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## Introduction to Winter Quarter

This quarter focuses on the subjects of *final control elements* and *PID control*. Ideas to keep in mind for special projects (alternatives to standard lab as well as extra-credit) include applications using variable-frequency motor drives and other non-valve control elements. Applications exist as well for building your own PID controller, either from analog components (i.e. opamps) or using a programmable logic controllers (PLC) with analog I/O.



























































































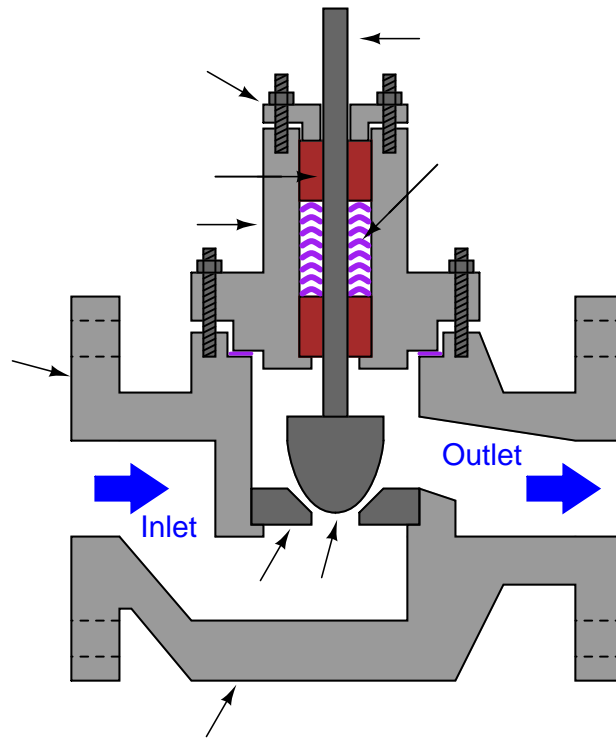


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Question 31

Match these component names with parts in this valve illustration (note the arrows):

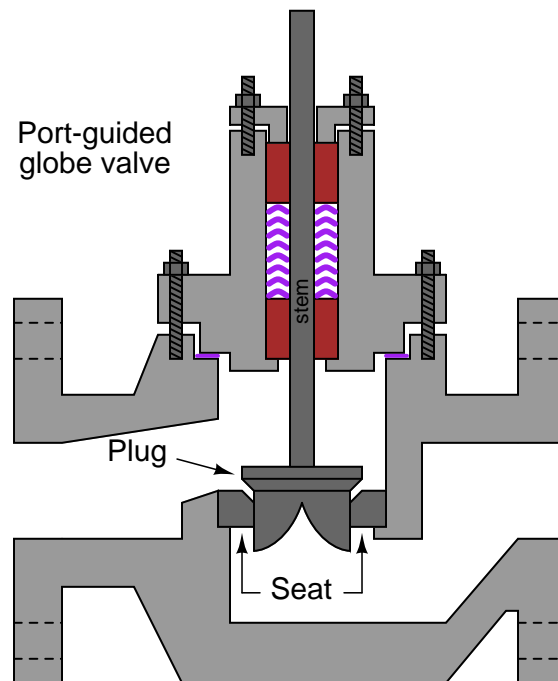
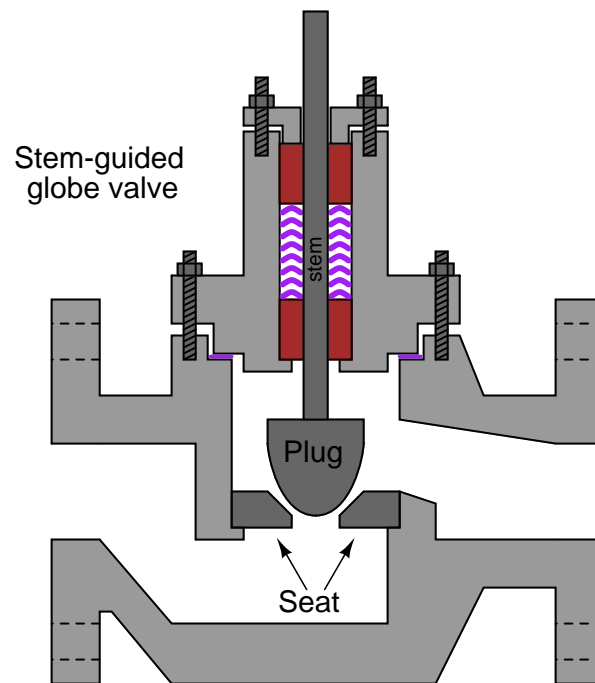
- Bonnet
- Seat
- Stem
- Plug
- Packing
- Pipe flange
- Body
- Bushing
- Packing flange (or packing gland)



Also, explain why the direction of flow shown in this illustration goes from left to right. What would happen if we sent fluid flow through this valve from right to left instead?

file i00771

Three different forms of globe valve are shown here: *stem-guided*, *port-guided*, and *cage-guided*:











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#### Question 41

Read and outline the “Fluid Power Systems” section of the “Discrete Control Elements” chapter in your *Lessons In Industrial Instrumentation* textbook.

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

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

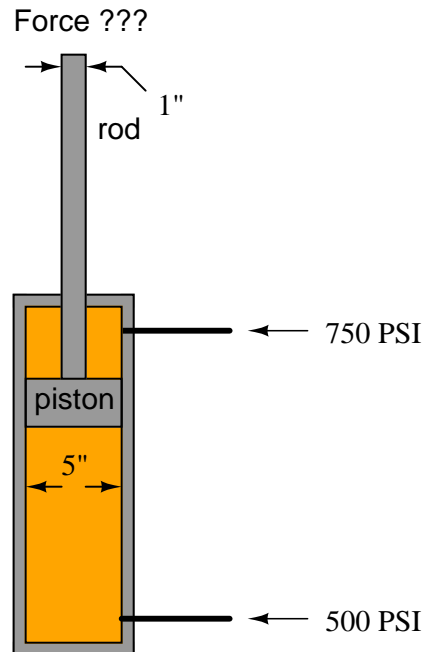
file i04178





#### Question 44

A double-acting hydraulic cylinder has 500 PSI of pressure applied to the side without the rod and 750 PSI of pressure applied to the rod-side. Calculate the resultant force generated at the piston and transmitted through to the rod, and also determine this force's direction. The piston is 5 inches in diameter, and the rod is 1 inch in diameter.



