current and an external magnetic field, all three being perpendicular to one another:

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



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

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



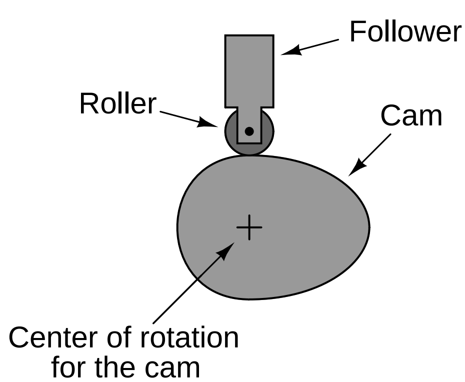
Examine this setup and then explain how the Hall Effect sensor is able to detect valve stem position. In other words, what sort of voltage signal would you expect from the Hall Effect sensor at various stem positions? Be as specific as you can in your answer.

file i01700

Question 12

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

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



Suggestions for Socratic discussion

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

file i01366

Question 13

Question 14

Question 15

Question 16

Question 17

Question 18

Question 19

Question 20

Question 21

Read and outline the "Complementary Valve Sequencing" subsection of the "Split-Ranging" section of the "Control Valves" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04208

Question 22

Read and outline the "Exclusive Valve Sequencing" subsection of the "Split-Ranging" section of the "Control Valves" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04220

Question 23

Read and outline the "Progressive Valve Sequencing" subsection of the "Split-Ranging" section of the "Control Valves" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04221

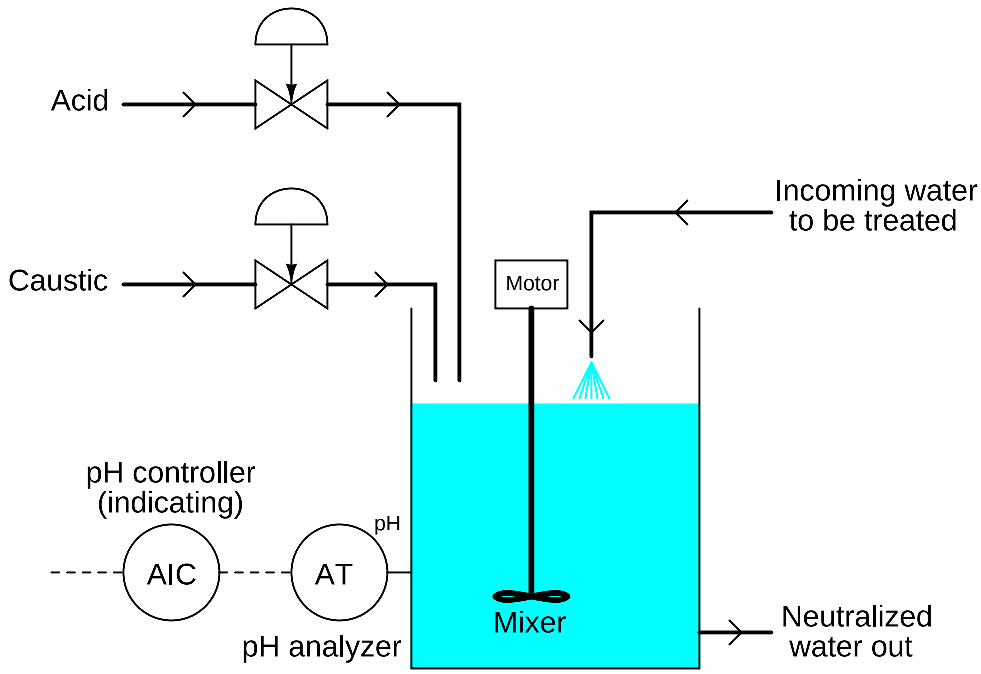
Question 24

Read and outline the "Valve Sequencing Implementations" subsection of the "Split-Ranging" section of the "Control Valves" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04209

Question 25

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



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

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

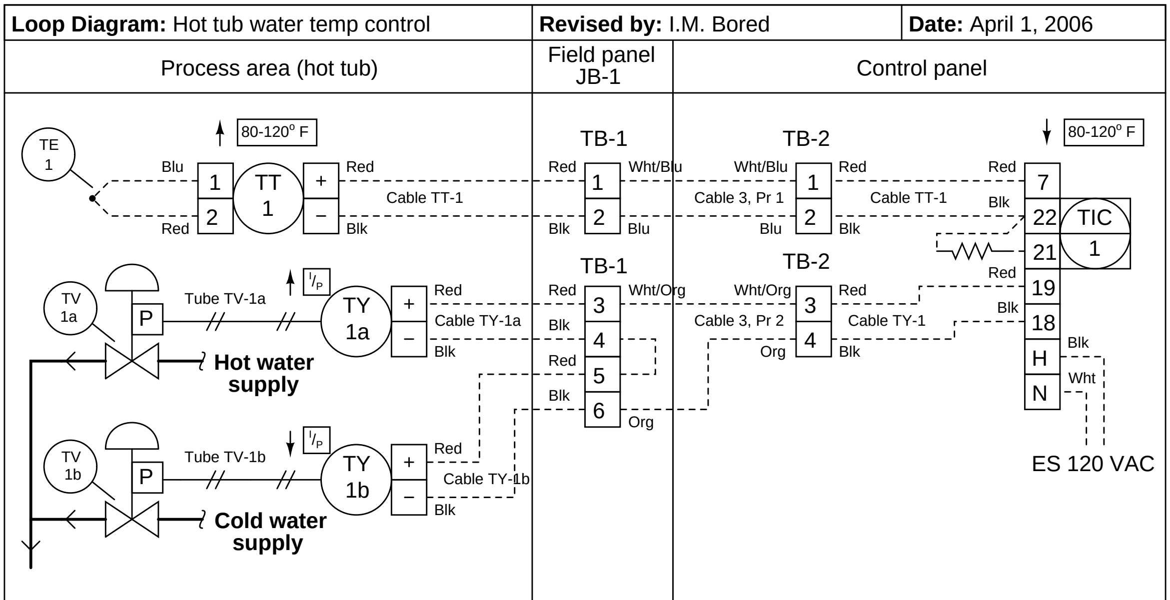
Suggestions for Socratic discussion

- A good problem-solving technique to apply in cases where we need to determine the direction of a change is to consider *limiting cases*. Instead of asking ourselves what would happen if the pH changes slightly, we ask ourselves what would happen if the pH changes *dramatically*. Explain how this problem-solving technique applies to this particular system where we must determine necessary controller action and final control element sequencing.
- What do the arrow symbols on the valve stems represent?
- Identify the consequence of losing instrument air to the control valves – what will happen to the effluent pH?
- What exactly is *pH*, and why do we care about controlling this variable in wastewater?
- How is pH most commonly measured?

file i01395

Question 26

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



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

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

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

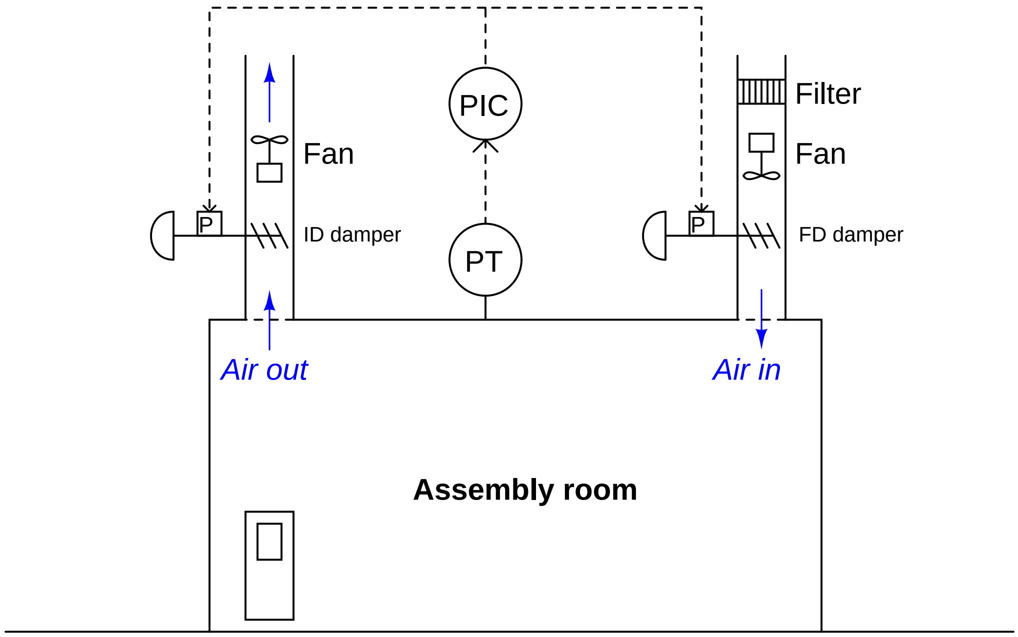
Suggestions for Socratic discussion

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

file i01397

Question 27

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



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

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

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

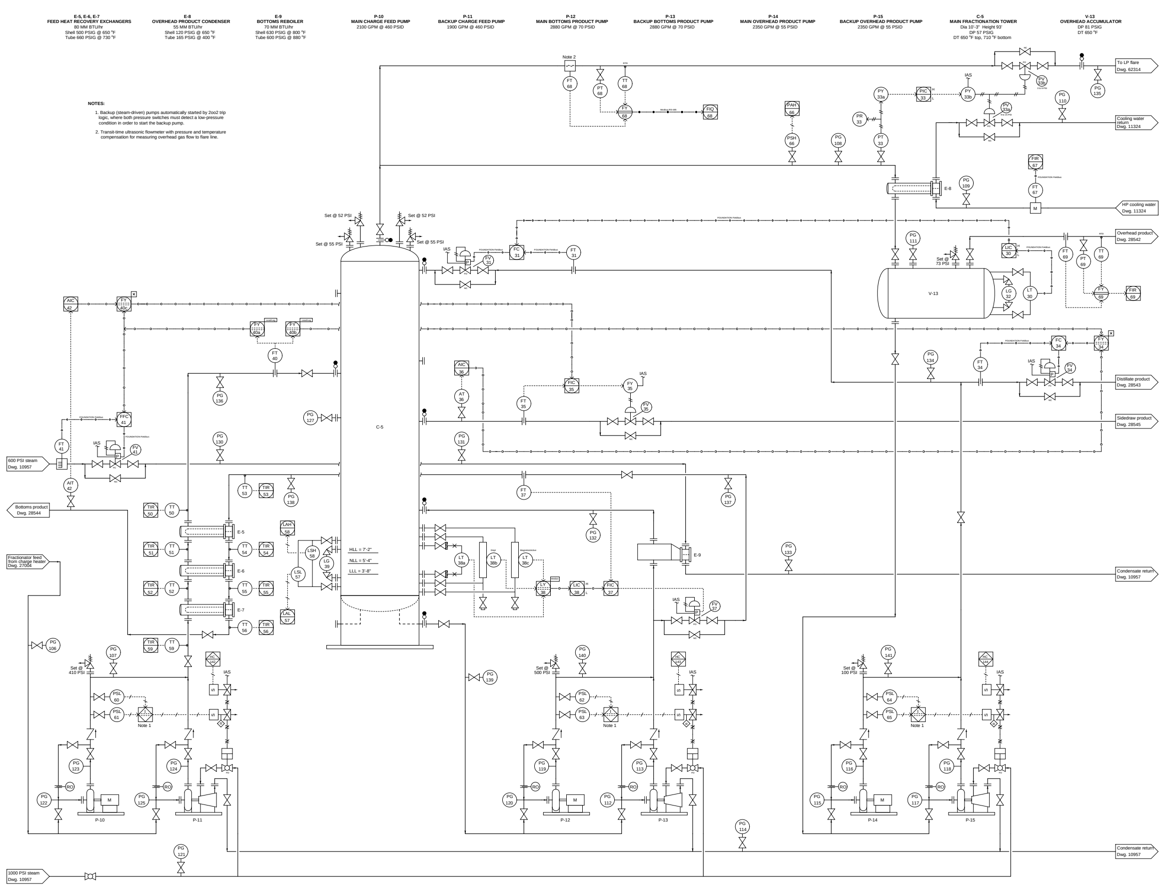
Suggestions for Socratic discussion

- A good problem-solving technique to apply in cases where we need to determine the direction of a change is to consider *limiting cases*. Instead of asking ourselves what would happen if the room air pressure changes slightly, we ask ourselves what would happen if the room air pressure changes *dramatically*. Explain how this problem-solving technique applies to this particular system.
- Can you think of a more energy-efficient way of regulating air pressure in this "clean room" than using dampers?
- What is the purpose of having an induced draft (ID) fan at all, since eliminating it entirely would *guarantee* positive pressure in the room so long as the forced draft (FD) fan was running?
- Determine the most likely fail-states of each damper, assuming we wish to default to a condition where the room remains as clean as possible.

file i03785

Question 28

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



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

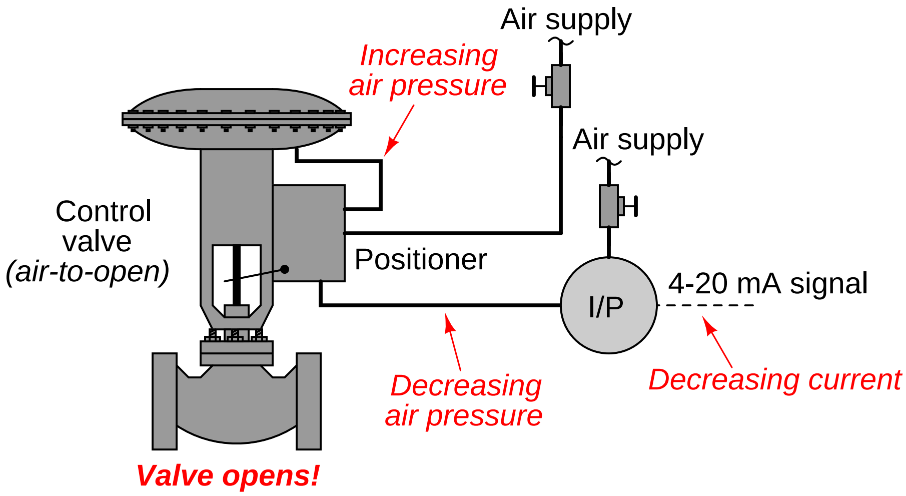
Suggestions for Socratic discussion

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

file i03569

Question 29

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



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

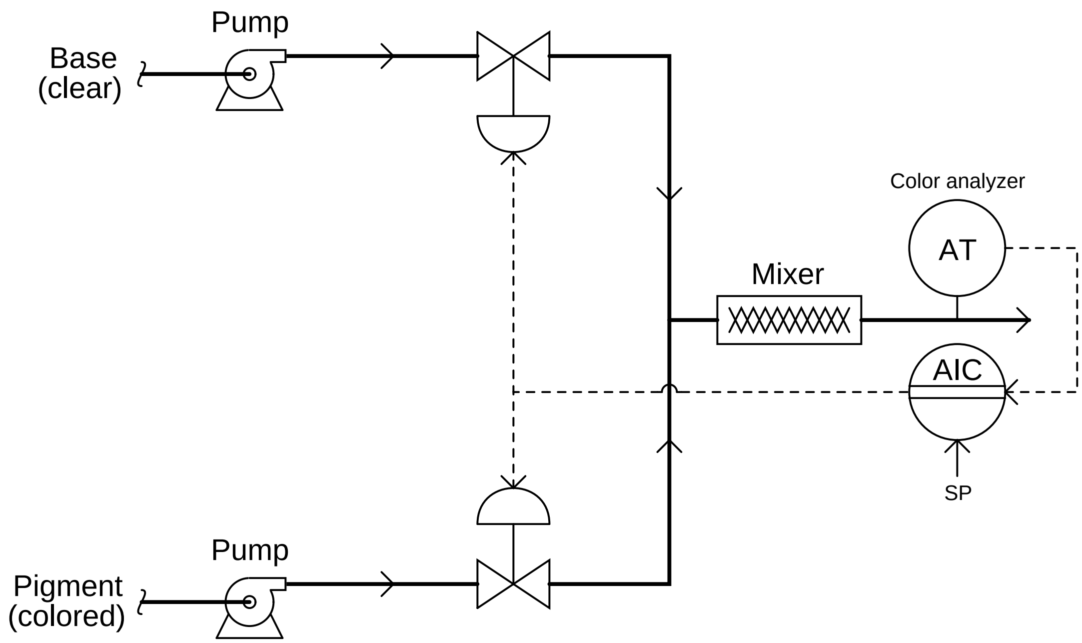
Suggestions for Socratic discussion

- Identify a practical reverse-acting range for a control valve, and an application where it might be used.

