PNEUMATIC TECHNICIAN CERTIFICATION

Manual
Including Study Guide, Solutions, & Pre-Tests

Manual # 405 - 7/02

FLUID POWER CERTIFICATION BOARD

FLUID POWER SOCIETY

The International Organization for Fluid Power and Motion Control Professionals

General Pneumatic Safety Guidelines

Compressed air can be dangerous unless precautions are taken. These precautions are mostly common sense, but are nonetheless worth listing in places where compressed air is used. Consideration should be given to placing these, or similar, guidelines in a prominent place.

- Only pressure vessels built to a national or international standard should be used for air receivers.
- It is essential that a check valve and shut-off valve are fitted in the delivery line when the compressor is to be coupled in parallel with another compressor or connected to an existing air supply system. In such cases, a safety valve must be provided upstream of the valves, unless one is already fitted on the compressor.
- Do not use frayed, damaged or deteriorated hoses. Always store hoses properly and away from heat sources or direct sunlight. A hose failure can cause serious injury.
- Use only the correct type and size of hose end fittings and connections. Use heavy duty clamps made especially for compressed air systems.
- Use eye protection. If using compressed air for cleaning down equipment, do so with extreme caution. Take care not to blow dirt at people or into machinery.
- When blowing through a hose or air line, ensure that the open end is held securely. A free end will whip and can cause injury. Open the supply air cock carefully and ensure that any ejected particles will be restrained. A blocked hose can become a compressed air gun.
- Never apply compressed air to the skin or direct it at a person. Even air at a pressure of 15 psi (1 bar) can cause serious injury. Never use a compressed air hose to clean dirt from your clothing.
- Do not use air directly from a compressor for breathing purposes, for example charging air cylinders, unless the system has been specifically designed for such purpose and suitable breathing air filters and regulators are in place.

Precautions during start-up:

- If an isolating or check valve is fitted in the compressor discharge, it is essential to check that an adequate safety valve is in place between this isolating valve and the compressor and that the isolating valve is open.
- Before starting any machinery, all protective guards should be in position and be secure.
- On the initial start-up, the direction of rotation of an compressor must be checked. Severe damage may be caused if the compressor is allowed to run in the wrong direction.
- Ensure that a machine can not be started inadvertently. Place a warning notice at the lock-out.
- Do not weld or in anyway modify any pressure vessel.
- Isolating valves should be of the self venting type and designed to be locking in the “off” position so that air pressure cannot be applied inadvertently while the machine is being worked on.
- Exposure to excessive noise can damage hearing. Wear ear protection.
- Noise reducing mufflers can be fitted to machines to lessen the noise health hazard.
- A concentration of oil mist in the air from system lubricators can be hazardous.
- Check hoses and couplings daily before use. Use only hoses designed to handle compressed air. Provide all hose couplings with a positive locking device. Secure Chicago-type fittings together with wire or clips.
- Never crimp, couple, or uncouple pressurized hose. Shut off valves and bleed down pressure.
- When using compressed air for cleaning purposes, ensure pressure does not exceed 30 psi. Use goggles or a face shield over approved safety glasses for this application. Do not use compressed air to clean dust or debris off your body.
- Make sure all hoses exceeding 1/2 inch ID have a safety device at the source of supply or branch line to reduce the pressure in case of hose failure.

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Pneumatic Technician Certification

Introduction

This Study Guide has been written for candidates who wish to prepare for the Pneumatic Technician Certification exam. It contains numbered Outcomes, from which test items on the exam were written, a discussion of the related subject matter with illustrations, references for additional study, and review questions. While the Study Guide covers the basics of the exam, additional reading in the references is recommended.

The numbered outcomes and review questions are intended to focus attention on a representative sample of the subject matter addressed by the exam. This does not mean that the Study Guide will teach the test. Rather, the Study Guide is to be used as a self-study course, or taught course if a Review Training Seminar is available, to address representative subject matter covered by the exam. Both the exam questions and review questions have been written from the same outcomes. And to this extent, if the candidate understands the subject matter given here and can answer the review questions correctly, he or she should be prepared to take the Pneumatic Technician exam.

To use the Study Guide, simply read each outcome and the related subject matter that follows, and then answer the review questions. For convenience, record your answers to the review questions on a separate piece of paper. After you have answered several questions, refer to the answers. If you answered all review questions correctly, continue with your review. You are on the right track. If you answered a review question incorrectly, refer back to the outcome with the same number as the review question, and then re-read the related subject matter that covers the material. If you are still in doubt about the correct answer, additional reading is recommended from the references which are cited throughout the Study Guide.