#### Suggestions for Socratic discussion

- Identify which fundamental principles of science, technology, and/or math apply to each step of your solution to this problem. In other words, be prepared to explain the reason(s) “why” for every step of your solution, rather than merely describing those steps.
- What would happen if fluid pressure were applied to the bottom port and a fluid *vacuum* were applied to the top port? Would this generate more force, less force, or the same amount of force as if the same fluid pressure were applied to bottom port and the top port left vented?
- Would the piston experience a resultant force if both ports were connected together with a length of tubing (made “common” to each other) and then pressurized with the exact same amount of fluid pressure? Why or why not?
- Suppose both ports of this cylinder were connected together with a length of tubing (made “common” to each other) and to a pressure gauge. What would that gauge register if the piston were then pushed in the downward direction? Would the gauge’s reading increase, decrease, or remain the same? Explain your answer in detail.

[file i00156](#)



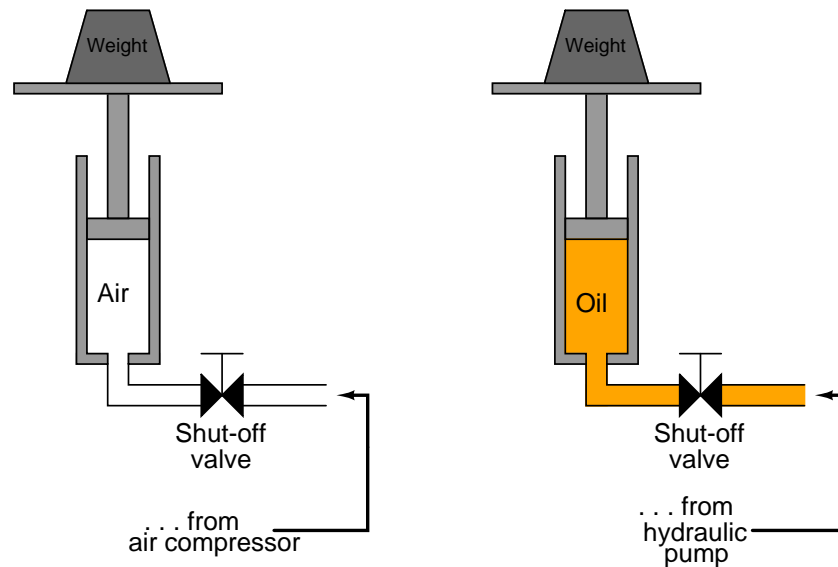






### Question 49

Two pressure-actuated “lifts” are used to raise a heavy weight off the ground. One lift uses oil under pressure (from a hydraulic pump) while the other lift uses air under pressure (from an air compressor). Each lift is equipped with a shut-off valve on the line feeding fluid to the cylinder, so that the piston’s motion may be halted:



What will happen if the weight were to fall off the lift platform after it had been raised up from ground level, in each case? Assume that the shut-off valve is closed (no fluid flow from pump or compressor into the cylinder) when this happens.

#### Suggestions for Socratic discussion

- What general lessons may we draw from this example regarding pressurized fluid safety?
- Does the calculation of piston force based on pressure ( $F = PA$ ) change at all if the fluid in question is a *gas* rather than a *liquid*?

file i00750















































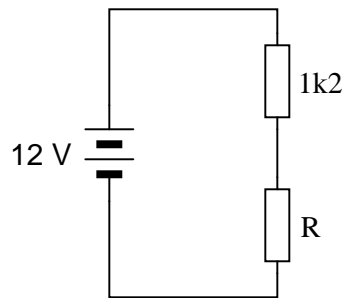




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Question 86

Combine any relevant formulae for series resistor circuits to create a new formula calculating the power dissipation of  $R$ , given the other values (constants) in this circuit and the resistance value  $R$ :



Your answer should be in fully-expanded form (no parentheses or compound fractions). Be sure to show all your work!

$$P_R =$$



















## Lab Exercise – setting stroke length and bench-set pressure

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

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

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

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

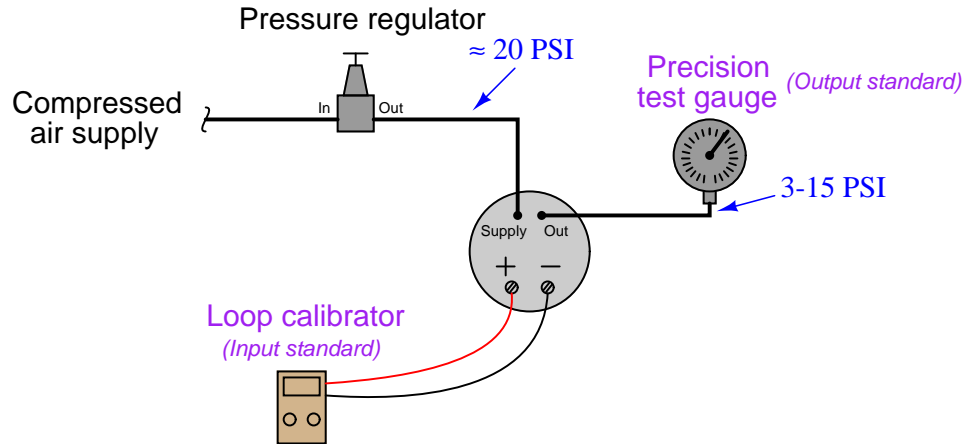
### Common mistakes:

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

## Lab Exercise – I/P calibration

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

### Typical calibration setup for an I/P converter



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





## Lab Exercise – building the system

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

After getting your prototype sketch approved by the instructor, you are cleared to build a hand-control system for it. This will consist of a loop controller placed into “manual” mode to allow direct control over the valve’s position. There will be no transmitter installed in this loop – just the valve and the I/P converter necessary to convert the controller’s 4-20 mA output signal into a pneumatic signal to move the valve. Feel free to use 1/4 inch plastic tubing for all pneumatic signal connections, and be sure not to exceed the rated supply pressure for the I/P (as documented in the I/P manual).