file i01399

Question 30

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



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

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

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

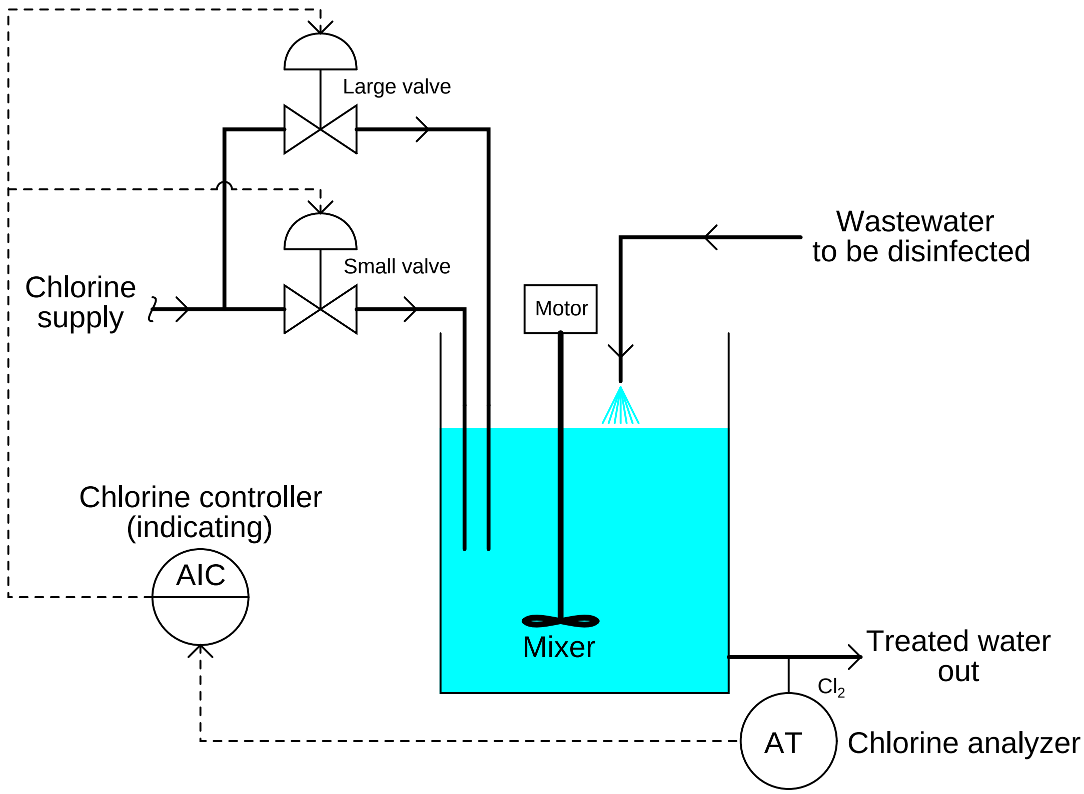
Suggestions for Socratic discussion

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

file i03781

Question 31

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



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

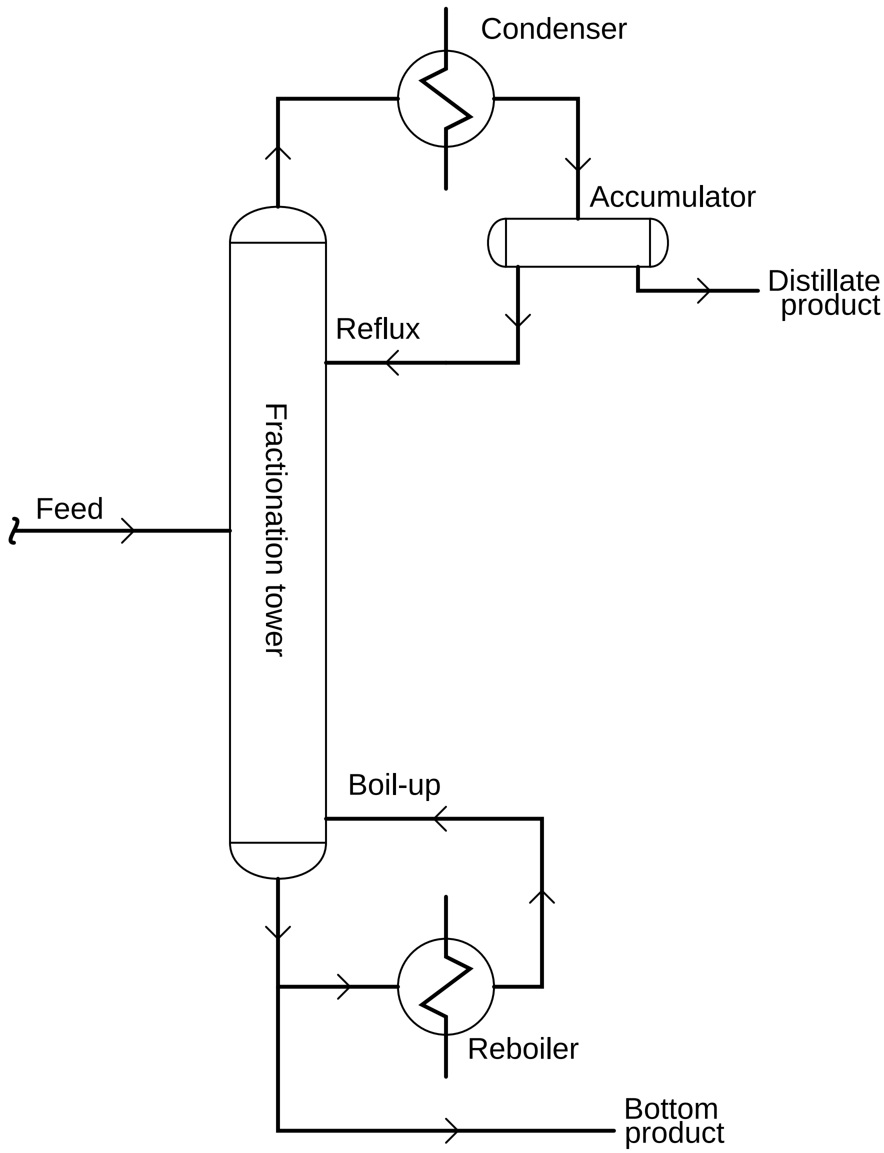
Small valve position	Controller output signal
Fully shut (0%)	??? mA
Wide open (100%)	??? mA

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

file i03783

Question 32

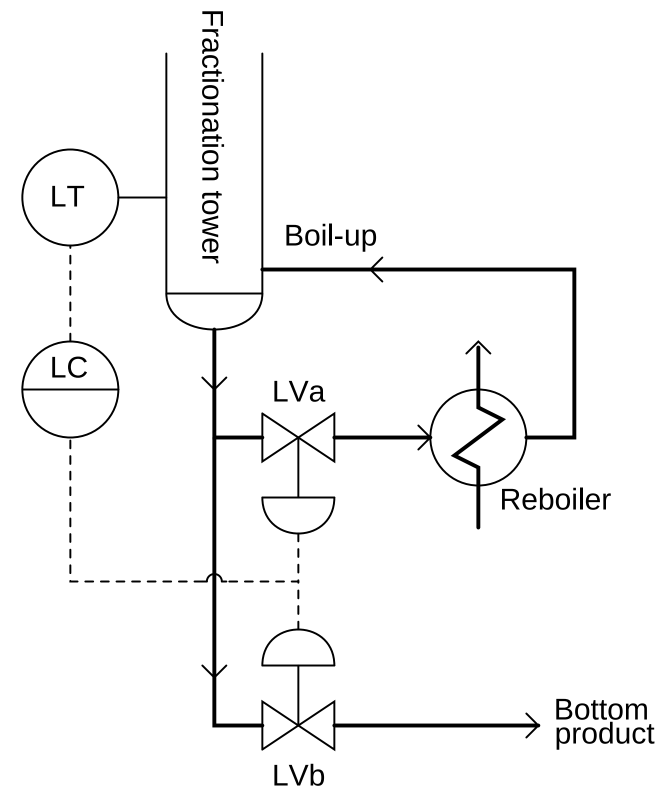
Shown here is a distillation tower, used to separate a liquid mixture of substances into its constituent components. The process of *distillation*, or *fractionation* as it is sometimes called, is very common in heavy process industries, most notably petrochemical processing:



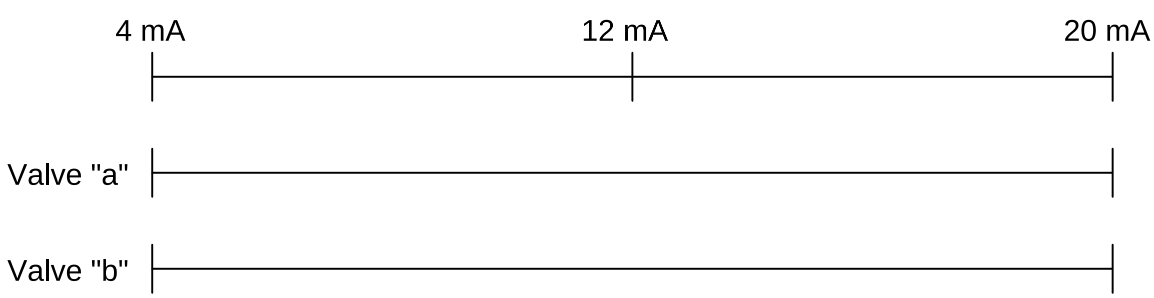
Distillation of this nature works on the principle of different boiling points. The distillation of alcohol (to separate a water/alcohol mix in order to obtain a purer alcohol product) is a well-known application of this technology. In a fractionation tower, the process of boiling and condensation of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

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

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



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



Suggestions for Socratic discussion

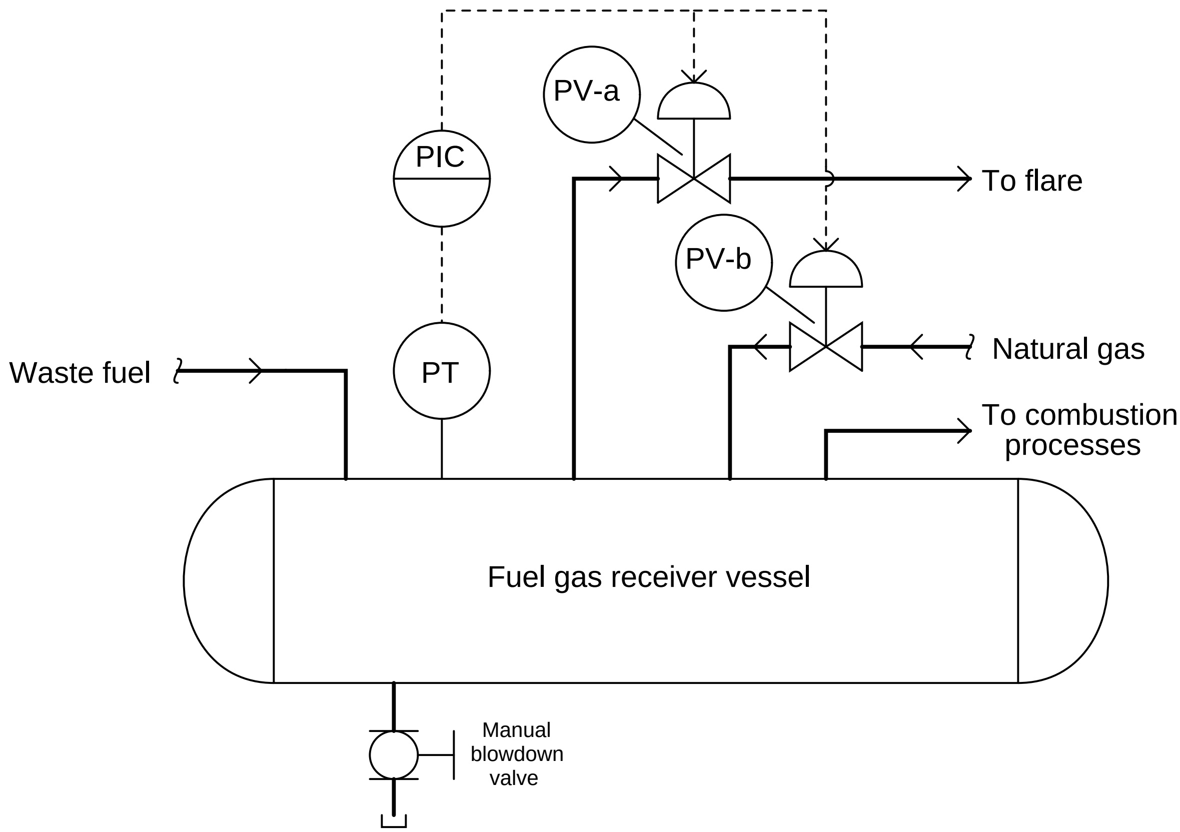
- A good idea in this control system is to install a *minimum travel stop* in level valve A, so that it cannot close beyond a certain point. Explain why this might be important to the overall control of the fractionation tower.

file i03215

Question 33

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

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

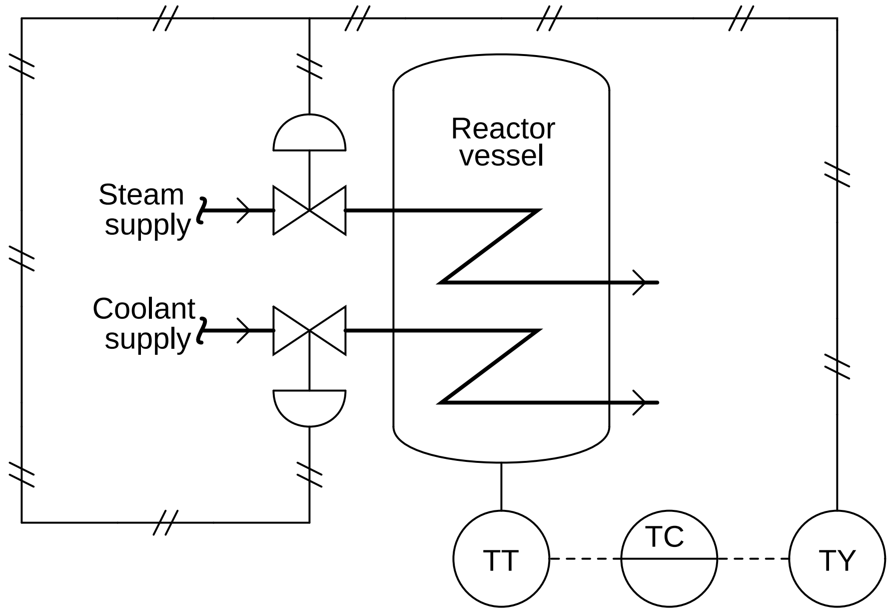


Explain how the two control valves, PV-a and PV-b, may be *split-ranged* so that a single pressure controller operates both valves simultaneously. Assuming a direct-acting transmitter and reverse-acting controller (that output 4-20 mA each), determine the calibration range for each control valve.

file i03221

Question 34

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



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

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

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

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

Suggestions for Socratic discussion

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

file i01394

Question 35

Question 36

Question 37

Question 38

Question 39

Question 40

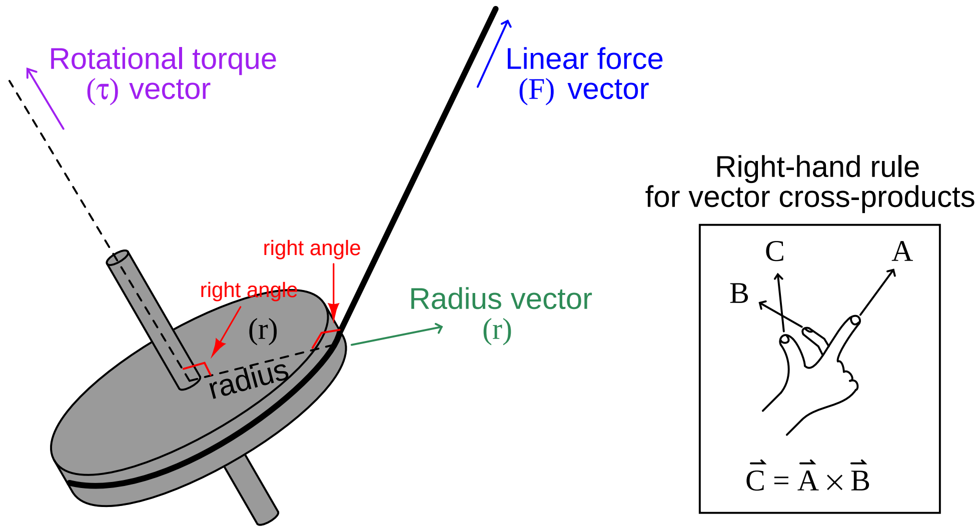
Question 41

Read and outline the "Work, Energy, and Power" subsection of the "Classical Mechanics" section of the "Physics" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04028