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Reference Equations

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Equations	**Page #**	**Equation**	**Equation**
Eq. #1	20	Temperature Conversions:	
		˚F to ˚C: ˚C = (˚F –32) / 1.8 ˚C to ˚F: ˚F = (˚C x 1.8) + 32 ˚R to ˚F: ˚F = ˚R - 459.7 ˚F to ˚R: ˚R = ˚F + 459.7 ˚K to ˚C: ˚C = ˚K – 273.7 ˚C to ˚K: ˚K = ˚C + 273.7 ˚R to ˚K: ˚K = ˚R / 1.8 ˚K to ˚R: ˚R = ˚K x 1.8	
Eq. #2	21	Absolute Pressure_{psia} = Gauge Pressure_{psig} + 14.7 Gauge Pressure_{psig} = Absolute Pressure_{psia} – 14.7	PSIA = PSIG + 14.7 PSIG = PSIA – 14.7
Eq. #3	22	(Initial Pressure_{psia} x Initial $\text{Volume}_{cu\text{-}in}$) = (Final Pressure_{psia} x Final $\text{Volume}_{cu\text{-}in}$)	(P1 x V1) = (P2 x V2)
Eq. #4	23	(Initial Pressure_{psia} x Initial $\text{Volume}_{cu\text{-}in}$) / Initial $\text{Temperature}_{°R}$ = (Final Pressure_{psia} x Final $\text{Volume}_{cu\text{-}in}$) / Final $\text{Temperature}_{°R}$	(P1 x V1) / T1 = (P2 x V2) / T2
Eq. #5	24	Relative $\text{Humidity}_{\%}$ = (Actual $\text{Humidity}_{lbs/cu\text{-}ft}$ x 100) / (Humidity at $\text{Saturation}_{lbs/1000\ cu\text{-}ft}$ x 0.001)	RH = (AH x 100) / (SH x 0.001)
Eq.#6	26	Compression Ratio = (Pressure_{psig} + 14.7) / 14.7	CR = (PSIG + 14.7) / 14.7
Eq. #7	27	Pressure_{psig} = - Height of Mercury_{in} x 0.4912	PSIG = in-Hg x 0.4912
Eq. #8	28	Vacuum Force_{lbs} = Negative Pressure_{psig} x $\text{Area}_{sq\text{-}in}$	VF = -P x A
Eq. #9	30	Air Leakage $\text{Cost}_{\$/min}$ = Flow_{cfm} x Time_{min} x Electricity $\text{Used}_{kWh/cu\text{-}ft}$ x Electricity $\text{Cost}_{\$/kWh}$	$ = cu-ft x min x (kWh/cu-ft) x ($/kWh)
Eq. #10	31	Line Drop_{in} = Line Run_{ft} x $\text{Grade}_{\%}$ x 0.12	LD = R x G x 0.12
Eq. #11	35	Receiver Volume_{gal} = (K x scfm x 7.48) / CR	VR = (K x SCFM x 7.48) / CR
Eq. #12	40	$C_v = \text{Flow}_{scfm} / 22.67 \times \sqrt{T_{°Rankine} / [(P\ in_{psia} - P\ out_{psia})K]}$ Where: K = $P\ out_{psia}$ if Δp =< 10% of $P\ max_{psia}$ K = ($P\ in_{psia}$ + $P\ out_{psia}$) / 2 if Δp = 10 to < 25% K = $P\ in_{psia}$ if Δp >= 25%	$Cv = Q/22.67\sqrt{T / [P_{in} - P_{out}) K}$
Eq.13	41	Receiver Supply Time_{min} = [Receiver $\text{Volume}_{cu\text{-}ft}$ x ($P\ max_{psia}$ – $P\ min_{psia}$)] / (Flow Rate_{scfm} x 14.7)	$T = [V \times (P_{max} - P_{min})] / (Q \times 14.7)$