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

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

### Common mistakes:

- Neglecting to consult the manufacturer’s documentation for the I/P converter (e.g. how to connect pneumatic signal lines, how to calibrate it).
- Improper pipe/tube fitting installation (e.g. trying to thread tube fittings into pipe fittings and vice-versa).
- Applying Teflon tape to tube fitting threads; failing to apply Teflon tape to pipe fitting threads.
- Over-tightening tube fittings (remember, no more than 1-1/4 turns when installing a new ferrule set, and no more than “snug” when re-making the connection!).
- Students working on portions of the system in isolation, not sharing with their teammates what they did and how. It is important that the whole team learns all aspects of their system!



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

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

#### **Common mistakes:**

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

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

### **Lab Exercise – decommissioning and clean-up**

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

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

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

#### **Return the following components to their proper storage locations:**

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

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

[file i02865](#)











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

[file i00654](#)



**Summary of principles:**

- Conservation of Energy
  - Energy cannot be created or destroyed
- Conservation of Electric Charge
  - Electric charges cannot be created or destroyed
- Properties of a series network
  - Definition: *only one path for electric current*
  - Current the same through each component (Conservation of Electric Charge)
  - Voltages add to equal the total (Conservation of Energy)
  - Resistances add to equal to total
- Properties of a parallel network
  - Definition: *each component connected across the same two sets of electrically common points*
  - Voltage the same across each component (Conservation of Energy)
  - Currents add to equal the total (Conservation of Electric Charge)
  - Resistances diminish to equal to total
- Kirchhoff's Voltage Law (KVL)
  - A test charge moved from one location to any series of other locations and back to the starting location must arrive with the same amount of potential energy as it began (Conservation of Energy)
- Kirchhoff's Current Law (KCL)
  - Every charge entering a point must be balanced by a charge exiting that point (Conservation of Electric Charge)
- Ohm's Law
  - The voltage dropped across a resistance is equal to the product of its resistance and the amount of current through it:  $V = IR$
- Capacitance and Inductance
  - The ability to store energy in and retrieve energy from electric fields and magnetic fields, respectively
  - Current through capacitance is equal to the product of its capacitance and the rate-of-change of voltage across it:  $I = C \frac{dV}{dt}$
  - Voltage across inductance is equal to the product of its inductance and the rate-of-change of current through it:  $V = L \frac{dI}{dt}$



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Answer 9

<b>Fault</b>	<b>Possible</b>	<b>Impossible</b>
PR-33 calibration error	✓	
PT-33 calibration error		✓
PIC-33 (input) calibration error	✓	
PY-33a calibration error	✓	
PY-33b calibration error		✓
PV-33a calibration error		✓
PV-33b calibration error		✓

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Answer 10

PSIG	PSIA	inches Hg (G)	inches W.C. (G)
18	32.7	36.65	498.25
385.3	400	784.5	10665
16.21	30.91	33	448.6
2.168	16.87	4.413	60
222.0	236.7	452	6145.1
0.4335	15.13	0.8826	12
-13.7	1	-27.89	-379.2
-5	9.7	-10.18	-138.4

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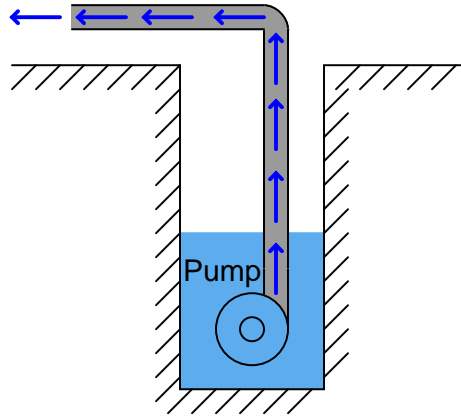
Answer 11

406.9 inches, which is a little bit less than 34 feet. For this amount of “lift height,” the pump would have to create a near-perfect vacuum in the inlet pipe. To calculate this figure, convert 14.7 PSIA into inches of water column absolute (14.7 PSIA)(27.68 "W.C. / PSI).

Since this kind of water pump works by creating a vacuum (reducing the inlet pressure to something less than 14.7 PSIA), it is inherently limited in lift height. Since atmospheric pressure is always 14.7 PSIA (on Earth, anyway), this kind of pump simply cannot suck water any higher than this amount of pressure expressed in inches or feet of water.

The average barometric pressure in Denver is 24.63 inches of mercury absolute (12.097 PSIA). This equates to a water-lifting height of 334.9 inches, or 27.9 feet.

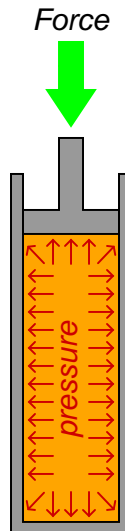
Submersible pumps overcome this limit by creating a *positive pressure* rather than a *vacuum*. The pumping action is therefore not limited by the relatively low pressure of Earth’s atmosphere, but only by the capacity and design of the pump itself:



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Answer 12

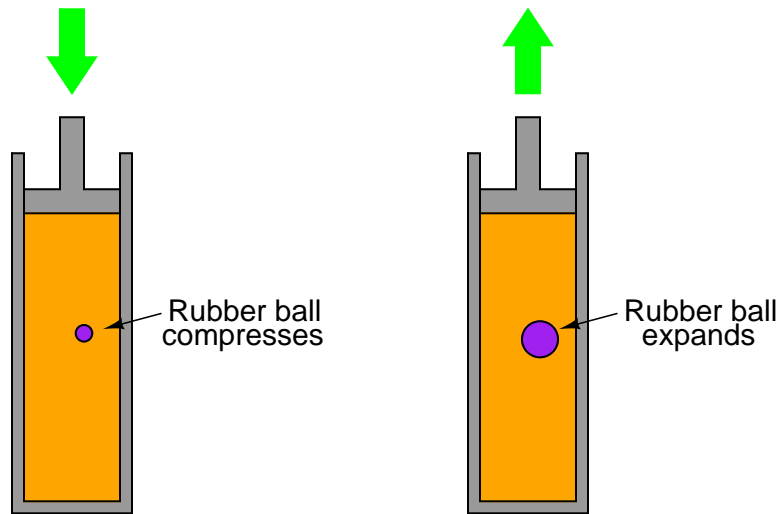
The fluid pressure will exert an outward force on the cylinder walls, like this:



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Answer 13

A pushing force on the rod will compress the rubber ball to a smaller diameter. A pulling force will expand it to a larger diameter.