Question 42

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

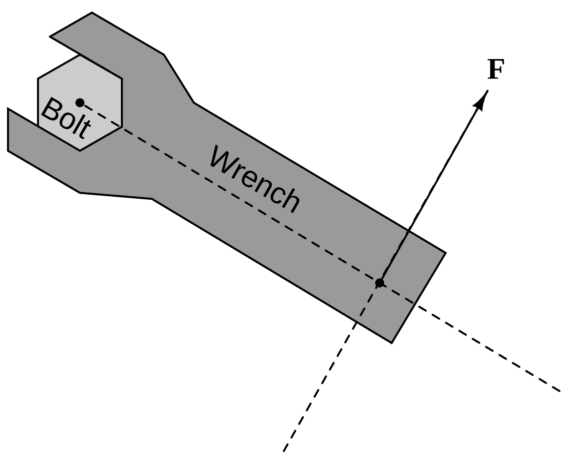


Mathematically, torque is the product of the force vector and the radius vector perpendicular to the force (called the "moment arm"):

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

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

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

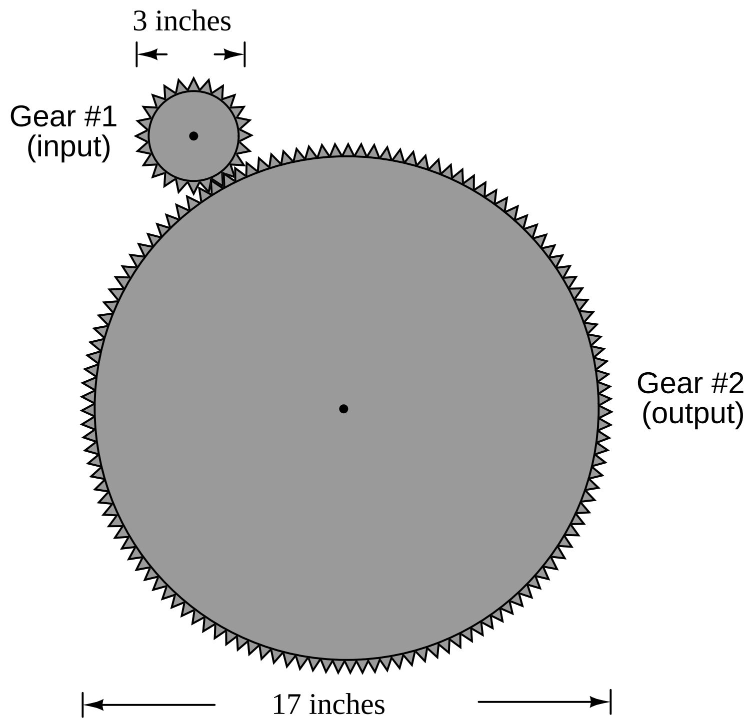


file i01403

Question 43

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

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



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

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

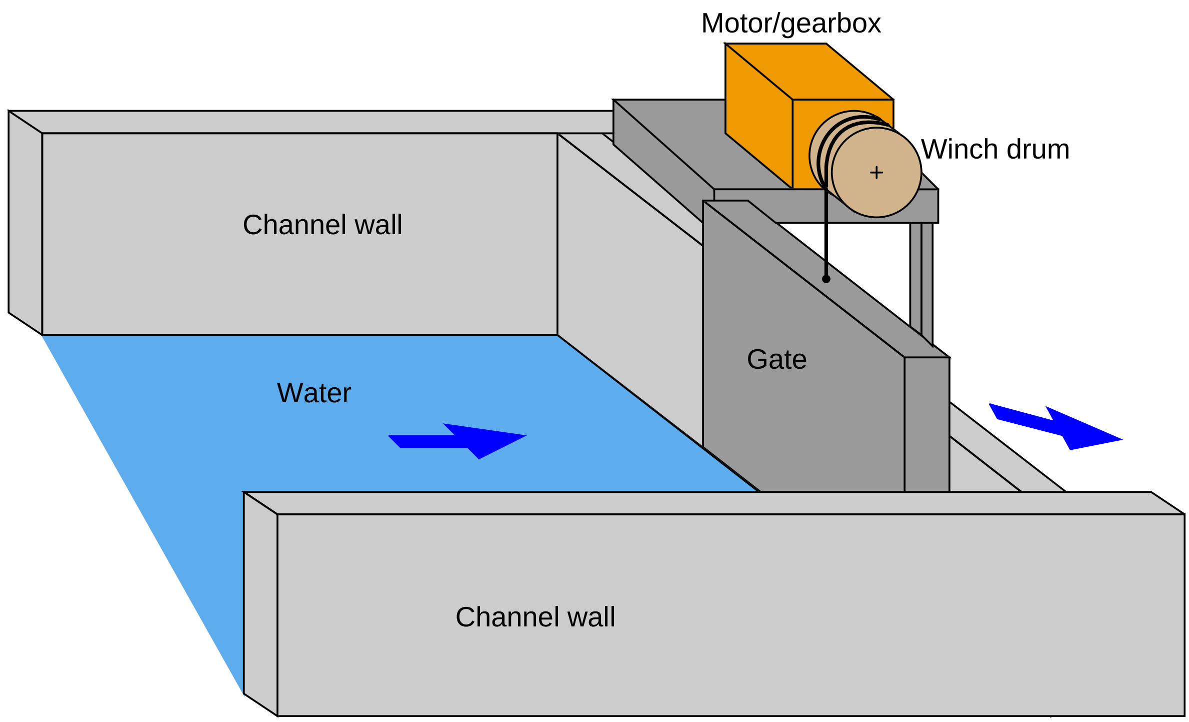
Suggestions for Socratic discussion

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

file i01405

Question 44

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



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

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

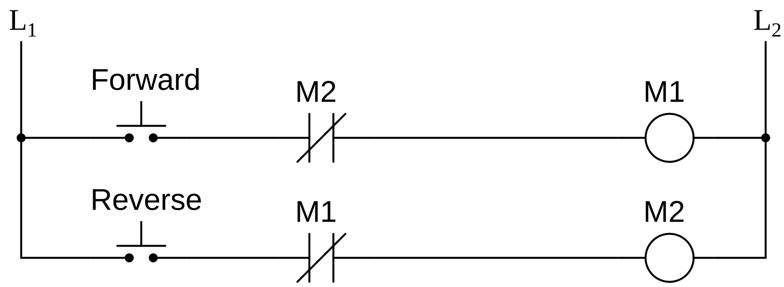
Suggestions for Socratic discussion

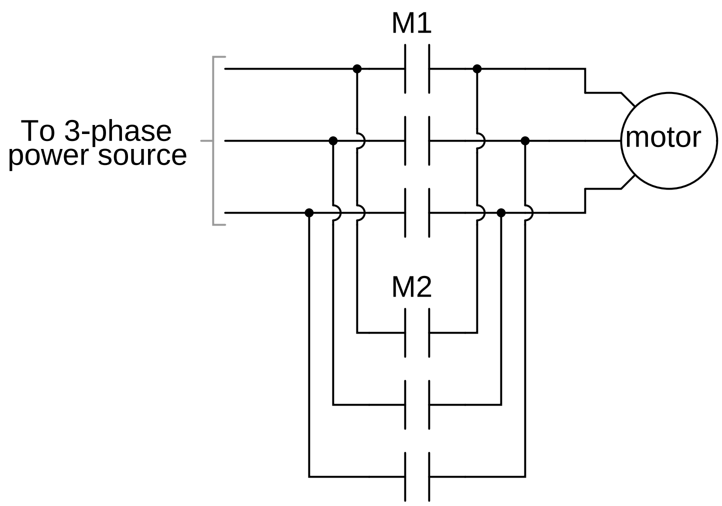
- Like all "story problems" involving mathematical calculation, the most important aspect of your answer is *how* you arrived at it, not the numerical value(s) of your answer. Explain how you were able to set up the proper equations to solve for drum torque, motor torque, lifting speed, and motor output power.

file i00584

Question 45

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





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

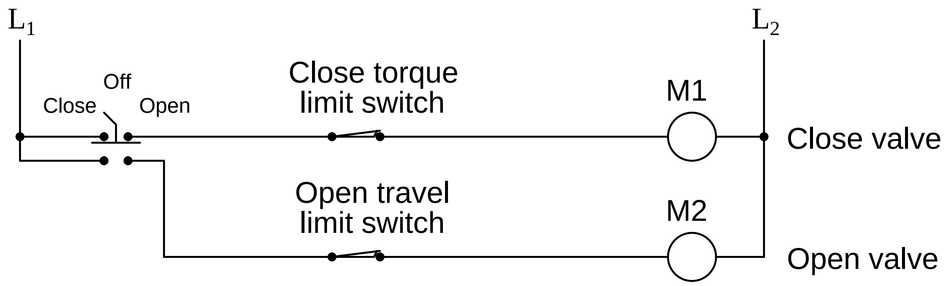
Suggestions for Socratic discussion

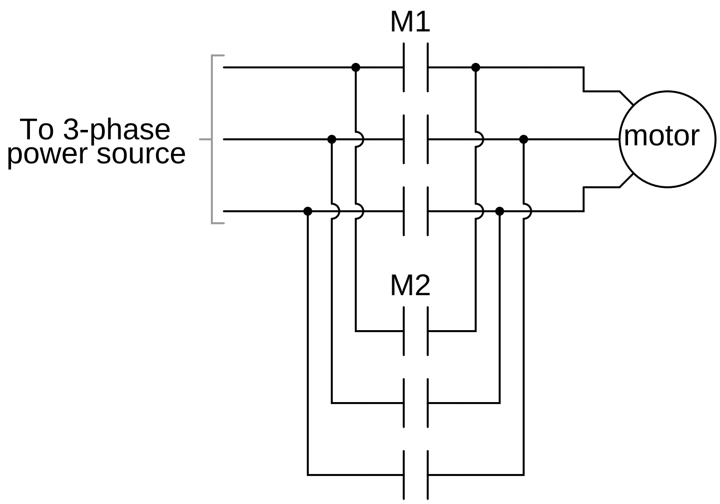
- Explain *why* reversing any two phase conductors supplying AC power to an induction motor will cause it to reverse direction.
- Explain what *arc flash* is, and how to protect yourself from it while working on high-voltage motor control circuits such as this one.

file i01391

Question 46

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





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

Suggestions for Socratic discussion

- Explain what *arc flash* is, and how to protect yourself from it while working on high-voltage motor control circuits such as this one.

file i01392

Question 47

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

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

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

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

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

file i04223

Question 48

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

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

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

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

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

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

file i04224

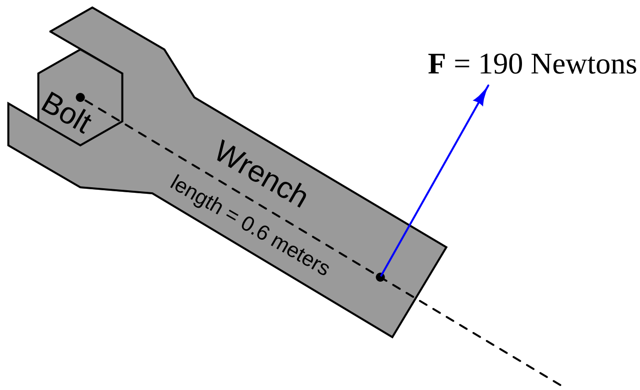
Question 49

Read and outline the introduction to the "Variable-Speed Motor Controls" chapter as well as the "Metering Pumps" section of that same chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04231

Question 50

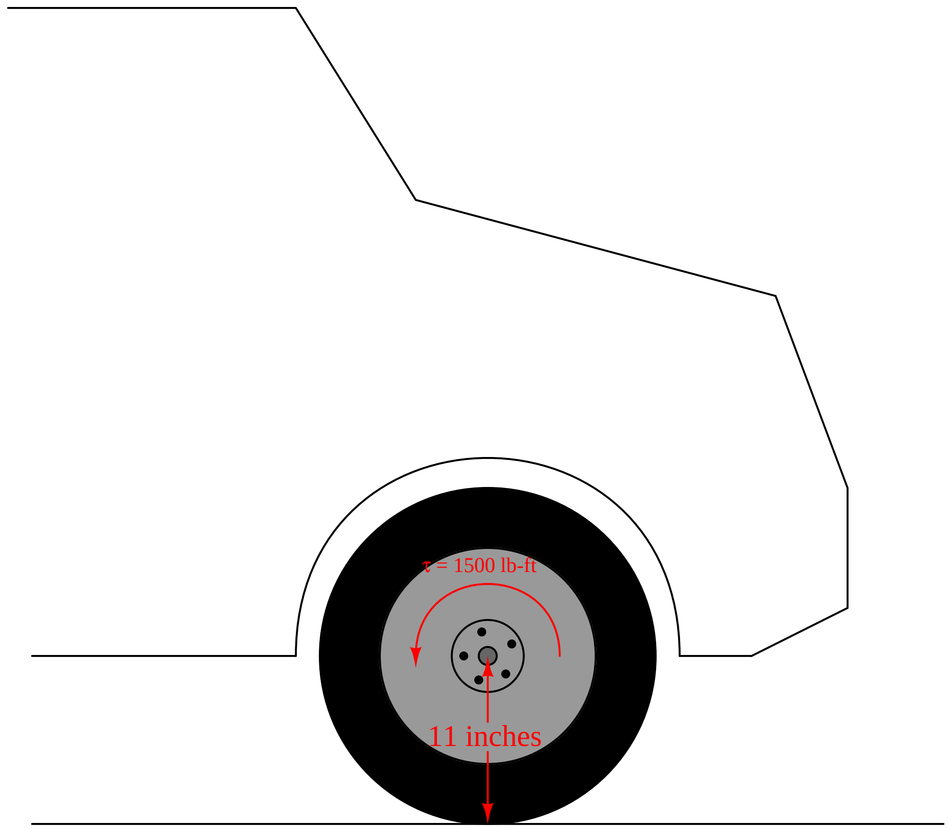
Suppose a mechanic pulls perpendicularly at the end of a wrench 0.6 meters in length with a steady force of 190 newtons for two complete revolutions. Calculate the amount of work done by the mechanic (in newton-meters or joules), and also calculate his power output in watts if those two turns were completed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



file i03777

Question 51

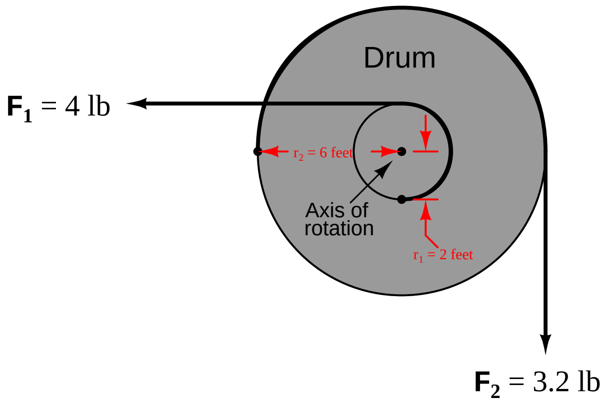
How much linear force will the car's tire exert on the ground if the axle exerts a torque of 1500 lb-ft on the wheel, and the tire's radius is 11 inches?



file i01402

Question 52

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



file i01428

Question 53

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

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

file i01429

Question 54

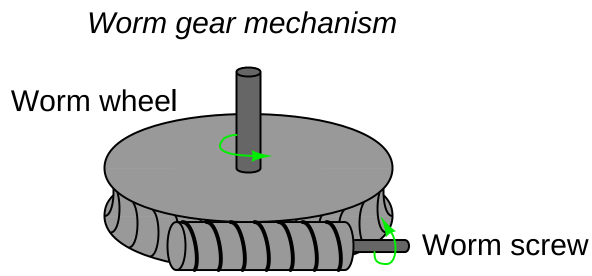
For most electric motors, the amount of *torque* output strongly influences the amount of current drawn from the power source. For some electric motors (most notably, permanent magnet DC motors), current and torque are directly proportional to one another.