Reference Equations

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Equations	**Page #**	**Equation**	**Equation**
Eq. 14	42	Pressure Drop_{psid} = (Receiver Pressure_{psig} – Tool Pressure_{psig}) / Line Distance_{ft}	PSID = (RP – TP) / D
Eq. 15	43	Force_{lbs} = Pressure_{psig} x $\text{Area}_{sq\text{-}in}$	P = F x A
Variations on Eq. 15:		$\text{Area}_{sq\text{-}in}$ = Force_{lb} / Pressure_{psig} Pressure_{psig} = Force_{lb} / Area_{in}	A = F / P P = F / A
Eq. 16	43	$\text{Area}_{sq\text{-}in}$ = Diameter^2 x 0.7854	A = D^2 x 0.7854
Eq. 17	43	Annular $\text{Area}_{sq\text{-}in}$ = Piston $\text{Area}_{sq\text{-}in}$ – Rod $\text{Area}_{sq\text{-}in}$	AA = PA – RA
Eq. 18	44	SCFM = (Compression Ratio x $\text{Area}_{sq\text{-}in}$ x Stroke^{in} x Strokes/Cycle x Cycles/Minute) / 1728	SCFM = (CR x A x S x SPC x CPM) / 1728
Eq. 19		Electromotive Force_{volts} = Currentamps x Resistance_{Ohms}	E = I x R

Pneumatic Symbols

Graphic symbols tested on the Pneumatic Technician exam are taken from ISO 1219 Fluid Power Systems and Components - Graphic Symbols. Some differences exist between these symbols and those given by USAS Y-32.10 USA Standard Graphic Symbols for Fluid Power Diagrams, that conform to the standards accepted by ANSI and NFPA, and to others that are commonly used, such as DIN 24300.

A number of graphic symbols that are used most often in pneumatic circuits are explained here. These symbols are also a representative sample of those tested by the exam.

Outcome 1. **Identifies graphic symbols for pressure control and flow control valves.**

Pressure regulators control actuator force. This is done by maintaining a constant output pressure downstream from a variable inlet pressure source upstream, provided the upstream pressure source remains higher than the required outlet pressure. Pressure regulators are shown, typically, as a square envelope with the internal line aligned with the external line, meaning that the regulator is normally open, regulated closed. The internal line has arrows on both ends, meaning that air can flow in both directions, with the pilot line connected between the downstream line to the actuated control and the side of the symbol, meaning that pressure is controlled from the downstream side of the regulator. If the pressure regulator is equipped with a vent, it means that the unit will compensate and vent over pressure air when the outlet pressure is reset to a lower pressure. Non-vented pressure regulators require venting an outlet to dispose of over pressure air when the regulator is set to a lower pressure. An external pilot line is connected opposite the internal pilot line if remote control is desired. Differential pressure control and proportional pressure control are shown by pilot lines connected to the regulating actuator from both upstream and downstream lines. Notice that differential and proportional pressure regulators are normally non-passing.

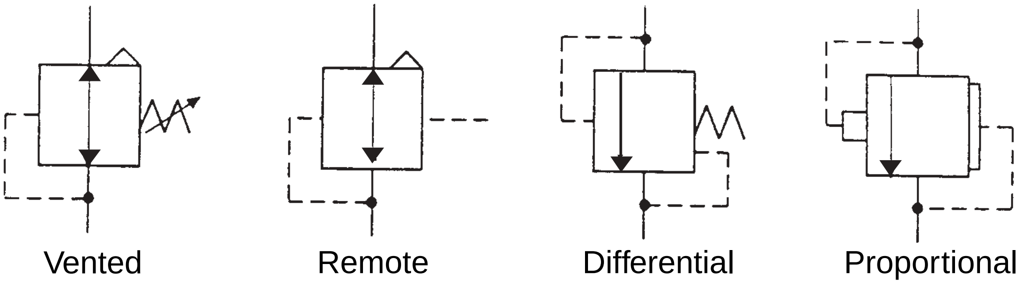


Fig. 1. Vented, remote, differential, and proportional pressure control valves.

Review: 1.1.
How is the vent (relieving) feature shown on one or more of the regulator symbols in Fig. 1?

a. Arrow drawn at 45 degrees
b. Spring shown opposite pilot
c. Internal line with one arrow head
d. Open triangle attached to the square box
e. Pilot connected to the downstream line

Outcome 2. **Understands that port connections in directional control valve symbols count as ways.**

Pneumatic directional control valves stop, start, and redirect the flow of air. The number of positions are shown as rectangular envelopes, with the lines and arrows giving the direction of flow when the valve assumes the various positions. Two position valves have two envelopes. Three position valves have three envelopes, and so on. The lines within the position envelopes indicate the number of flow paths the valve can provide. This is commonly referred to as "ways": for example, a two-way valve has two flow paths, but this is not universally accepted. The accepted designation is to count the number of port openings, excluding pilot ports, followed by positions. For example, a 3/2 valve has three port connections and two operating positions, while a 4/3 valve has four port connections and three operating positions.