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Answer 14

*Absolute* pressure is the measurement of a pressure as compared to a pure vacuum. Atmospheric (“barometric”) pressure, like the pressure figures reported by meteorologists, is an example of absolute pressure measurement.

*Gauge* pressure is the measurement of a pressure as compared to the pressure of Earth’s atmosphere. The pressure indicated by a pressure gauge (like an oil pressure gauge for a car engine, or a tire pressure gauge) is an example of gauge pressure. When vented, such a gauge will register zero, even though there is still absolute pressure all around us due to Earth’s atmosphere.

*Differential* pressure is the measurement of a difference between two different pressures. In essence, all pressure measurements are differential in nature: notice how *absolute* and *gauge* pressures are defined in terms of a comparison of one pressure against another!

Suffixes are sometimes appended to pressure units to distinguish between absolute (A), gauge (G), and differential (D) pressures. For example, you might see an absolute pressure represented as “150 PSIA”, a gauge pressure as “35 PSIG”, or a differential pressure as “86.5 PSID”. If no such suffix is given, the pressure unit is assumed to be *gauge*.

Some units of pressure measurement are *always* absolute, never gauge or differential. These units include the *atmosphere* (14.7 PSIA), the *bar* (very close to 1 atmosphere – think of it as a “metric” atmosphere), and the *torr*, which is absolute millimeters of mercury column.



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Answer 19

Weight of water = 117,674 lbs

Area of circular pool bottom = 45,239 in<sup>2</sup>

Pressure at bottom of pool =  $P = 2.601 \text{ lb/in}^2$  (PSI) = 72 inches of water column (" W.C.)

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Answer 20

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Answer 21

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Answer 22

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Answer 23

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Answer 24

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Answer 25

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Answer 26

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Answer 27

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Answer 28

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Answer 29

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Answer 30

Valve #1: Ball valve (rotary)

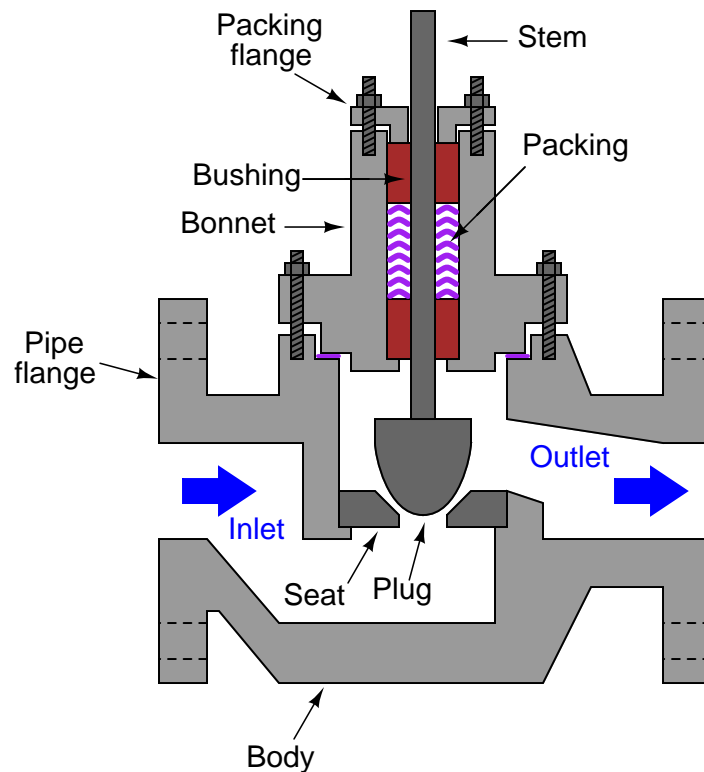
Valve #2: Single-ported globe valve (sliding stem)

Valve #3: Dual-ported globe valve (sliding stem)

Valve #4: Saunders valve (diaphragm)

Valve #5: Gate valve (sliding stem)

Valve #6: Butterfly valve (rotary)



If we were to use this valve “backwards,” the pressure drop across the plug would tend to “slam” it closed whenever it approached the closed position. In other words, the process fluid’s differential pressure drop would make it very difficult to maintain any plug position near full-closed.

This is actually an example of a mechanical feedback system. As the valve closes, the pressure drop across it (in most processes) usually rises because other pressure losses in the piping system decrease with decreased flow, leaving the valve to drop all the fluid pressure. Since plug position has an effect on pressure drop, and pressure drop exerts a mechanical force on the plug, there is a system of feedback at work here.

In the proper flow direction, the feedback is negative: closing the valve results in greater pressure drop, which in turn tries to keep the valve open. In true negative feedback form, the feedback works *against* the initial action. The more the valve is closed, the more the process pressure tries to keep it open.

In the backwards flow direction, the feedback is positive: closing the valve results in greater pressure drop, which in turn tries to close the valve even more. The result is a tendency for the system to *saturate*, staying open or slamming shut, but avoiding any in-between conditions. This makes it very difficult to position the valve mechanism near full-closed, and would result in erratic control near the lower end of the valve’s working range.