Explain what "torque" is, why it may be important to measure in a valve actuator mechanism, and how electric motors provide a convenient means for measuring torque.

file i01389

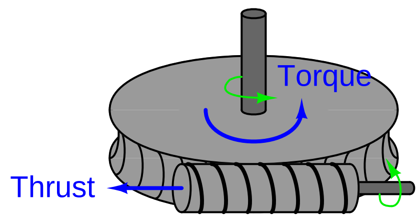
Question 55

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



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

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

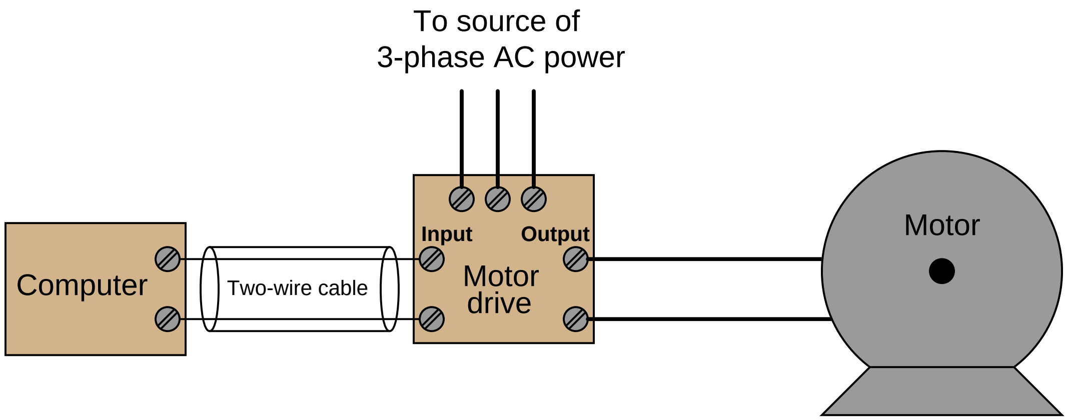


If we can find a way to measure this linear thrust on the worm screw, we may infer the torque output by the wheel. Explain how this could be done in an electric valve actuator mechanism.

file i01390

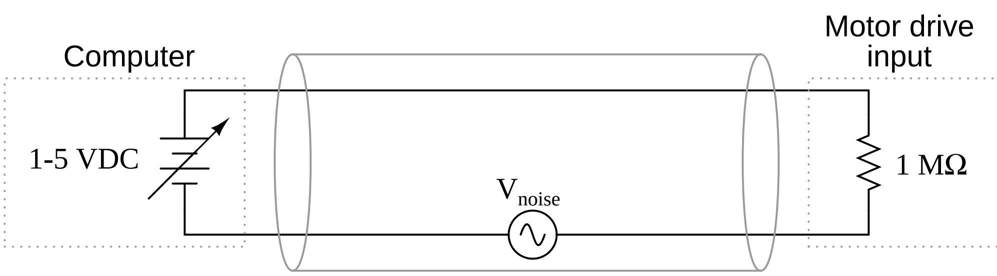
Question 56

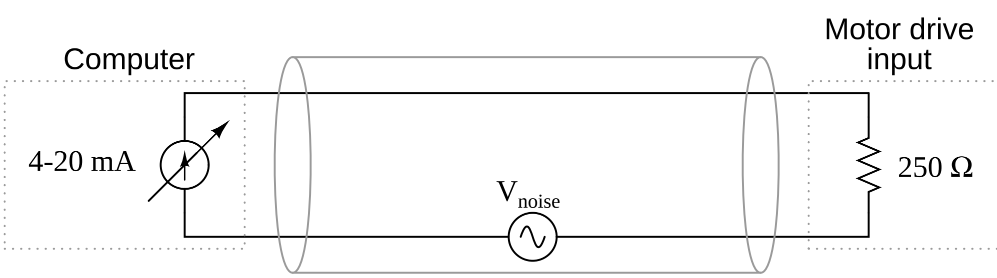
Electrical signals are frequently used in industrial control applications to communicate information from one device to another. An example of this is motor speed control, where a computer outputs a speed command signal to a motor "drive" circuit, which then provides metered power to an electric motor:



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

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





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

file i00128

Question 57

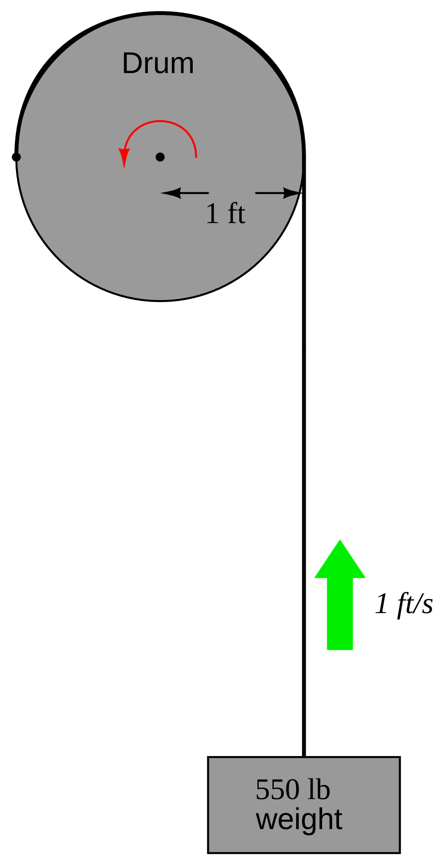
A *horsepower* is defined as 550 ft-lbs of work done in one second of time. An example of this would be a 550 pound weight lifted vertically at a speed of one foot per second, or a one pound weight lifted vertically at a speed of 550 feet per second.

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

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

$$P = k\tau S$$

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

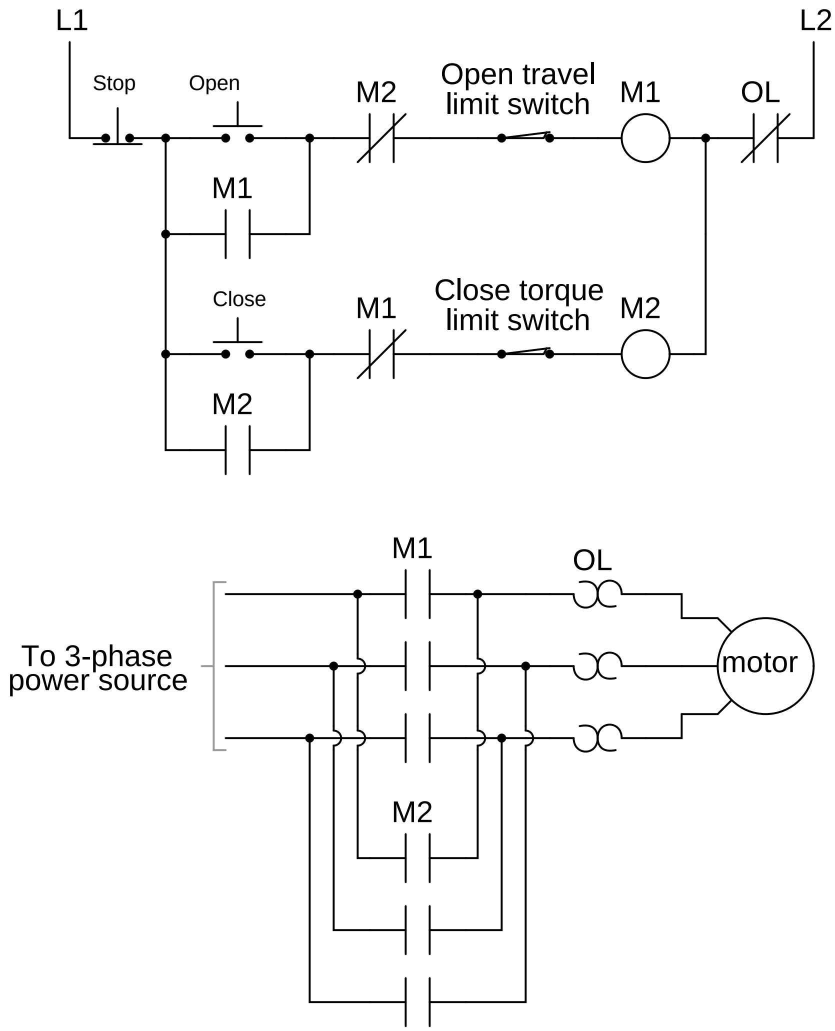


In this case, we have a 1 foot radius drum hoisting a 550 pound weight at a linear velocity of 1 foot per second, the definition of one horsepower. Translate the linear force and linear velocity to rotary force (torque) and rotary velocity (revolutions per minute), and then calculate the necessary k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

file i01430

Question 58

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

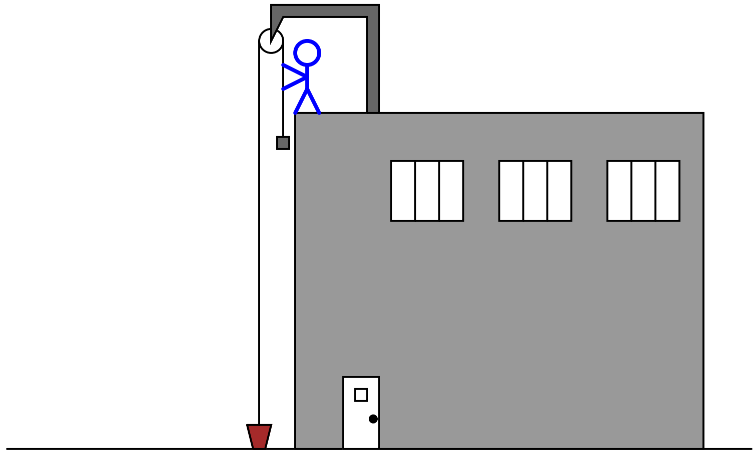


Explain the function and purpose of each switch in the ladder logic circuit.

file i01824

Question 59

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



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

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

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

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

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

file i00428

Question 60

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

file i00429

Question 61

Read and outline the "Physics of Energy Dissipation in a Turbulent Fluid Stream" subsection of the "Control Valve Sizing" section of the "Control Valves" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04225

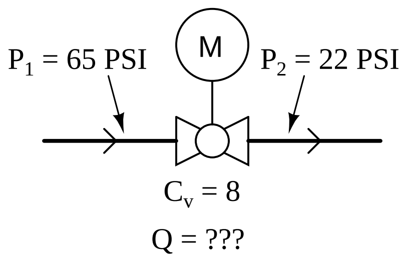
Question 62

Read and outline the "Importance of Proper Valve Sizing" subsection of the "Control Valve Sizing" section of the "Control Valves" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04226

Question 63

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



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

Suggestions for Socratic discussion

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

file i01373

Question 64

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

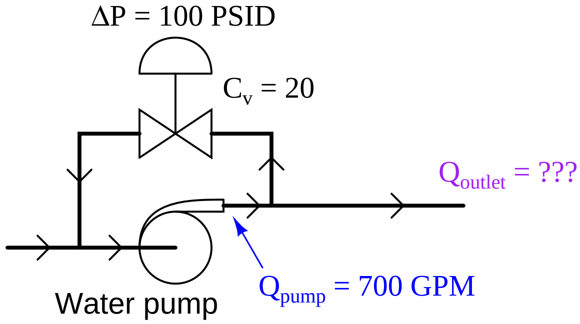
Suggestions for Socratic discussion

- If water were substituted for gasoline, but all other factors remained the same, would the flow rate increase, decrease, or remain the same?

file i01370

Question 65

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



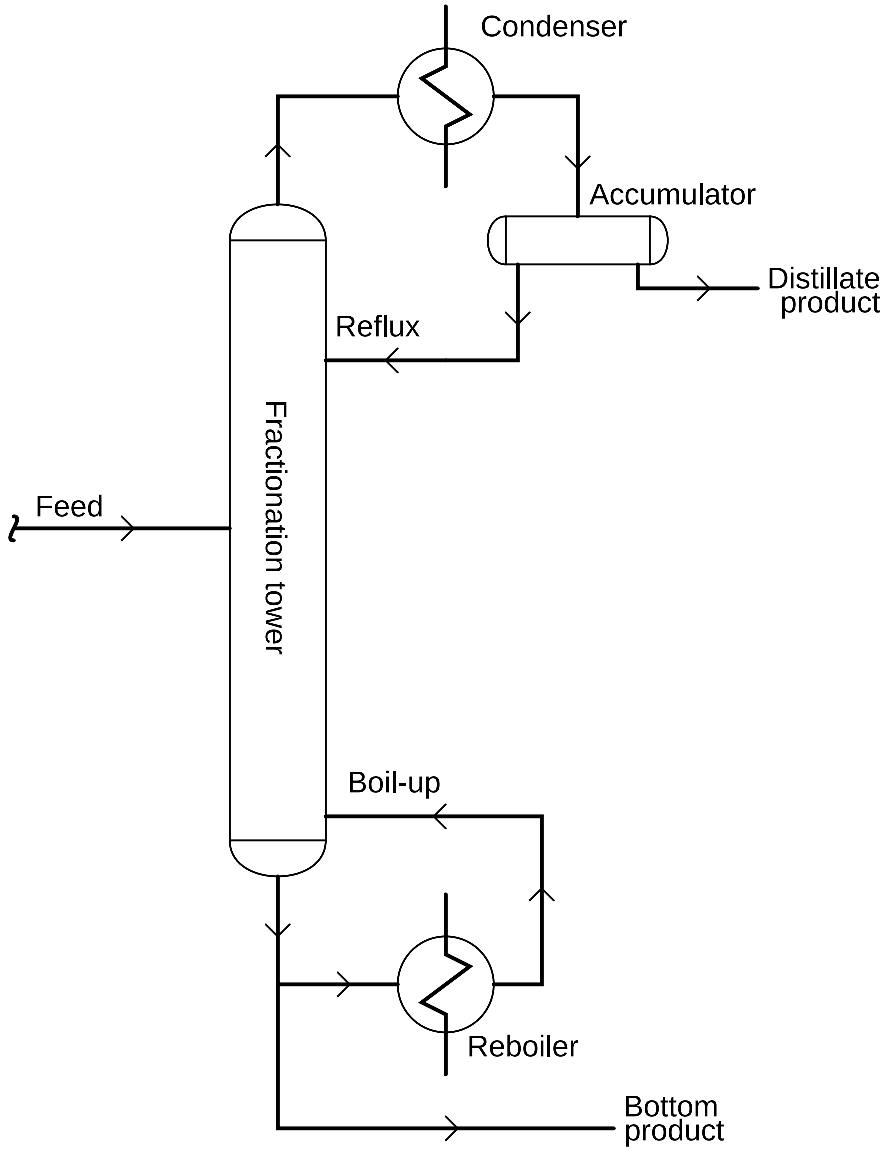
Suggestions for Socratic discussion

- This control valve arrangement – where the valve recirculates water flow from discharge to suction – is far preferable to one where a valve simply blocks off the pump discharge. Explain why recirculation is better than blockage as far as control valve placement is concerned.

file i01374

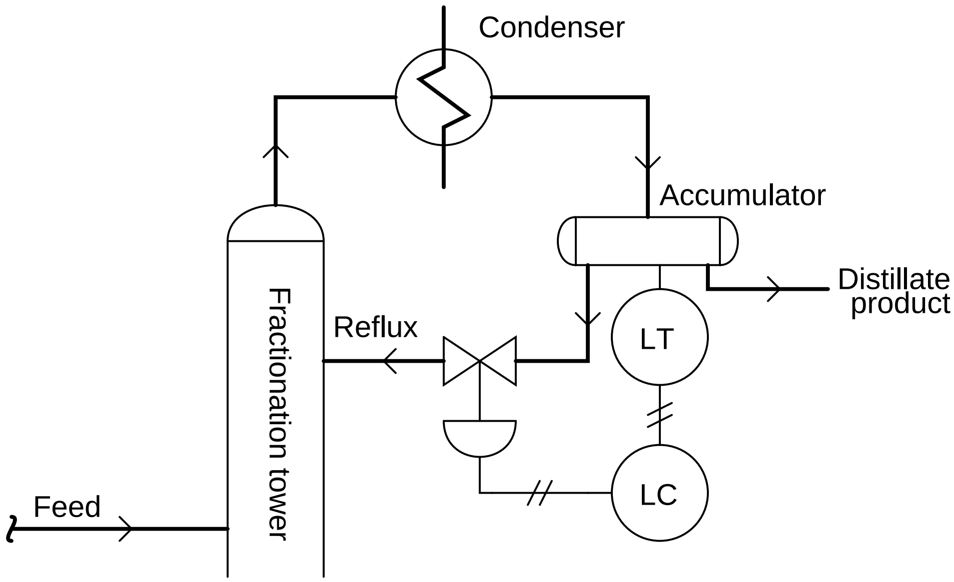
Question 66

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



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

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



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

Suggestions for Socratic discussion

- Identify some practical purposes for distillation towers in industry.
- Which of the two heat exchangers *adds* heat to the tower?
- Which of the two heat exchangers *removes* heat from the tower?