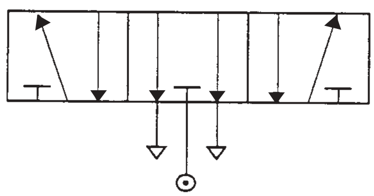
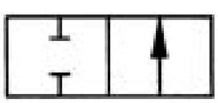
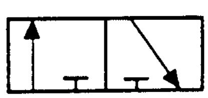
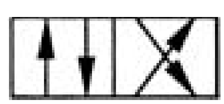


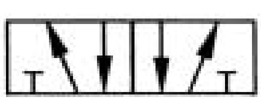
Fig. 2. Basic symbol for five port, four way, three-position directional control valve with exhaust center.

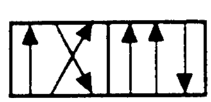
Review 2.1
Which one of the symbols is a four way, two position valve (4/2)?

a. 

b. 

c. 

d. 

e. 

Outcome 3. **Recognizes that blocked center, pressure center, and exhaust center are the most common center conditions for three position**

pneumatic directional control power valves.

Outcome 4. **Distinguishes between pneumatic blocked center, pressure center, and exhaust center three-position directional control power valve symbols.**

The three most common center positions for pneumatic directional control power valves are blocked center, pressure center, and exhaust center. A blocked center position valve has all ports closed in the center position. A pressure center valve connects the pressure port to the A and B ports in the center position. An exhaust center valve blocks the pressure port and directs the A and B ports to atmosphere, allowing the actuator to coast or float.

Blocked center valves may be used to hold a double-acting cylinder at some intermediate position, or to stall a rotary actuator. Of course, the spongy nature of air affects the accuracy and load holding capacity as does leakage.

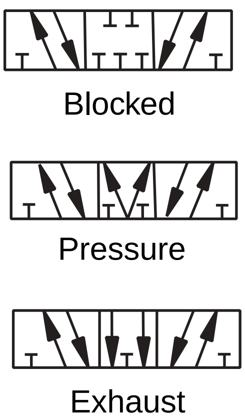


Fig. 3. Blocked Center, Pressure Center and Exhaust Center Directional Control Valves.

Pressure center valves can be used to control two single-acting cylinders. In the center position, both cylinders would extend. In one extreme position one cylinder would reverse, while in the other extreme position, the other cylinder would reverse.

Exhaust center valves can be used to allow a double-acting cylinder to free-float. That is, the load would take over to move the cylinder.

Blocked center valves show all five ports blocked in the center position. Pressure center valves show two lines connected at the pressure port, with the arrows pointing to the A and B ports. Exhaust center valves show the pressure port blocked and two lines connected at the A and B ports, with the arrows pointing to the respective exhaust ports.

Outcome 5. **Recognizes flow paths through pneumatic directional control valves in different positions.**

Review: 3.1.
Which center position would allow a reversible air motor to coast in the center position?

a. Open center
b. Closed center
c. Tandem center
d. Exhaust center
e. Pressure center

Review: 4.1.
A three-position, exhaust center, directional control air valve connects:

a. two cylinder ports to both exhaust ports.
b. one pressure port to both exhaust ports.
c. two cylinder ports to one exhaust port.
d. one pressure port to both cylinder ports.
e. two pressure ports to both cylinder ports.

Review: 4.2.
A three-position, pressure center, directional control air vavle connects:

a. two pressure ports to both cylinder ports.
b. one pressure port to both cylinder ports.
c. two cylinder ports to one exhaust port.
d. one pressure port to both exhaust ports.
e. two cylinder ports to both exhaust ports.

Outcome 6. **Identifies symbols for various directional control valves.**

Directional control valves that use the square envelope symbol for the various positions, with lines and arrows inside the squares to describe the flows paths, are read using a systematic procedure. The number of ports is identified first, followed by the number of positions. Then the various flow paths of the numbered ports are identified in each position.

The ports on directional control power valves are identified using a standard numbering system. The pressure port is labeled 1. On a five port valve, the remaining odd numbered ports, 3 and 5, identify the exhaust ports, and the even numbers (2 and 4) identify the outlet ports, sometimes referred to as the A and B ports. Shifted positions of the valve connect port 2 to port 3 in one position, and port 4 to port 5 in the reverse position. Pilot control ports are identified as 10, 12, and 14.