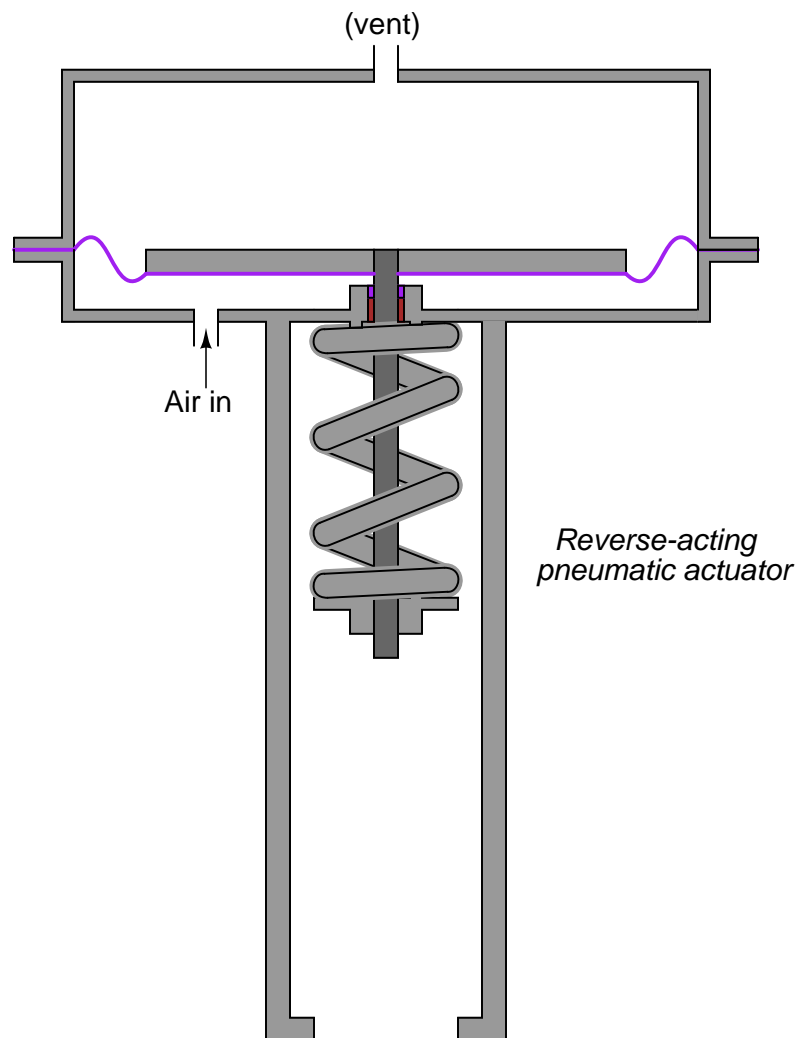
The cage-guided valve design is the most popular today.

In a cage valve, the flow is throttled not by the size of the restriction formed between a contoured plug and the seat, but rather by the restriction formed by the piston-shaped plug's uncovering of holes in the cage. The seat serves only one purpose, and that is tight shutoff at the 0% open (fully-closed) position.

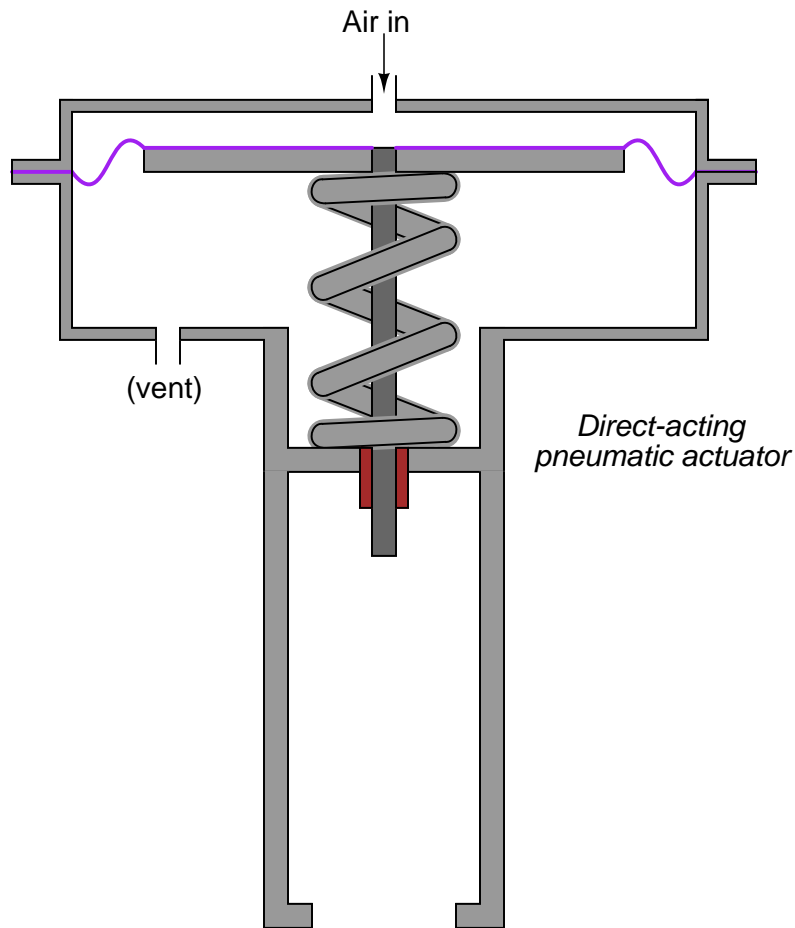
Because of this, the seat in a cage valve is subject to less wear than in a globe valve with a contoured plug or a "v-ported" plug, extending its service life. Opening characteristics of the valve (quick-opening, linear, and equal-percentage) may be easily altered by changing only the cage. In a regular globe valve, the plug must be changed for one of a different contour. Since cages are more easily changed than plugs, this provides better flexibility.

A valve *actuator* is the mechanism that moves the valve stem or shaft in response to a control signal, usually compressed air.

A *reverse-acting* valve actuator is one where the actuating stem retracts into the actuator (pulls up from the valve body) when air pressure is applied:



By contrast, a *direct-acting* actuator extends its stem (pushes into the valve body) when air pressure is applied:




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#### Answer 34

For an “air-to-open” valve, either of these two combinations will work:

- Direct-acting valve + reverse-acting actuator
- Reverse-acting valve + direct-acting actuator

For an “air-to-close” valve, either of these two combinations will work:

- Direct-acting valve + direct-acting actuator
- Reverse-acting valve + reverse-acting actuator

It should be noted that direct-acting globe valves are far more common than reverse-acting globe valves. In industry, you usually see direct acting valve bodies coupled to either direct- or reverse-acting actuators to configure the valve assemblies for air-to-close or air-to-open action, respectively.