file i01376

Question 67

Read and outline the "Relative Flow Capacity" subsection of the "Control Valve Sizing" section of the "Control Valves" chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04227

Question 68

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

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

Where,

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

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

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

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

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

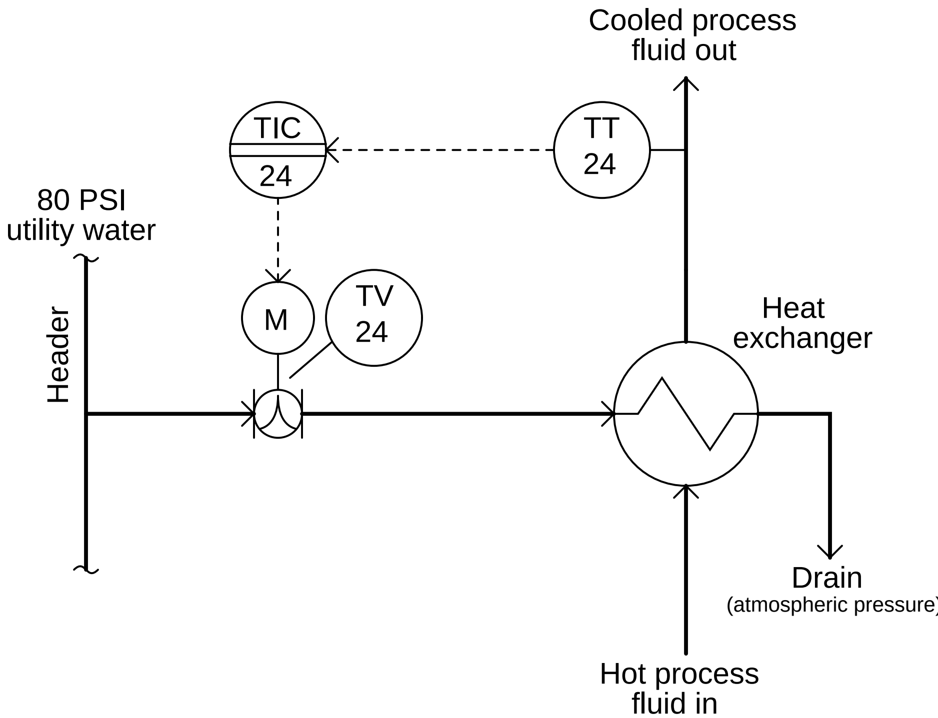
Suggestions for Socratic discussion

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

file i01371

Question 69

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



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

C_v = __________

Nominal pipe size = __________

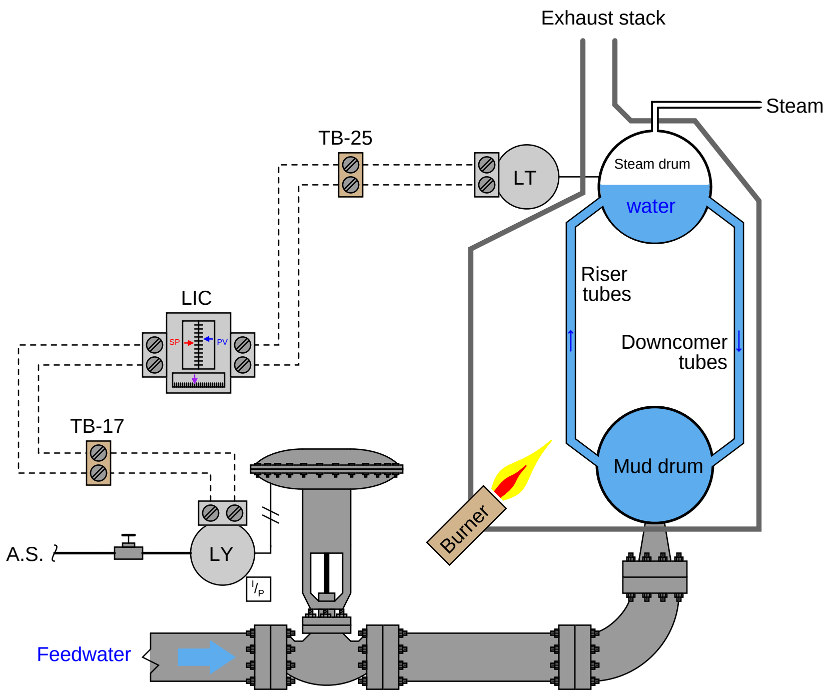
Suggestions for Socratic discussion

- Explain how a shell-and-tube heat exchanger is constructed, and exactly how heat gets transferred from one fluid to another in such a device.
- Identify some of the *loads* in this process control loop. A "load" is some influencing factor on the process variable that is not directly regulated by the control loop.
- What type of control valve and actuator are used in this application?

file i03213

Question 70

This boiler steam drum level control system has a problem. The water level in the steam drum is below setpoint (as indicated by the controller display showing 42% water level with a 50% setpoint), and has been for the past several hours despite the operator's attempt to raise water level by raising the setpoint on the controller. Meanwhile, the boiler is operating at full power, making steam at a normal rate of flow:



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

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

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

file i01368

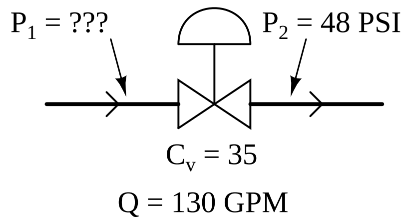
Question 71

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

file i01369

Question 72

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



file i01377

Question 73

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

file i01375

Question 74

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

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

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

file i00430

Question 75

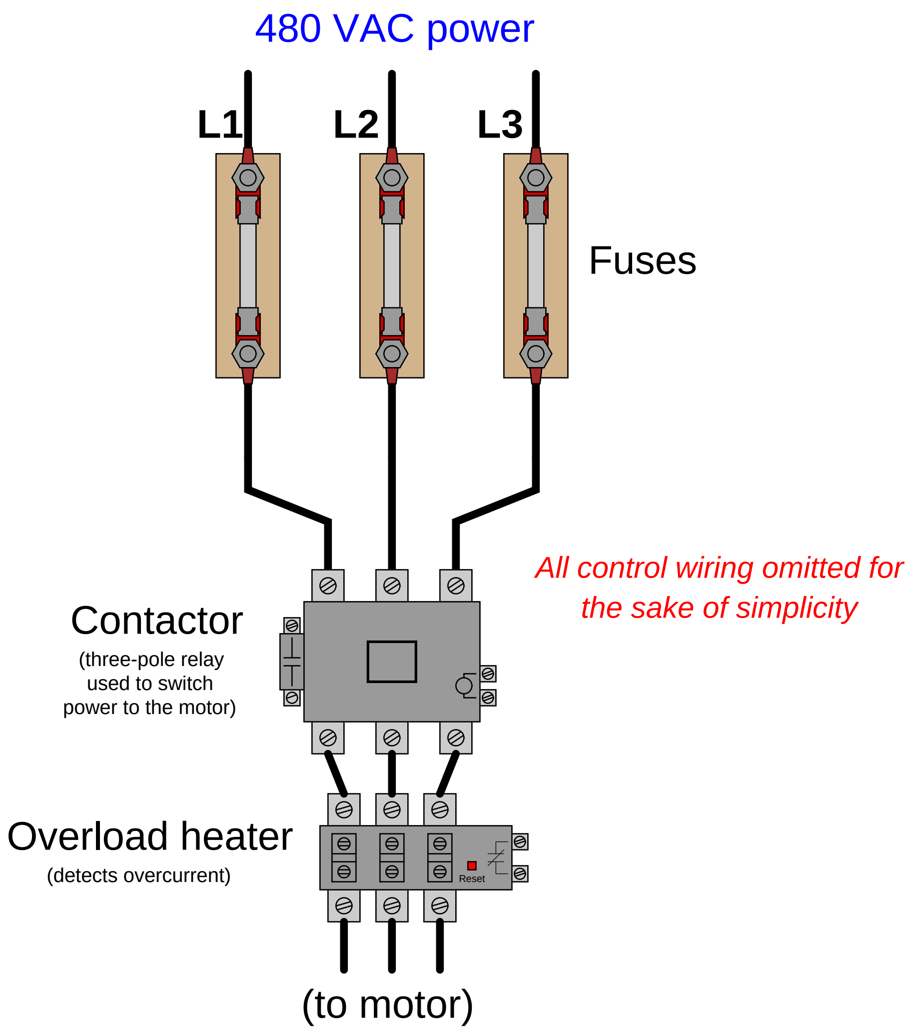
A truck weighing 39,000 newtons (N) is traveling at 10 meters per second when its clutch blows out, disconnecting the engine from the drivetrain (transmission, axle, wheels, etc.). This failure occurs exactly at the base of a steep incline. How many meters (vertical) will the truck coast up the hill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

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

file i00431

Question 76

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



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

Suggestions for Socratic discussion

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

file i03737

Question 77

Question 78

Question 79

Question 80

Question 81

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

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

file i00061

Question 82

Suppose the liquid flowing through a control valve suddenly doubles in density (ρ). Assuming both the upstream and downstream pressures at the valve remain the same as before the density change, and the valve stem does not move from where it was before, predict the change in volumetric flow rate (Q). Express your answer as a *percentage* of the original flow rate (i.e. if you calculate that the flow rate will double with a doubling in density, your answer should be 200%).

Show the mathematical work (and/or any "thought experiments") you performed in obtaining your answer.

file i04228

Question 83

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

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

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

Valve A = __________ Valve B = __________

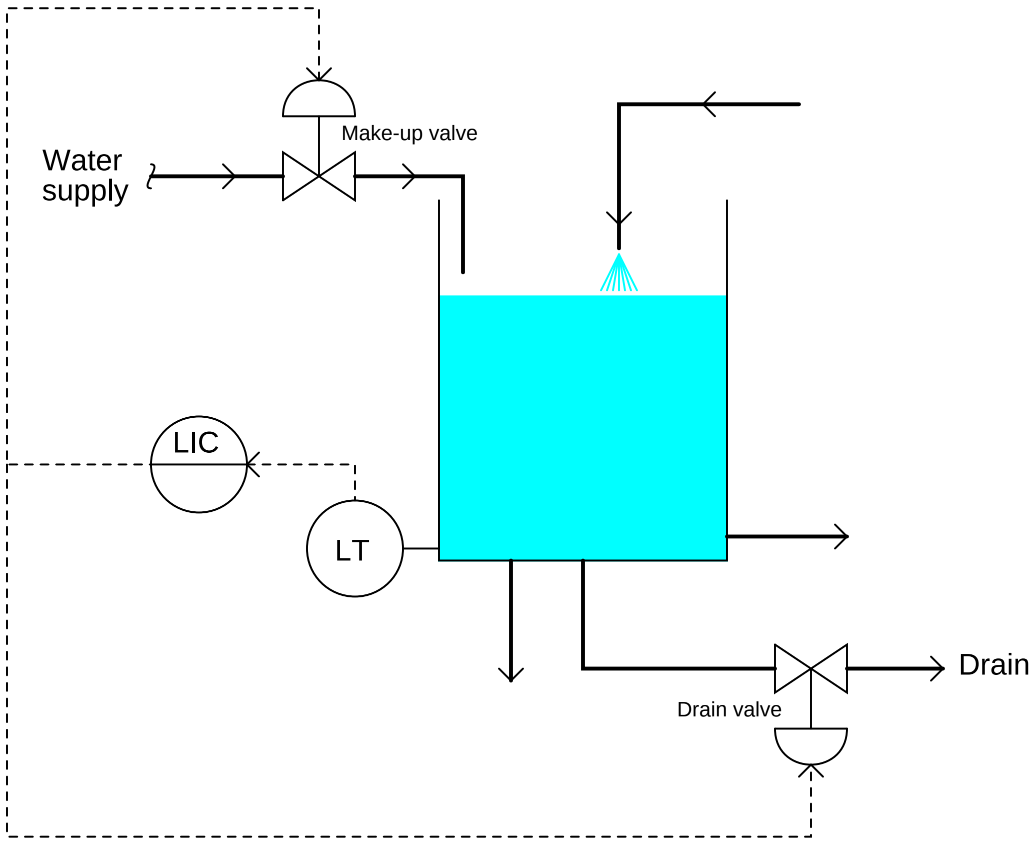
Now, calculate the stem position of each control valve at a signal value of 15.81 mA:

Valve A = __________ Valve B = __________

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

Question 84

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



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

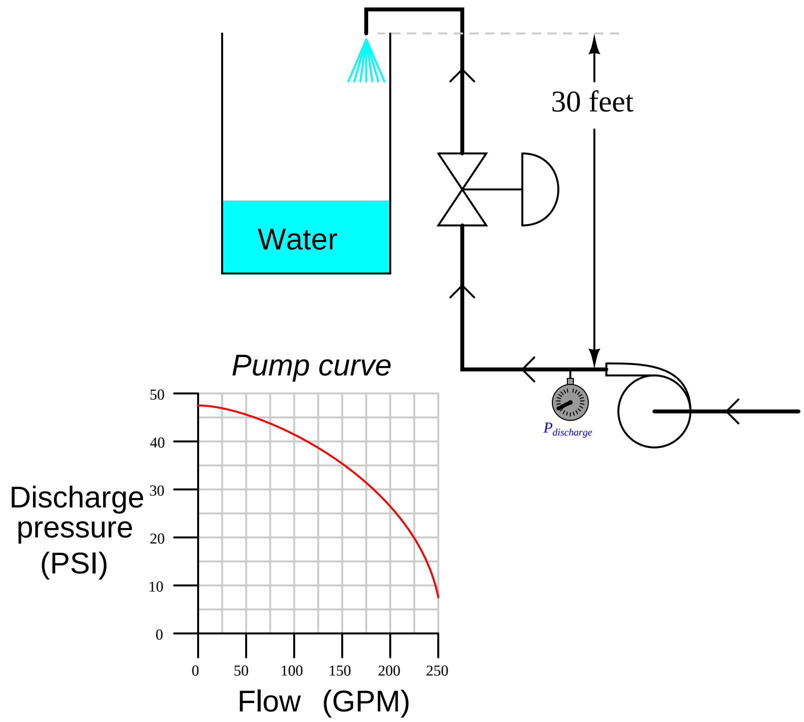
Drain valve position	Controller output signal
Fully shut (0%)	??? mA
Wide open (100%)	??? mA

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

file i03784

Question 85

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

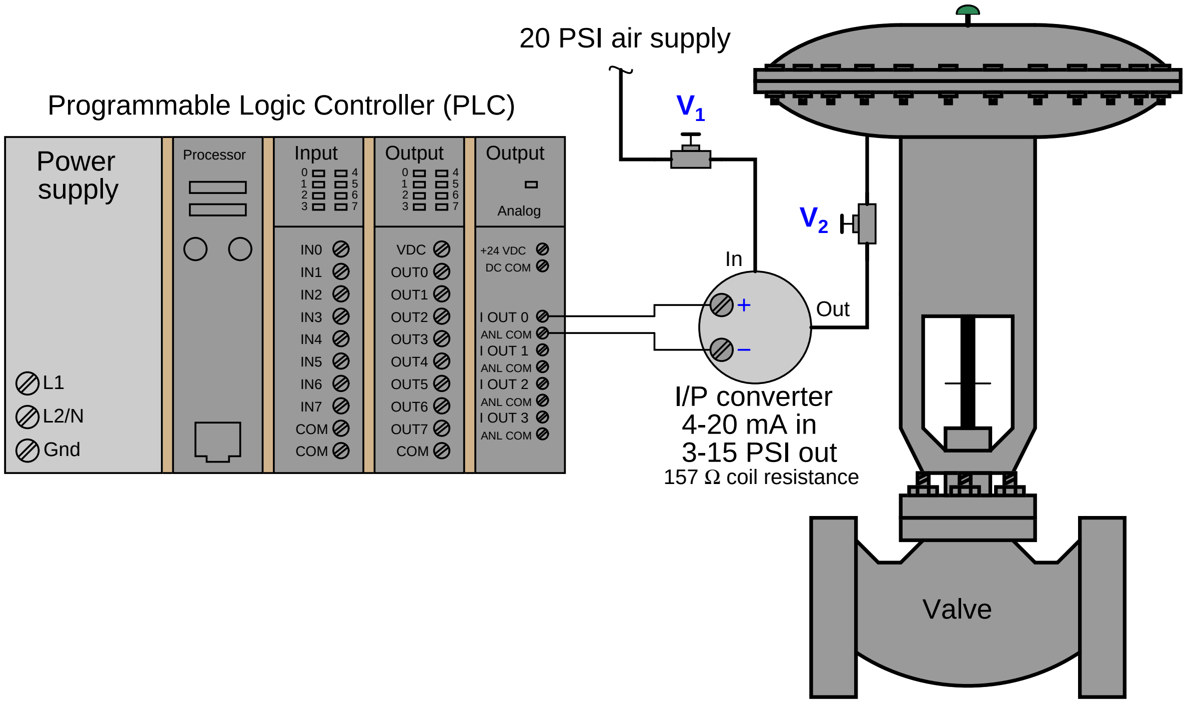


Also, calculate the approximate size of the valve (nominal pipe diameter, in inches) given a single-ported, ported plug globe valve ($C_d = 9.5$).

file i01406

Question 86

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



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

First, calculate the correct valve position corresponding to this register value. Next, identify the likelihood of each specified fault for this circuit. Consider each fault one at a time (i.e. no multiple faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this circuit.