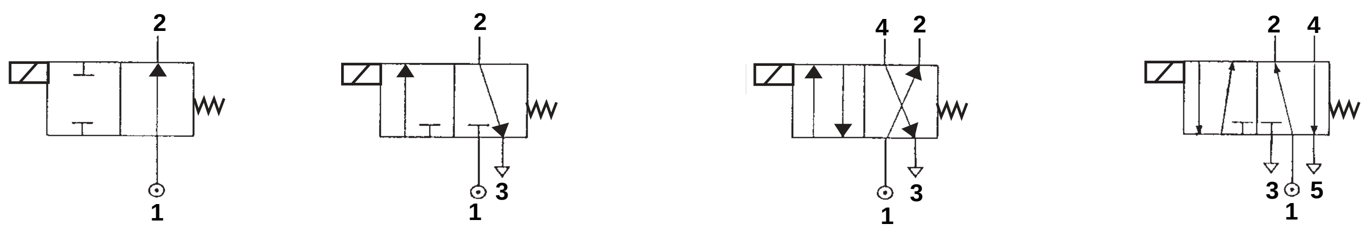


Fig. 4. 2/2 valve, 3/2 valve, 4/2 valve and 5/2 valve port numbering.

Check valves are easily identified, but when the check valve is incorporated into components such as shuttle valves and quick exhaust valves, the function of the check is less obvious.

Quick exhaust valves, for example, incorporate a check valve to increase circuit speed by exhausting a double-acting air cylinder directly to atmosphere on the return stroke without the pressure losses that accompany running the exhaust air back through the directional control valve. Quick exhaust valves look like shuttle valves, but operate like a three-way directional control valve. In a typical application, when pressurized air is directed to extend the cylinder, the check valve closes the valve exhaust port and routes air to the blind end to extend the cylinder at a pressure determined by the load. When the cylinder retracts, air exiting from the blind end pilot operates the check valve to open the free-flowing exhaust port directly to atmosphere. Thus, the valve powers and exhausts a single port, the same as a three-way valve does, but uses a shuttle valve mechanism with an internal pilot to accomplish this task.

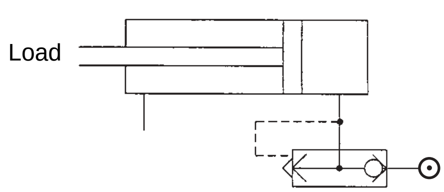


Fig. 5. Application of a quick exhaust valve.

Review: 5.1.

On a five port, two-position air valve, like that shown in Fig. 4, if port 1 is connected to port 2 in the normal position, what port is connected to port 1 when the valve is actuated?

a. 1 is connected to 2
b. 1 is connected to 3
c. 1 is connected to 4
d. 1 is connected to 5
e. None, Port 1 is blocked.

Review: 6.1.

The position of the check in the quick exhaust valve shown in Fig. 5. indicates that the cylinder is:

a. holding
b. extending
c. retracting
d. exhausting
e. decelerating

Outcome 7. **Recognizes component operation from its graphical symbol.**

Graphic symbols also can be used to show how a component operates. Simplified symbols are the easiest to recognize because only the basic function is shown. Detailed symbols are more difficult to recognize and understand because they show how the component operates inside an enclosure. This is accomplished by connecting a number of components to make up a circuit. To identify a detailed symbol, simply trace the circuit to understand how it functions. The function can then be associated with the simplified symbol.

A filter-regulator-lubricator (F-R-L) is a common example. The simplified symbol is a rectangle with two ports that shows a dotted line for the filter, circle with an arrow for the regulator, and short line at the top for the lubricator. The direction of flow is from left to right.

The detailed symbol shows three separate symbols within the valve envelope. The filter is shown as a diamond shaped with the ports connected to two diagonal corners, and the filter element as a dotted line between the other two diagonal corners. The basic diamond shape is used to represent fluid conditioning components such as filters, water traps, lubricators and air dryers. If the FRL unit has a combination filter and water separator, the water separator will be located before the filter element because the water must be removed before the unit can filter the air. The pressure regulator is shown as a rectangle. It is recognized as a pressure regulator because the pilot control connects to the downstream line. The valve is normally passing because the line with arrow is shown connected to the ports, and is held open by the spring at the top. A gauge is shown that reads the downstream pressure. To indicate that the pressure is adjustable, a line with an arrow is drawn through the valve spring at a 45 degree angle. The pressure setting balances downstream pressure against the force of the spring. The pressure at the downstream port will remain at the setting as long as there is sufficient resistance at the outlet to create that pressure, and the upstream pressure remains above the value of the setting.