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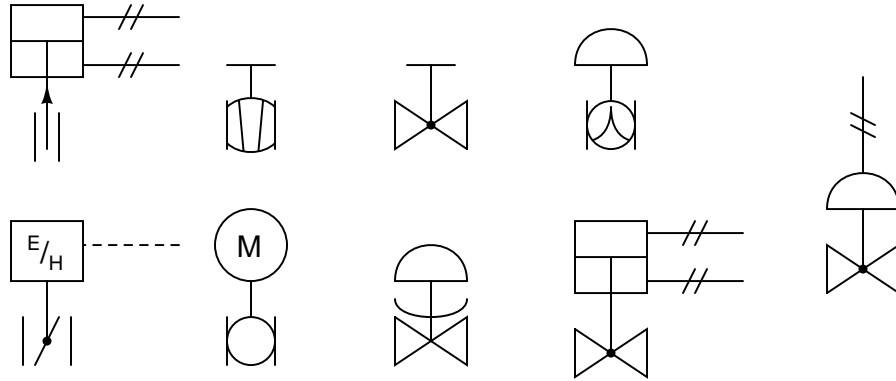
#### Answer 35

Double-ported globe valves are easier to position than single-ported globe valves, because double-ported valve trim minimizes the force produced by fluid pressure on the plug(s). With less process-induced force on the valve stem, the actuator has an easier job of moving the valve to any given position.

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Answer 36

Here are the valve symbols, shown in no particular order:




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Answer 37

If the operator watches the control valve stem position, he or she needs to stop opening the bypass valve as soon as the control valve reaches the full-closed position under automatic control.

If the operator watches the flow indicator, he or she needs to stop opening the bypass valve as soon as the indicator registers a flow rate above setpoint that does not recover back to setpoint after a short time.

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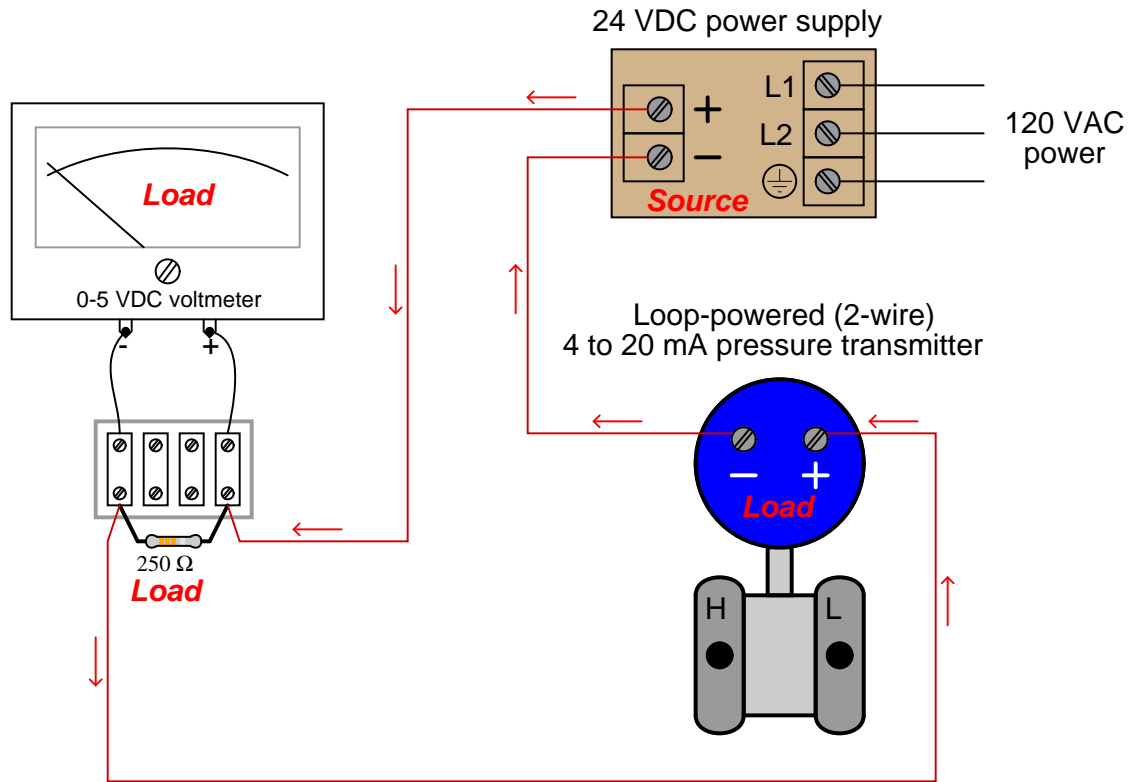
Answer 38

Fault	Possible	Impossible
Switch failed open		✓
$R_1$ failed open	✓	
$R_2$ failed open		✓
$R_3$ failed open	✓	
Switch failed shorted	✓	
$R_1$ failed shorted		✓
$R_2$ failed shorted	✓	
$R_3$ failed shorted		✓
Voltage source dead	✓	

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Answer 39

This is just one possible solution:



Note how current (shown in the direction of conventional flow) always exits the positive terminal of a source, and always enters the positive terminal of a load.

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Answer 40

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Answer 41

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Answer 42

**Partial answer:**

- $P = 1100 \text{ PSI}$        $F = \underline{21,598.4 \text{ lbs}}$
- $P = 461 \text{ kPa}$        $F = \underline{1312.8 \text{ lbs}}$
- $P = 2.77 \text{ bar (gauge)}$        $F = \underline{788.8 \text{ lbs}}$

---

Answer 43

**Partial answer:**

- $P = 15 \text{ PSI}$        $F = \underline{2309.1 \text{ lbs}}$
- $P = 22 \text{ "Hg}$        $F = \underline{1663.4 \text{ lbs}}$

---

Answer 44

Net force = **4,319.69 pounds**, in the downward direction.

If your calculated force turned out to be 4,908.7 pounds, you made a very common error. Once you have figured out what this error is, go back and try to see how the scenario would have to be altered in order to actually generate 4,908.7 pounds of force with the two pressures being 750 PSI and 500 PSI, respectively.

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Answer 45

Shut-off valve #1 (the oil valve) would be the safer one to close for halting the platform's vertical motion.

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Answer 46

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Answer 47

With a piston diameter of 4 inches, a hydraulic pressure of 456.83 PSI is necessary to generate 5740.6 pounds. This is a *minimum* pressure, for safety reasons. More than 456.83 PSI won't do any harm, but less than this amount will fail to hold down the lid!