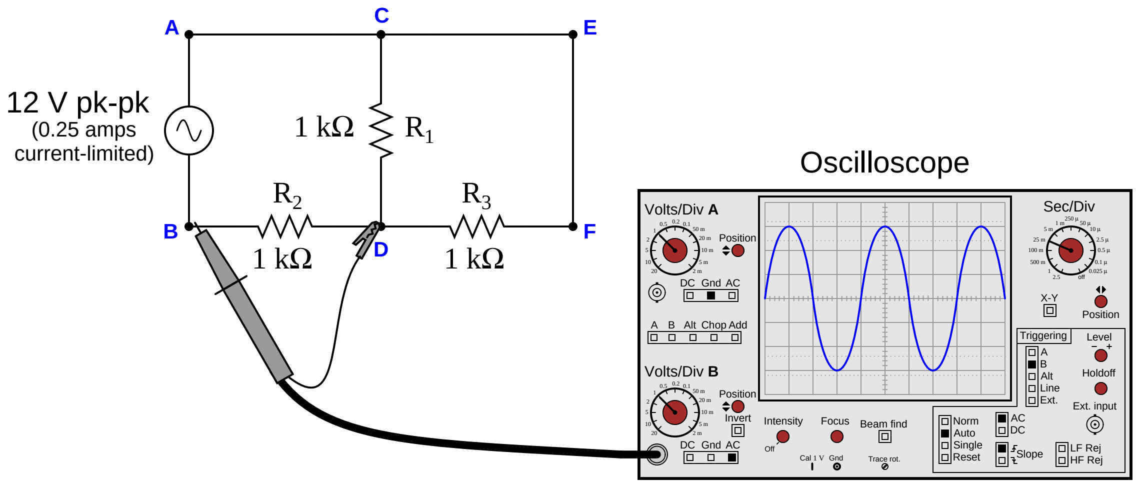
Fault	**Possible**	**Impossible**
Open wire between "I OUT 0" and "+" terminals		
Open wire between "ANL COM" and "-" terminals		
I/P mis-calibration		
Shorted cable between PLC and I/P		
Defective analog output card in PLC		
Valve V1 shut		
Valve V2 shut		
I/P restrictor plugged (completely or partially)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

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

file i00737

Question 87

Note the oscilloscope measurement of AC voltage between test points **B** and **D** in this series-parallel circuit:



Identify the likelihood of each specified fault for this circuit. Consider each fault one at a time (i.e. no multiple 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		

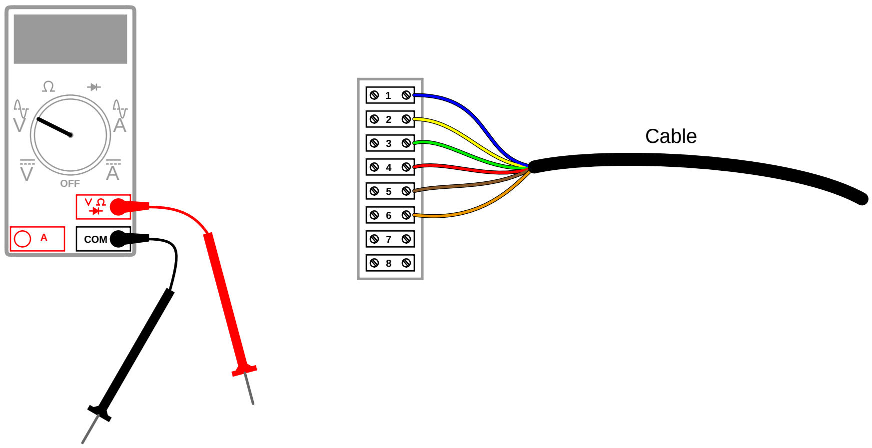
Finally, identify the *next* diagnostic test or measurement you would make on this system, using only the oscilloscope (no multimeter or other test equipment). Assume you are able to break any wire connections you desire in performing your test. Explain how the result(s) of this next test or measurement help further identify the location and/or nature of the fault. Whichever resistor is failed open, will show no change when its branch wire connection is opened.

file i03234

Question 88

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

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



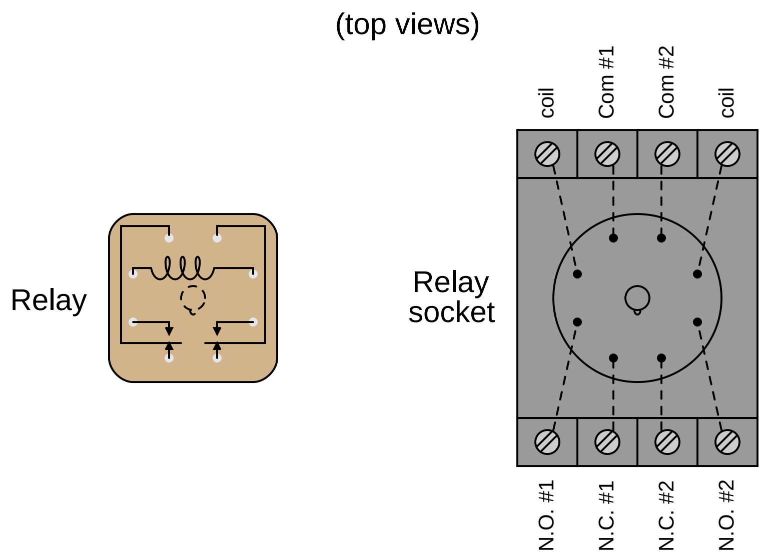
List all possible pairs of points you should test for voltage between, in order to ensure the conductors are safe for you to touch. Don't forget to include earth ground as one of those points!

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

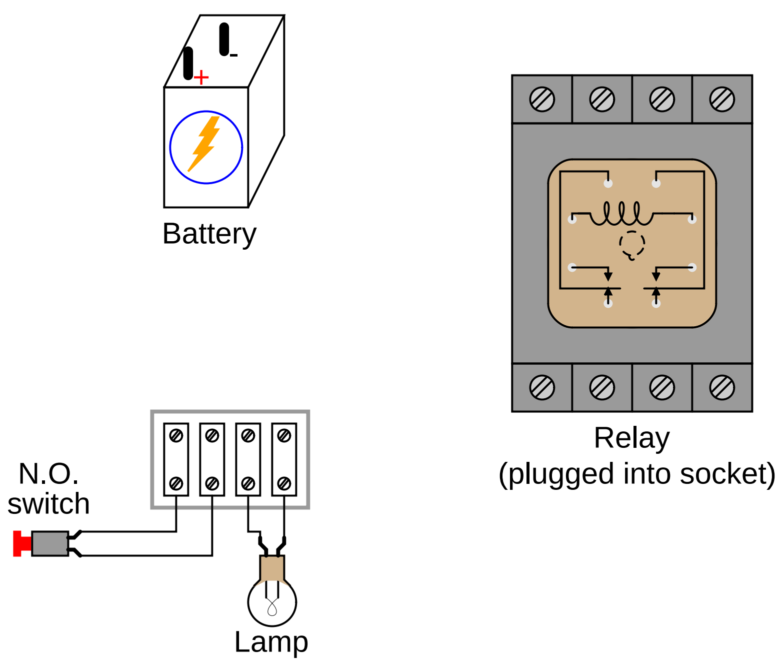
file i04261

Question 89

Small relays often come packaged in clear, rectangular, plastic cases. These so-called "ice cube" relays have either eight or eleven pins protruding from the bottom, allowing them to be plugged into a special socket for connection with wires in a circuit. Note the labels near terminals on the relay socket, showing the locations of the coil terminals and contact terminals:



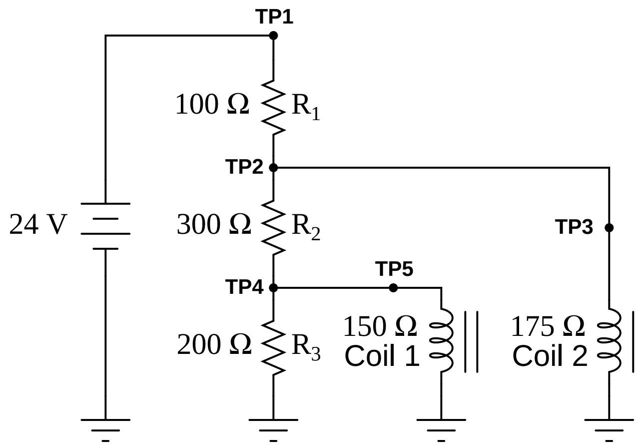
Draw the necessary connecting wires between terminals in this circuit, so that actuating the normally-open pushbutton switch sends power from the battery to the coil to energize the relay, with one of the relay's normally-open contacts turning the lamp on. The pushbutton switch should not carry any lamp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



file i03211

Question 90

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



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

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

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

file i03166

Question 91

Lab Exercise – introduction

Your task is to build, document, and troubleshoot a *split range* valve system with another team, where a pair of control valves are controlled from the control room area by adjusting the output of a single "Hand Indicating Controller" (HIC) in its "manual" mode. Each control valve will use a positioner to implement the split-ranges. Each instrument in the loop should be labeled with a proper tag name (e.g. "HV-78a" and "HV-78b" for two split-ranged, hand-controlled valves), with all instruments in each loop sharing the same loop number. Write on pieces of masking tape to make simple labels for all the instruments and signal lines.

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

<u>Objective completion table:</u>

Performance objective	Grading	1	2	3	4	Team
Prototype sketch (*before building the system!*)	mastery	–	–	–	–	
Final loop diagram and system inspection	mastery					– – – –
Split-range calibration (with saturation)	mastery	–	–	–	–	
Demonstration of working system	mastery	–	–	–	–	
Troubleshooting (5 minute limit)	mastery					– – – –
Lab question: Selection/testing	proportional					– – – –
Lab question: Commissioning	proportional					– – – –
Lab question: Mental math	proportional					– – – –
Lab question: Diagnostics	proportional					– – – –
Decommission and lab clean-up	mastery	–	–	–	–	

The only "proportional" scoring in this activity are the lab questions, which are answered by each student individually in a private session between the instructor and the team. A listing of potential lab questions are shown at the end of this worksheet question. The lab questions are intended to guide your labwork as much as they are intended to measure your comprehension, and as such the instructor may ask these questions of your team day by day, rather than all at once (on a single day).

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.

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: __________

Lab Exercise – installing a positioner on the valve

You team will need to install a positioner on the control valve you formerly "rebuilt" to facilitate split-ranging. While valves lacking positioners can be split-ranged, the task of split-ranging is greatly simplified by using a positioner because it is relatively easy to change zero and span settings. It is recommended that your team coordinate with one other team in order to build a split-range valve pair, and that you use different models of positioner.

An important first step should be finding appropriate documentation for your valve positioner. Nearly every instrument in the lab is documented electronically at the manufacturer's website, 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 identify how to properly install, wire, tube, and calibrate the positioner. Your instructor will check to see you have located and are familiar with the equipment manual(s).

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

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

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

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

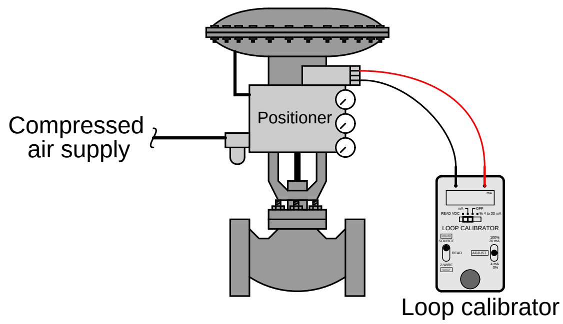
Positioners act as "position controllers" for control valves, sending enough air pressure as necessary to move the valve to match the signal given by the controller's output. As controllers in their own right, positioners require a supply of compressed air to "power" them. This air supply often needs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

Common mistakes:

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

Lab Exercise – calibrating the positioner

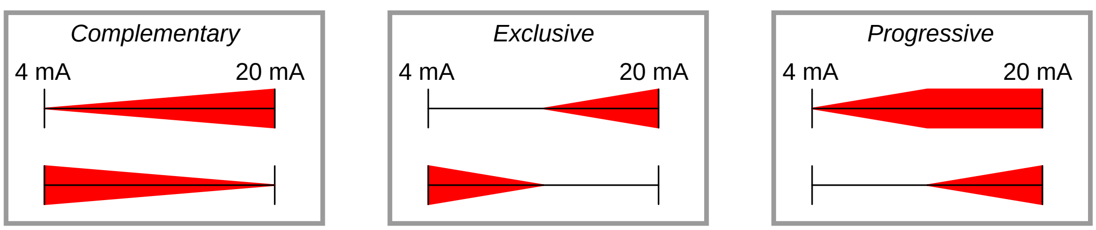
When finished installing the positioner, you should test it prior to building the rest of the loop system. Simply simulate the output signal of a loop controller by using a 4-20 mA loop calibrator in "source" mode, driving a signal to the I/P (or to the positioner directly, depending on the model) to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



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

Mechanical positioners have interactive "zero" and "span" calibration adjustments much like analog transmitters, requiring multiple adjustments to get right. Digital "smart" positioners are comparatively easy to set up because they often have their own self-calibration mode where the positioner finds the valve's stroke limits automatically and calibrates itself between those limits. In either case, you should consult the manufacturer's documentation to determine a calibration procedure for your valve's positioner.

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



Be sure to note the limitations of your team's valve when deciding on a split range: some positioners are limited in the ranges they can handle (e.g. some models of Fisher DVC6000 positioner cannot be configured for reverse action)!

Common mistakes:

- Calibrating the I/P converter for a non-standard range (i.e. something other than 3-15 PSI) instead of using the positioner's calibration to achieve split-ranging
- Not learning about the *other* positioner (different model) in your split-range loop, but rather focusing exclusively on your team's positioner
- Incorrect supply pressure given to positioner

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

Lab Exercise – selecting components and planning the system

One of the most common problems students encounter when building any working system, whether it be a circuit on a solderless breadboard or an instrument loop spanning an entire room, is properly connecting and configuring all components. An unfortunate tendency among most students is to simply start connecting parts together, essentially designing the system as they go. This usually leads to improperly-connected components and non-functioning systems, sometimes with the result of destroying components due to those improper connections!

An alternative approach is to plan ahead by designing the system before constructing it. This is easily done by sketching a diagram showing how all the components should interconnect, then analyzing that diagram and making changes before connecting anything together. When done as a team, this step ensures everyone is aware of how the system should work, and how it should go together. The resulting "prototype" diagram need not be complex in detail, but it should be detailed enough for anyone to see which component terminals (and ports) connect to terminals and ports of other devices in the system. For example, your team's prototype sketch should be clear enough to determine all DC electrical components will have the correct polarities. If your proposed system contains a significant amount of plumbing (pipes and tubes), your prototype sketch should show all those connections as well.

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!* 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.

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 – building the system

The Instrumentation lab is set up to facilitate the construction of working instrument "loops," with over a dozen junction boxes, pre-pulled signal cables, and "racks" set up with 2-inch vertical pipes for mounting instruments. The only wires you should need to install to build a working system are those connecting the field instrument to the nearest junction box, and then small "jumper" cables connecting different pre-installed cables together within intermediate junction boxes.