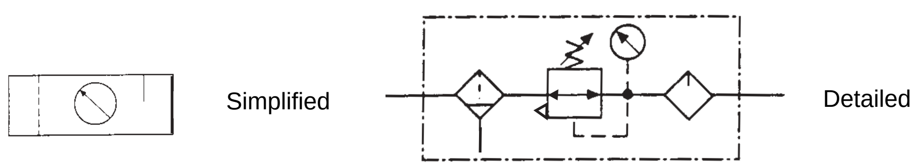


Fig. 6. Simplified and detailed symbols for an FRL.

The lubricator is the last component in the envelope. It is shown as a diamond with a short line at the top, indicating that oil is dripped or syphoned into the airstream, usually by passing the airstream through a venturi.

Another common example of simplified and detailed symbols is the shuttle valve shown in Fig. 7. A shuttle valve delivers an output from one of two inputs. In this case an output will result from a pressure source input at P_1 or P_2. This is a typical two station control circuit. That is, applying a pressure source to either P_1 or P_2 will deliver an output. When pressure is applied to P_1, the check seals P_2, and air is delivered to the output. When pressure from P_1 is discontinued and pressure is applied from P_2, the check will move up to seal P_1 and air will flow from P_2 to output. If a pressure source is applied to P_1 and P_2 at the same time, the valve will pass the air from the highest pressure source. If both sources have the same pressure, the valve will hold its present position.

The detailed shuttle valve symbol shown in Fig. 7 is a pilot operated, three port, two position valve that operates the same as the valve shown in the simplified symbol. Notice that the pilot operators connect to the pressure ports. When pressure is applied from P_1, the valve is shifted to deliver air from P_1 to the output. When pressure from P_1 is discontinued and pressure is applied from P_2, the lower pilot shifts the valve to deliver air from P_2 to the output. Again, applying a pressure source to P_1 and P_2 at the same time will not shift the valve.

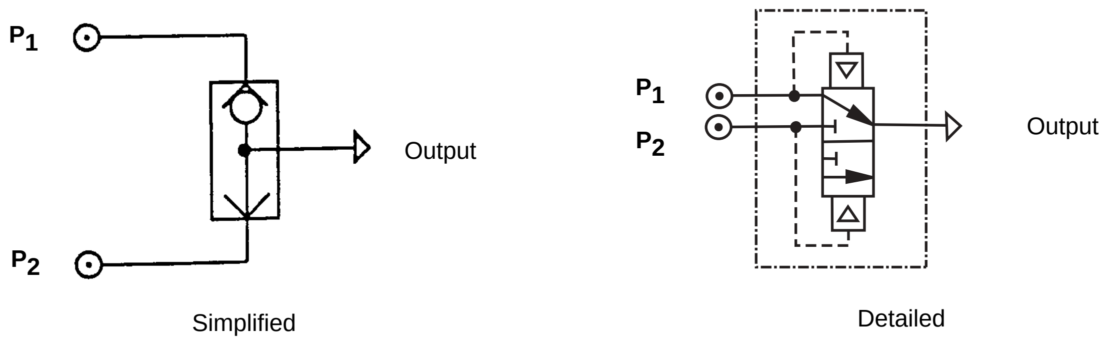


Fig. 7. Simplified and detailed symbols for shuttle valve.

Review: 7.1.
Where is the water separator located in an FRL unit?

a. Before the filter element.
b. After the filter element.
c. After the regulator.
d. After the lubricator.
e. At the drain tap.

Review: 7.2.
Which of the following applications would use a shuttle valve like that shown in Fig. 7?

a. Quick exhaust.
b. Safety release.
c. Quick disconnect.
d. Two station control.
e. Pressure relief valve.