---

Answer 48

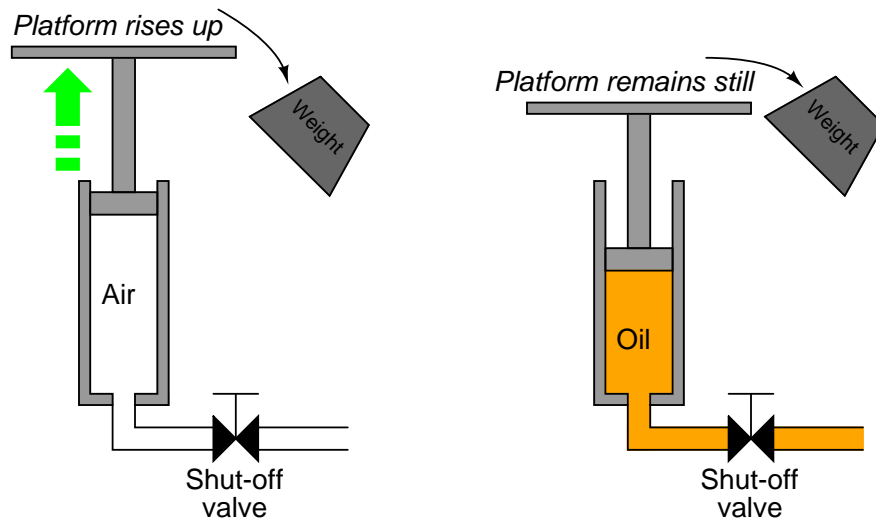
**Partial answer:**

<b>Fault</b>	<b>Possible</b>	<b>Impossible</b>
Valve A shut		
Valve B open		✓
Valve F shut		
Valve G shut		
Silencer plugged		✓
Ash grate jammed		
Air supply dead		

---

Answer 49

If the weight falls off the oil-actuated lift, the piston will hold its original position. If the weight falls off the air-actuated lift, the piston will rise substantially (perhaps even ejecting from the cylinder!) due to expansion of the air:



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Answer 50

A vitally important concept to grasp here is that of *incompressibility*. Air is a compressible fluid, but hydraulic oil is incompressible for all practical purposes. Thus, a positive-displacement pump mechanism will lock up if the incompressible fluid has no place to exit.





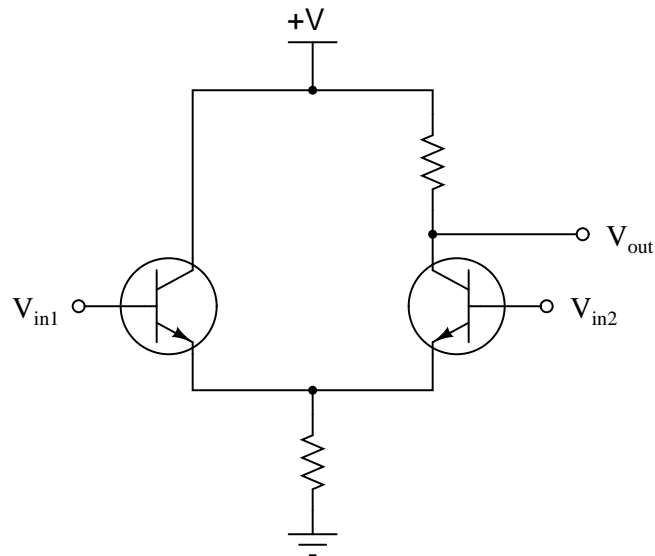


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Answer 64

A bit of explanation might be in order for the two diaphragms. The larger diaphragm is called the *sensing* diaphragm, while the smaller diaphragm is called the *sealing* diaphragm. The purpose of the sealing diaphragm is to prevent air pressure at input B from leaking out into the vented chamber just to the left of the wedge-shaped pilot plug. This sealing diaphragm is made small enough that its contribution to force on the stem is negligible. Only the sensing diaphragm is large enough to have any consequence upon the pilot valve's action.

This is an equivalent electronic circuit:



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Answer 65

Input pressure applied ("W.C.)	Percent of span (%)	Output signal (PSI)
0	50	9
-30	35	7.2
-16.67	41.67	8
66.67	83.33	13
30	65	10.8
-80	10	4.2

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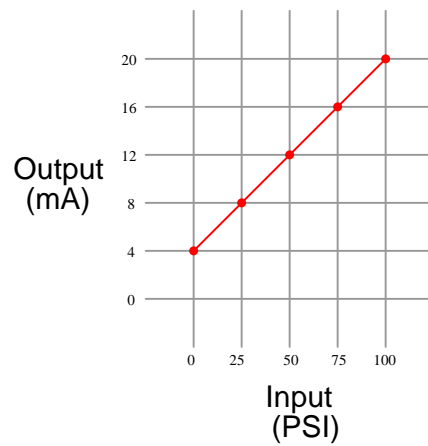
Answer 66

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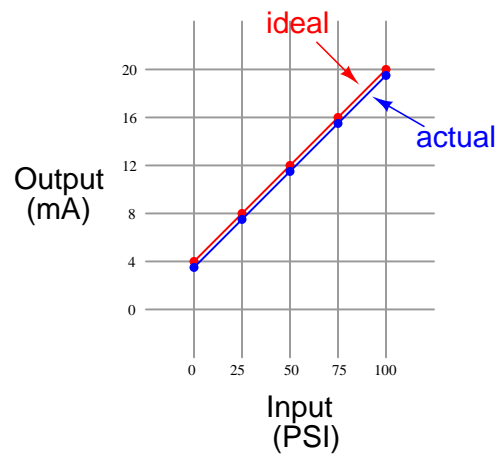
Answer 67

This instrument has a *zero shift* error, but not a *span shift* or *linearity* error.