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

The teams pairing up to build a split-range valve loop should use different models of positioner so that students from each team get to work with multiple positioner models. Even though your team is accountable for only calibrating your valve's positioner, each person on both teams should take the time to learn how the other valve's positioner is calibrated. If one positioner is all-mechanical and the other is "smart," the differences will be dramatic!

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

Select a specific loop controller to act as a display indicator for your system. Your instructor may choose the controller for your team, to ensure you learn more than one type of controller during the course of a quarter. The controller itself should be labeled "HC-" or "HIC-" because it is a "hand" controller, allowing a human operator manual control over the valve's position.

Note that for some positioners, dual 4-20 mA output signals from the controller will be necessary to connect the two valves together to form one split-range loop. This is especially true when pairing "smart" positioners, which may not be able to digitally communicate if two of them are in the same 4-20 mA series circuit due to address conflicts! Configuring a loop controller for dual 4-20 mA outputs will require some controller re-programming. For single-loop controllers, DCS, and DDC systems, this means adding an additional "output" function block to the program. For PLC controllers, this means adding an additional rung of ladder logic.

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

Common mistakes:

- Failing to tug on each and every wire where it terminates to ensure a mechanically sound connection.
- Students working on portions of the system in isolation, not sharing with their teammates what they did and how. It is important that the whole team learns all aspects of their system!

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

Lab Exercise – documenting the system

Each student must sketch their own *loop diagram* for their team's system, following proper ISA conventions. Sample loop diagrams are shown in the next question in this worksheet. These loop diagrams must be *comprehensive* and *detailed*, showing every wire connection, every cable, every terminal block, range points, etc. The principle to keep in mind here is to make the loop diagram so complete and unambiguous that anyone can follow it to see what connects to what, even someone unfamiliar with industrial instrumentation. In industry, loops are often constructed by contract personnel with limited understanding of how the system is supposed to function. The loop diagrams they follow must be so complete that they will be able to connect everything properly without necessarily understanding how it is supposed to work.

Every instrument and every signal cable in your loop needs to be properly labeled with an ISA-standard tag number. An easy way to do this is to wrap a short piece of masking tape around each cable (and placed on each instrument) then writing on that masking tape with a permanent marker. Although no industry standard exists for labeling signal cables, a good recommendation is to label each two-wire cable with the tag number of the field instrument it goes to. Thus, every length of two-wire cable in a hand valve circuit should be labeled "HV-x" (where "x" is the loop number). If you are using two separate cables for the split-ranged valves, differentiate one from the other by using suffix letters (e.g. HV-26a and HV-26b).

When your entire team is finished drafting your individual loop diagrams, call the instructor to do an inspection of the loop. Here, the instructor will have students take turns going through the entire loop, with the other students checking their diagrams for errors and omissions along the way. After successfully passing the inspection, each team member needs to place their loop diagram in the diagram holder located in the middle of the lab behind the main control panel. When it comes time to troubleshoot another team's system, this is where you will go to find a loop diagram for that system!

Common mistakes:

- Forgetting to label all signal wires (see example loop diagrams).
- Forgetting to label all field instruments with their own tag names (e.g. PT-83).
- Forgetting to note all wire colors.
- Forgetting to put your name on the loop diagram!
- Basing your diagram off of a team-mate's diagram, rather than closely inspecting the system for yourself.
- Not placing loop sheet instruments in the correct orientation (field instruments on the left, control room instruments on the right).

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

Lab Exercise – troubleshooting

The most important aspect of this lab exercise is *troubleshooting*, where you demonstrate your ability to logically isolate a problem in the system. All troubleshooting is done on an individual basis (no team credit!), and must be done *on a system you did not help build*, so that you must rely on loop diagrams to find your way around the system instead of from your own memory of building it.

Each student is given a limited amount of time to identify both the general location and nature of the fault, logically justifying all diagnostic steps taken. All troubleshooting activities will take place under direct instructor supervision to ensure students are working independently and efficiently.

Failure to correctly identify both the general location and nature of the fault within the allotted time, and/or failing to demonstrate rational diagnostic procedure to the supervising instructor will disqualify the effort, in which case the student must re-try with a different fault. Multiple re-tries are permitted with no reduction in grade.

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

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

Common mistakes:

- Neglecting to take measurements with your multimeter.
- Neglecting to monitor pressure gauges on both positioners while testing the system.
- Incorrectly interpreting the loop diagram (e.g. thinking you're at the wrong place in the system when taking measurements).
- Incorrect multimeter usage (e.g. AC rather than DC, wrong range, wrong test lead placement). This is especially true when a student comes to lab unprepared and must borrow someone else's meter that is different from theirs!

Remember that the purpose of the troubleshooting exercise is to foster and assess your ability to intelligently diagnose a complex system. Finding the fault by luck, or by trial-and-error inspection, is not a successful demonstration of skill. The only thing that counts as competence is your demonstrated ability to logically analyze and isolate the problem, correctly explaining all your steps!

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

Lab questions – (reviewed between instructor and student team in a private session)

- **Selection and Initial Testing**
- Identify and explain the purpose of using a valve positioner on a pneumatic control valve
- Explain what "progressive" split ranging is, and give a practical example of its use
- Explain what "complementary" split ranging is, and give a practical example of its use
- Explain what "exclusive" split ranging is, and give a practical example of its use
- Explain how to properly align the linkage connecting the positioner to the valve stem, and why this alignment is important

- **Commissioning and Documentation**
- Demonstrate how to isolate potentially hazardous energy in your system (*lock-out, tag-out*) and also how to safely verify the energy has been isolated prior to commencing work on the system
- Demonstrate the proper use of a combination wrench (which end is preferred)
- Demonstrate how to use a combination wrench to turn a nut or bolt in close quarters (where there is not enough room to swing the wrench more than 20 degrees or so)
- Demonstrate how to adjust the "zero" adjustment of a positioner
- Demonstrate how to adjust the "span" (travel range) adjustment of a positioner
- Demonstrate the use of a loop calibrator to *source* current to the valve
- Explain how to isolate a control valve for removal and service using manual block and bypass valves

- **Mental math** (no calculator allowed!)
- Calculate the flow coefficient (Cv) for a specific control valve given pressure drop and liquid flow rate
- Calculate the liquid flow rate through a specific control valve given flow coefficient (Cv) and pressure drop
- Calculate the positions of both valves in a *complementary* split-range pair for a controller output of x percent
- Calculate the positions of both valves in a *progressive* split-range pair for a controller output of x percent
- Calculate the positions of both valves in an *exclusive* split-range pair for a controller output of x percent
- Calculate force generated by a diaphragm or piston actuator given diameter and applied fluid pressure in units of PSI

- **Diagnostics**
- "Virtual Troubleshooting" – referencing their system's diagram(s), students propose diagnostic tests (e.g. ask the instructor what a meter would measure when connected between specified points; ask the instructor how the system responds if test points are jumpered) while the instructor replies according to how the system would behave if it were faulted. Students try to determine the nature and location of the fault based on the results of their own diagnostic tests.
- Identify and explain the effects of various faults in a pneumatic positioner (plugged restriction, plugged nozzle, plugged relay vent, etc.)
- Explain how to confirm the presence of an *open* in a 4-20 mA signal cable using only a voltmeter (no resistance or current measurement allowed!).
- Explain how to confirm the presence of a *short* in a 4-20 mA signal cable using only a voltmeter (no resistance or current measurement allowed!). Hint: you will need to break the circuit.

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 i00787

Question 92

The Rules of Fault Club

(1) Don't try to find the fault by looking for it – perform diagnostic tests instead

(1) *Don't try to find the fault by looking for it – perform diagnostic tests instead!*

(3) The troubleshooting is over when you have correctly identified the nature and location of the fault

(4) It's just you and the fault – don't ask for help until you have exhausted your resources

(5) Assume one fault at a time, unless the data proves otherwise

(6) No new components allowed – replacing suspected bad components with new is a waste of time and money

(7) We will practice as many times as we have to until you master this

(8) Troubleshooting is not a spectator sport: *you* have to troubleshoot!

These rules are guaranteed to help you become a better troubleshooter, and will be consistently emphasized by your instructor.

Loop Diagram:	Revised by:	Date:

Tag #	Description	Manufacturer	Model	Input range	Output range	Notes

Loop diagram requirements

Perhaps the most important rule to follow when drafting a loop diagram is *your diagram should be complete and detailed enough that even someone who is not an instrument technician could understand where every wire and tube should connect in the system!*

- **Instrument "bubbles"**
- Proper symbols and designations used for all instruments.
- All instrument "bubbles" properly labeled (letter codes and loop numbers).
- All instrument "bubbles" marked with the proper lines (solid line, dashed line, single line, double lines, no lines).
- *Optional:* Calibration ranges and action arrows written next to each bubble.

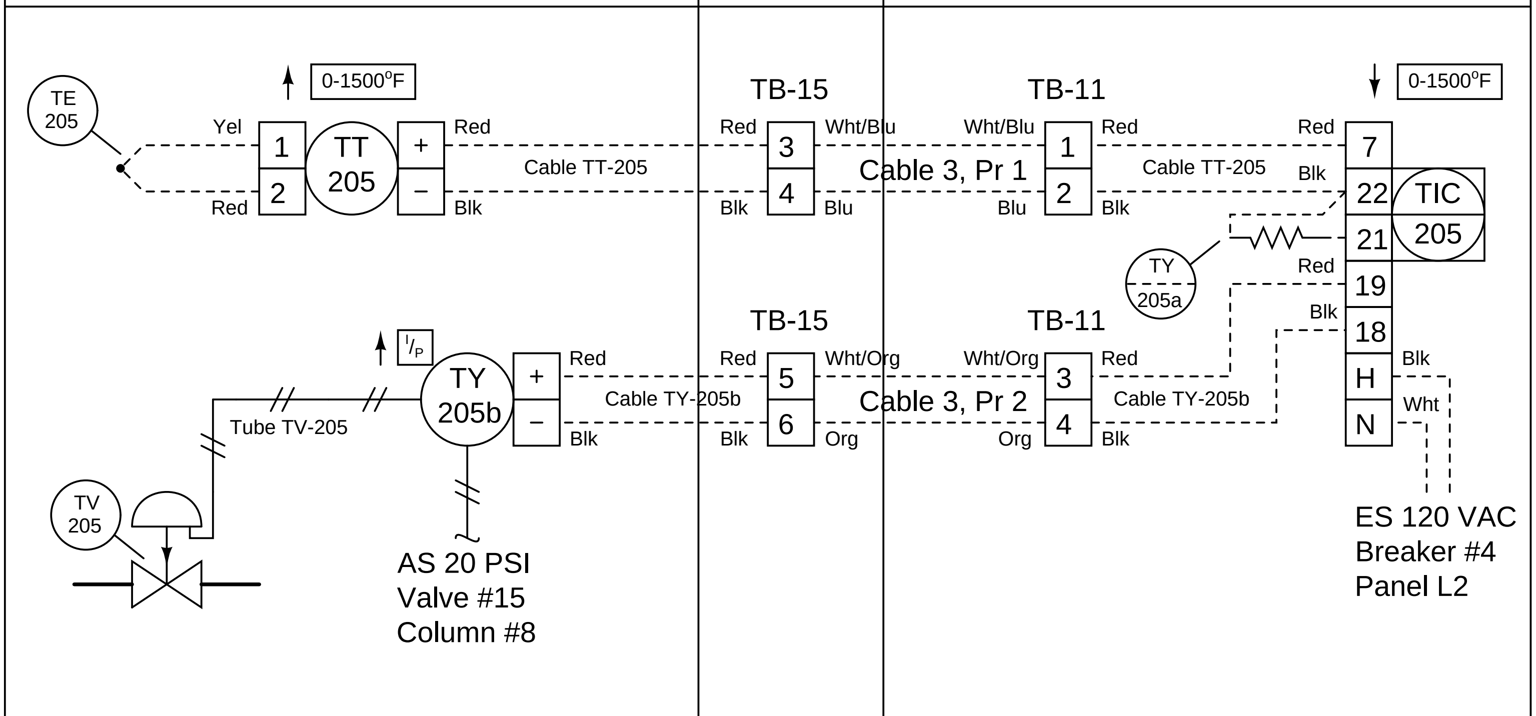
- **Text descriptions**
- Each instrument documented below (tag number, description, etc.).
- Calibration (input and output ranges) given for each instrument, as applicable.

- **Connection points**
- All terminals and tube junctions properly labeled.
- All terminal blocks properly labeled.
- All junction ("field") boxes shown as distinct sections of the loop diagram, and properly labeled.
- All control panels shown as distinct sections of the loop diagram, and properly labeled.
- All wire colors shown next to each terminal.
- All terminals on instruments labeled as they appear on the instrument (so that anyone reading the diagram will know which instrument terminal each wire goes to).

- **Cables and tubes**
- Single-pair cables or pneumatic tubes going to individual instruments should be labeled with the field instrument tag number (e.g. "TT-8" or "TY-12")
- Multi-pair cables or pneumatic tube bundles going between junction boxes and/or panels need to have unique numbers (e.g. "Cable 10") as well as numbers for each pair (e.g. "Pair 1," "Pair 2," etc.).

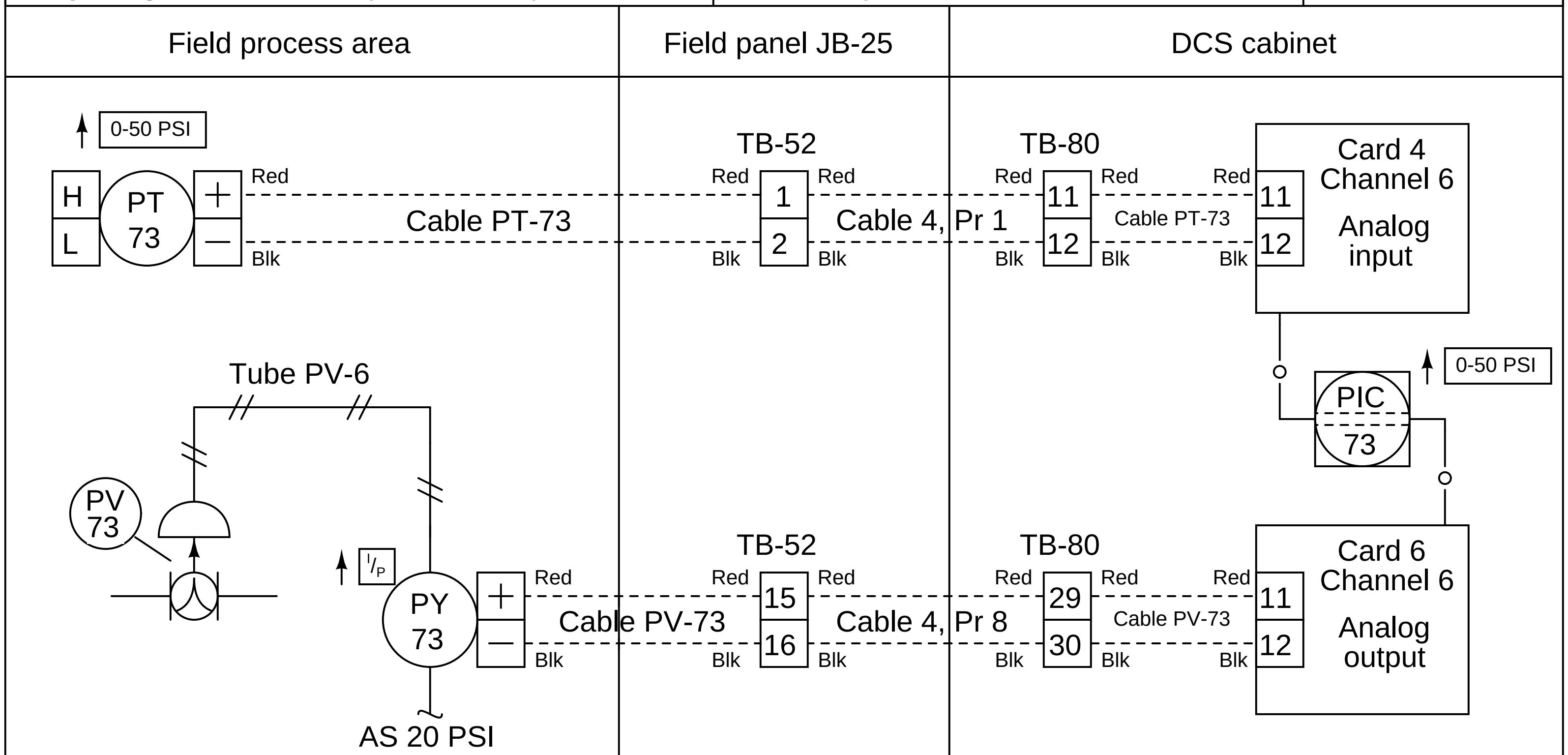
- **Energy sources**
- All power source intensities labeled (e.g. "24 VDC," "120 VAC," "20 PSI")
- All shutoff points labeled (e.g. "Breaker #5," "Valve #7")