Outcome 8. **Recognizes purpose and function of an excess pneumatic flow control valve (OSHA Regulation for construction. Part 1926.302, April 6, 1979.)**

Excess flow control valves are installed at the receiver and at 100 ft. intervals in air lines larger than 1/2 inch. They prevent injury to personnel from whipping should the hose lose a fitting or become severed. When there is a break in the hose, the sudden loss of air at the outlet of the valve increases the flow through the valve and pressure drops across the valve. The sudden rush of air and pressure drop actuates the spring loaded poppet or cartridge element to close the valve. The valve will remain closed until the pressure is equalized. After the excess flow control valve has closed, the shut-off valve at the receiver upstream of the excess flow valve would be closed. This would allow the excess flow control valve to reset (passing). Repairs would be made to the line, and then the shut-off valve would be opened. The system would function normally, until another break in the line causes the excess flow valve to close. Excess flow control vaves are sometimes called velocity checks, overspeed checks, or velocity fuses, and may be adjustable for the flow rate at which they will close.

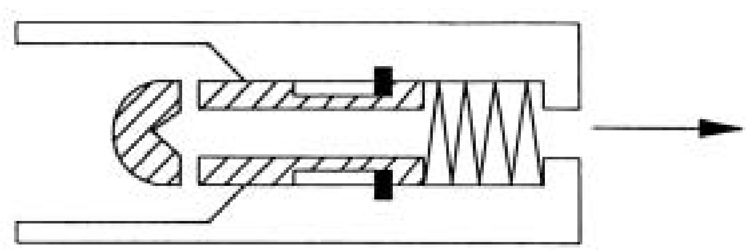


Fig. 8. Excess flow control valve.

Review: 8.1.
Excess flow control valves are designed to reduce:

a. costs.
b. injuries.
c. air consumption.
d. air hose length.
e. air line pressure drop.

Gas Laws

Outcome 9. **Converts temperature measurement to absolute values.**

Most calculations involving gases require the use of absolute values for pressure and temperature. When temperature changes must be accounted for, temperature values stated in Fahrenheit or Celsius must be converted to absolute values before proceeding with solving the gas calculation. Rankine is the absolute scale for Fahrenheit and Kelvin is the absolute scale for Celsius. The following equations cover these conversions:

˚F to ˚C:	˚C = (˚F –32) / 1.8	˚C to ˚F:	˚F = (˚C x 1.8) + 32
˚R to ˚F:	˚F = ˚R - 459.7	˚F to ˚R:	˚R = ˚F + 459.7
˚K to ˚C:	˚C = ˚K – 273.7	˚C to ˚K:	˚K = ˚C + 273.7
˚R to ˚K:	˚K = ˚R / 1.8	˚K to ˚R:	˚R = ˚K x 1.8

For most calculations where the Rankine scale is used, 459.7 may be rounded off to 460.

Review: 9.1.
What is the degree Rankine temperature of 125 °F?

a. 335 °R
b. 445 °R
c. 485 °R
d. 585 °R
e. 685 °R

Review: 9.2.
What is the degree Kelvin Temperature of 93˚C?

a. 126
b. 184
c. 223
d. 366
e. 485

Review: 9.3.
What is the degree Fahrenheit temperature of 585˚ R?

a. 90˚F
b. 110˚F
c. 115˚F
d. 125˚F
e. 140˚F

Outcome 10. **Converts pressure measurement between psig (gauge) and psia (absolute).**

The relationship between gauge pressure (psig) and absolute pressure (psia) is given by:

psi = psia - 14.7 or psia = psi + 14.7 (Eq. 2)

Review: 10.1.
A pressure gauge reads 110 psig. What is the pressure in psia?

a. 85.3 psia.
b. 95.3 psia.
c. 104.7 psia.
d. 110.7 psia.
e. 124.7 psia.

Review: 10.2.
A pressure gauge reads 0 psig. What is the absoute pressure in psia?

a. 0 psia.
b. 7.2 psia.
c. 14.7 psia.
d. 21.4 psia.
e. 28.6 psia.

Outcome 11. **Understands relationships given by Boyle's Law.**

Boyle's law relates the absolute pressure (P) and volume (V) of a given quantity of gas held at constant temperature:

$$P_1 \times V_1 = P_2 \times V_2 \qquad \text{(Eq. 3)}$$

Remember that the values for both pressure and temperature must be absolute values.

In a simple application, air at the initial pressure and volume is compressed into a smaller volume. This has the effect of raising the pressure. The piston in the cylinder shown in Fig. 9 would meet this condition. As the piston slides up in the bore it compresses the air, and as it slides down in the bore the air volume is increased. To meet the conditions of Boyle's law, the temperature would have to remain constant, no heat would be generated, and the piston seal would have to be leak-free. A slow moving piston might approximate these conditions.