**Ideal transfer function:**



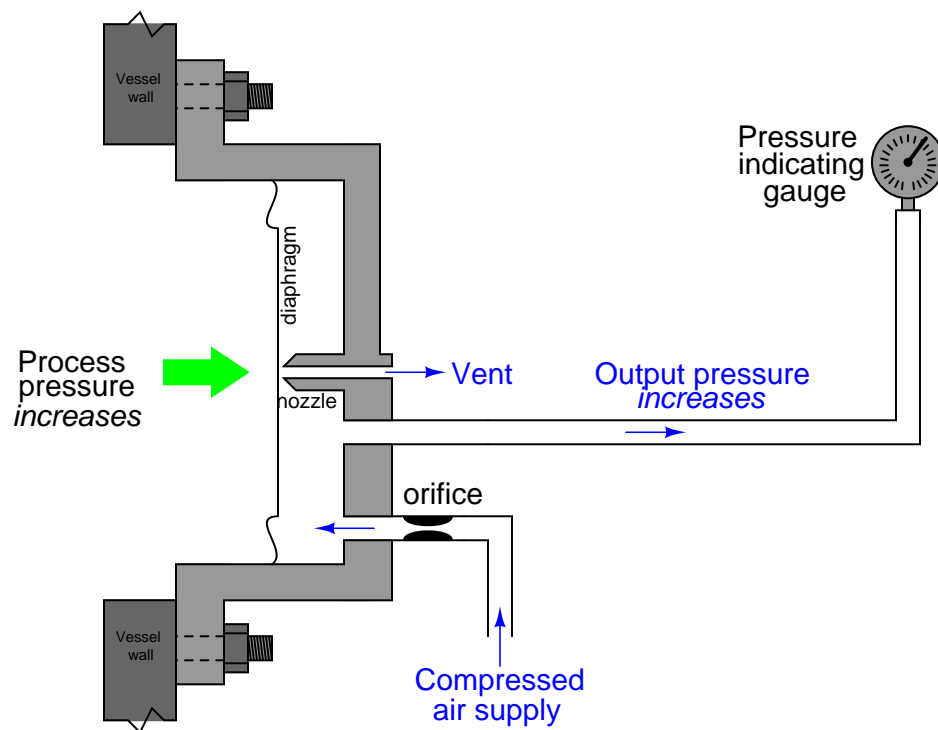
**Actual transfer function:** (zero error)



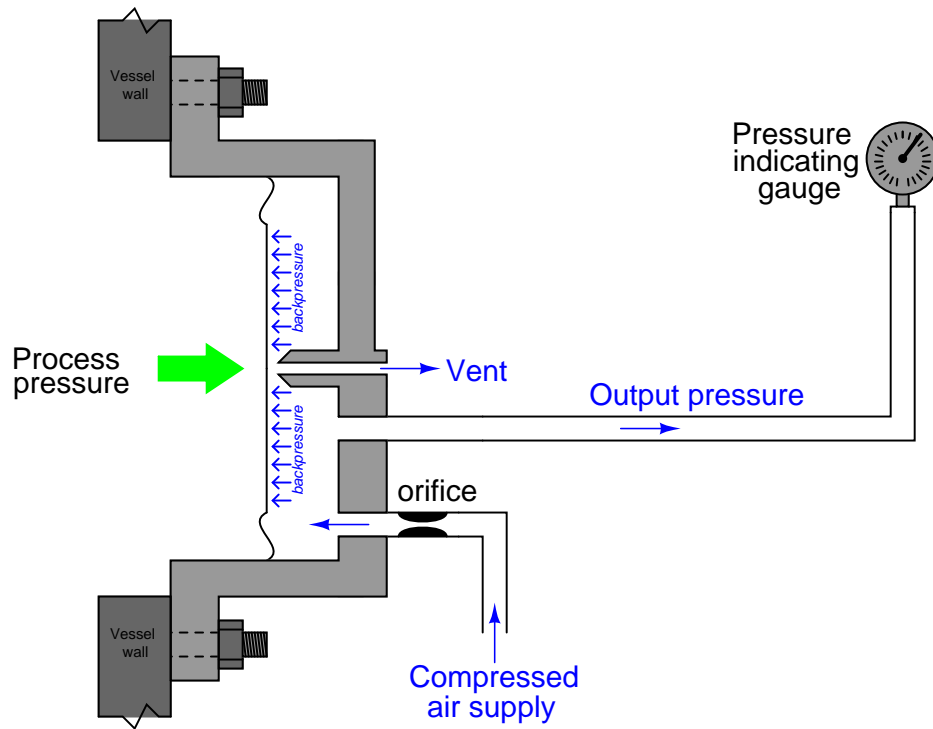




As process pressure increases, the force pressing right on the diaphragm increases as well. This makes the diaphragm move closer to the nozzle, making it more restrictive to air flow:



As air flow through the nozzle reduces, the “backpressure” built up by supply air through coming through the orifice increases. This increased backpressure forces the diaphragm to the left, against the process pressure, until the diaphragm begins to back away from the nozzle and a new point of balance (equilibrium) is reached:



Because both pressures (process fluid, and air backpressure) act against the same amount of surface area on the diaphragm, the point of force balance between them will be when the two pressures are equal to each other. Thus, the output air pressure (sensed by some remote pressure-measuring instrument) mirrors, or “repeats,” the process pressure.

Applications for a pressure repeater are found in the biopharmaceutical and food processing industries. If a pressure gauge were connected directly to the process vessel, the impulse tube connecting the gauge to the vessel would inevitably retain some of the process fluid. In biopharmaceutical and food processes, bacteria will grow in stagnant process fluid, meaning that such lengths of tubing will act as reservoirs of harmful bacteria which may contaminate subsequent batches within the vessel.

The flush-mounted diaphragm of a pressure repeater is easily cleaned by “clean-in-place” (CIP) protocols used to clean the process vessel. There are no crevices or small chambers for fluid to lie stagnant on the process side of a pressure repeater, therefore pressure repeaters eliminate the problem of bacterial contamination.

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Answer 73

Fault	Possible	Impossible
LT-12 miscalibrated		✓
LG-11 block valve(s) shut		✓
LSH-12 switch failed	✓	
LSL-12 switch failed		✓
Leak in tubing between LT-12 and LIC-12		✓
LIC-12 controller setpoint set too high		✓
LV-12 control valve failed open		✓
LV-12 control valve failed shut		✓



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Answer 89

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

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Answer 90

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

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Answer 91

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Answer 92

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