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



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

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

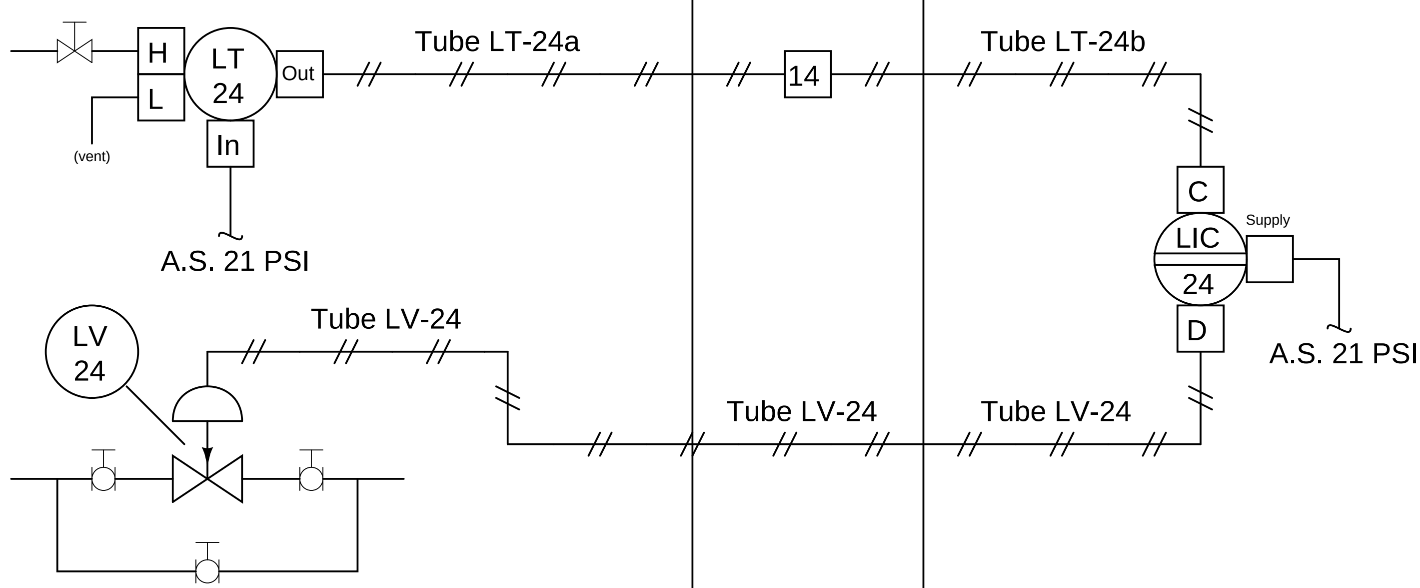


Tag #	Description	Manufacturer	Model	Input range	Output range	Notes
PT-73	Pressure transmitter	Rosemount	3051CD	0-50 PSI	4-20 mA	
PIC-73	Controller	Emerson	DeltaV	4-20 mA	4-20 mA	HART-enabled input Direct-acting control
PY-73	I/P transducer	Fisher	846	4-20 mA	3-15 PSI	
PV-73	Control valve	Fisher	Vee-ball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

file i00654

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

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

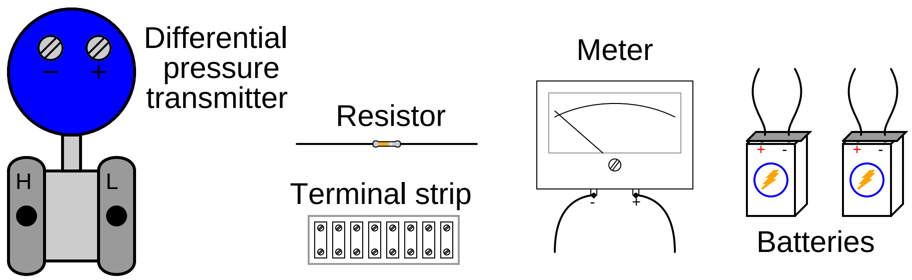


Tag #	Description	Manufacturer	Model	Input range	Output range	Notes
LT-24	Level transmitter	Foxboro	13A	25-150 "H_2O	3-15 PSI	
LIC-24	Controller	Foxboro	130	3-15 PSI	3-15 PSI	
LV-24	Control valve	Fisher	Easy-E / 667	3-15 PSI	0-100%	Fail closed

Question 93

Connect a loop-powered differential pressure transmitter (4-20 mA output) to a DC voltage source and a meter such that the meter will indicate a increasing signal when a certain stimulus is applied to the transmitter. All electrical connections must be made using a terminal strip (no twisted wires, crimp splices, wire nuts, spring clips, or "alligator" clips permitted).

This exercise tests your ability to properly connect power to a loop-powered differential pressure transmitter, connect multiple batteries together to achieve the required total supply voltage, choose the appropriate sensing port ("high" or "low" pressure) to apply the specified stimulus, condition the electrical signal (if necessary) so the meter can properly register it, properly connect an analog meter into the circuit, and use a terminal strip to organize all electrical connections.



The following components and materials will be available to you during the exam: assorted 2-wire 4-20 mA 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** ; **battery clips** (holders).

You will be expected to supply your own screwdrivers and multimeter for assembling and testing the circuit at your desk. The instructor will supply the battery(ies) to power your circuit when you are ready to see if it works. Until that time, your circuit will remain unpowered.

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

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

Study reference: the "Analog Electronic Instrumentation" chapter of *Lessons In Industrial Instrumentation*, particularly the sections on loop-powered transmitters and current loop troubleshooting.

file i03771

Answer 1

Answer 2

Answer 3

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

Answer 4

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

Answer 5

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

Answer 6

Answer 7

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

Answer 8

Partial answer:

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

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

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

Answer 9

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

Answer 10

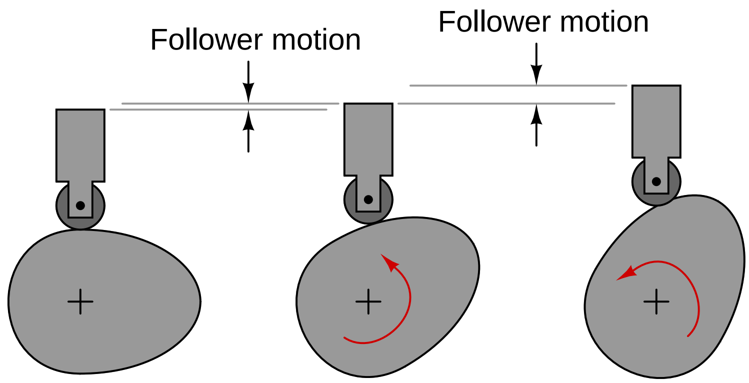
The glaring mistake in the technician's test is that he connected an ammeter in *parallel* when he should have connected it in *series*. As it stands, his test doesn't tell us much except that the controller is not at fault.

Answer 11

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

Answer 12

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



Answer 13

Answer 14

Answer 15

Answer 16

Answer 17

Answer 18

Answer 19

Answer 20

Answer 21

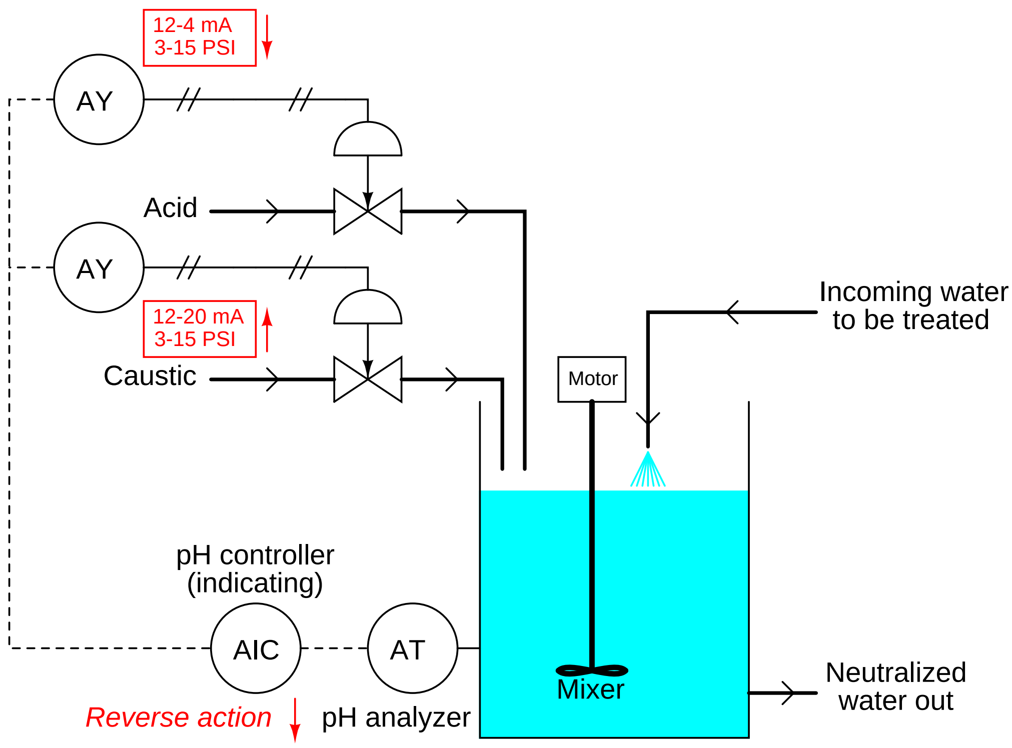
Answer 22

Answer 23

Answer 24

Answer 25

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



Answer 26

Partial answer:

- What will happen in the event that cable 3 becomes completely severed? **The hot water valve will completely shut and the cold water valve will completely open.**
- How much voltage will the controller have to output between terminals 19 and 18 when the output signal is at 100% of range? Assume a coil resistance of 176 ohms for each of the model 546 I/P transducers. **7.04 volts DC**

Answer 27

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

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

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

Answer 28

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

Answer 29

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

Answer 30

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

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

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

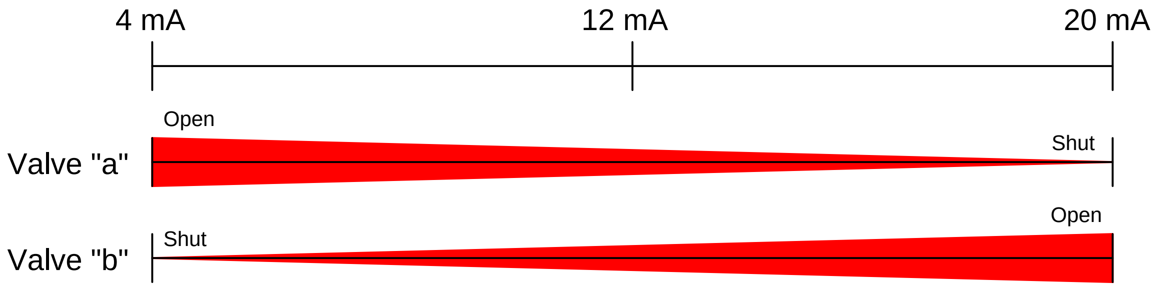
Answer 31

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

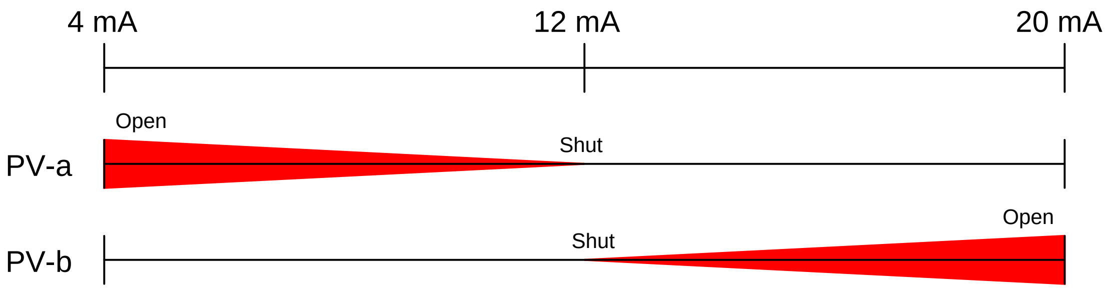
Large valve position	Controller output signal
Fully shut (0%)	12 mA
Wide open (100%)	4 mA

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

Answer 32



Answer 33



Answer 34

This requires an *exclusive* split range sequencing:

- Steam valve: air-to-open, 9-15 PSI calibrated range
- Coolant valve: air-to-close, 3-9 PSI calibrated range

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

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

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

Answer 35

Answer 36

Answer 37

Answer 38

Answer 39

Answer 40

Answer 41

Answer 42

$\tau = 7.26$ lb-ft

Answer 43

Partial answer:

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

- If the small gear has 15 teeth, how many teeth will the large gear have? *136 teeth*

Answer 44

Partial answer:

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

Motor output = 2.897 horsepower

Answer 45

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

Answer 46

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

Answer 47

Answer 48

A globe valve is an example of a valve style best suited for "torque seating," while a ball valve is an example of a valve style best suited for "limit seating."

Potential faults causing the valve not to open:

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

Answer 49

Answer 50

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

Answer 51

$F = 1636.36$ lb

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

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

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

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

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

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

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

Now, solving for force:

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

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

Answer 52

$\tau_{net} = 11.2$ lb-ft, clockwise

Answer 53

Maximum pulling force = 5236.36 pounds

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

Answer 54

Torque may be simply defined as "twisting force," mathematically defined as the product of force applied to the length of a moment arm. If you have ever accidently applied enough torque to a hand valve to damage the seat or to jam it shut (so it cannot be opened), you know very well the importance of torque in a valve actuator mechanism.

The most mathematically proper definition of torque (τ) is the *vector cross-product* of force (F) and radius (r):

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

Answer 55

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

Answer 56

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

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

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

Answer 57

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

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

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

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

Therefore,

$$P = k\tau S$$

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

$$k = 0.0001904$$

$$P = 0.0001904\tau S$$

. . . or . . .

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

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

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

Answer 58

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

Answer 59

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

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

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

Answer 60

Contrary to intuition, no work has been done. Just try telling that to the person moving the books, though! Lifting the 40 pounds of books 5 feet up constituted 200 ft-lb of work, but returning those books back to floor level constituted 200 ft-lb of energy *released* (negative work done). Thus, in physics terms, there was no net work performed.

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

Answer 61

Answer 62

Answer 63

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

Answer 64

Answer 65

Answer 66

$C_v = 219.22$

Answer 67

Answer 68

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

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

Answer 69

Partial answer:

$C_v = 21.1$

Answer 70

Students are often surprised to find that a transmitter calibration error would *not* cause this problem. A calibration error in the LT *would* cause the actual steam drum level to drift off setpoint, but with this being the only problem the controller would still register right on setpoint!

A vital "next test" is to check the controller output, to see what it is trying to tell the valve to do. It *should* be commanding the valve to open up. If not, the controller definitely has some sort of problem (or is in manual mode).

Answer 71

$Q = 55.902$ gallons per minute

Answer 72

$P_1 = 61.8$ PSI

Answer 73

Liquid density = 73.879 pounds per cubic foot

Answer 74

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

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

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

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

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

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

$$v^2 = 2gh$$

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

Answer 75

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

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

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

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

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

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

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

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

Answer 76

Here is a big hint: the presence of significant voltage between two points means those points are *not* electrically common to each other. However, the absence of significant voltage between two point does not necessarily mean those points must be common. For example: you could simply hold two voltmeter probes in open air and read 0 volts – here you have two points that are definitely not common to each other, yet drop 0 volts!

Answer 77

Answer 78

Answer 79

Answer 80

Answer 81

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

Answer 82

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

Answer 83

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

Answer 84

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

Answer 85

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

Answer 86

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

Answer 87

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

Answer 88

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

Answer 89

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

Answer 90

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

Answer 91

Answer 92

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

Answer 93