A more accurate example would be compressed air held in a receiver at an initial pressure P_1 and volume V_1, which is allowed to escape slowly through the outlet valve until some lower pressure P_2 is reached. Notice in this example that V_1 will be larger than V_2 after some air has escaped. A variation on this calculation is to calculate the pressure after an amount of air has been added to a reciever.

To solve problems using Boyle's law, set up the equation and then solve for the desired quantity using absolute pressure. Remember that 14.7 must be added to the gauge pressure when values are substituted in Eq. 3, and that 14.7 must be subtracted from the answer if the gauge reading is the desired value in the answer.

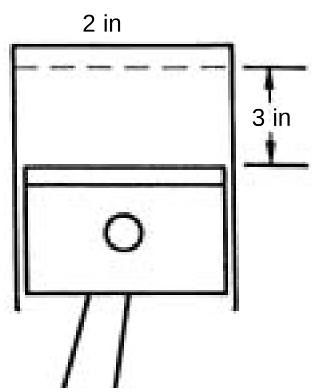


Fig. 9. Single stage compressor piston.

Review: 11.1.
A 2 inch diameter piston with a 3 inch stroke, like that shown in Fig. 9, compresses air at atmospheric pressure into a 2 cubic inch space at the top of the cylinder. Use Boyle's law to determine the pressure after the gas has been compressed.

a. 39.9 psig
b. 54.6 psia
c. 69.3 psig
d. 84.0 psig
e. 119.6 psia

Review: 11.2.
A compressor delivers 10 cfm for 2 minutes to a 50 gallon receiver. Assuming no losses, and that the reciever was empty, what is the final receiver gauge pressure at the ambient temperature?

a. 20 psig
b. 29 psig
c. 44 psig
d. 59 psig
e. 87 psig

Gas Laws

Outcome 12. **Understands pressure, volume and temperature relationships given by the ideal gas law $P_1 \times V_1 / T_1 = P_2 \times V_2 / T_2$.**

The ideal gas law relates the pressure, volume and temperature of an ideal gas as these variables change from one condition to another such that

$$\frac{P_1 \times V_1}{T_1} = \frac{P_2 \times V_2}{T_2} \quad \text{or} \quad P_1 \times V_1 \times T_2 = P_2 \times V_2 \times T_1 \qquad \text{(Eq. 4)}$$

Absolute values for pressure and temperature must be used in the calculation.

In a typical application, air is compressed by a piston from atmospheric pressure to some pressure determined by the compression ratio and, at the same time, is heated.

Review: 12.1.

If air at the inlet of a cylinder with a 3 inch bore and 3 inch stroke (like that shown in Fig. 9) is compressed into a 3.0 cubic inch space at the top of the cylinder, while the temperature increases from 70 °F to 120 °F, what would be the pressure when the piston is at the top of the cylinder? (Assume 100 volumetric efficiency and adiabatic conditions.)

a. 80.3 psia
b. 95.0 psig
c. 99.0 psia
d. 109.7 psig
e. 115.1 psig

Outcome 13. **Understands that the dew point of air is the temperature at which air is fully saturated with water.**

Outcome 14. **Determines the moisture content of air from pressure/temperature graphs.**

Outcome 15. **Understands the relationship between relative humidity, absolute humidity, and humidity at saturation**

Air from the atmosphere contains moisture. On humid days, more moisture is present. And on less humid days, less moisture is present. The amount of moisture in the air is measured in terms of relative humidity.

Relative humidity is defined as the ratio of the amount of water in the air to the amount of water the air will hold when saturated. The point of saturation is called the dew point. Dew point is defined as the temperature at which moisture will condense out of the air. The lower the dew point, the lower the temperature at which free moisture will condense and separate out of the air stream.

Review: 13.1.
Dew point must be reported as a given:
- a. volume.
- b. pressure.
- c. humidity.
- d. temperature.
- e. compression ratio.

When air is compressed in a receiver, a larger volume is squeezed into a smaller volume. This concentrates more water into the smaller space. And since one cubic foot of compressed air is only capable of holding the same amount of water vapor as one cubic foot of air at atmospheric pressure, when air is compressed, much of the water vapor condenses out. For example, air compressed to 100 psig contains about eight times the moisture of air in the atmosphere and, depending upon how much the temperature is lowered in the receiver, up to 90% of the moisture can be separated from the air at the receiver before it can cause problems in the system.

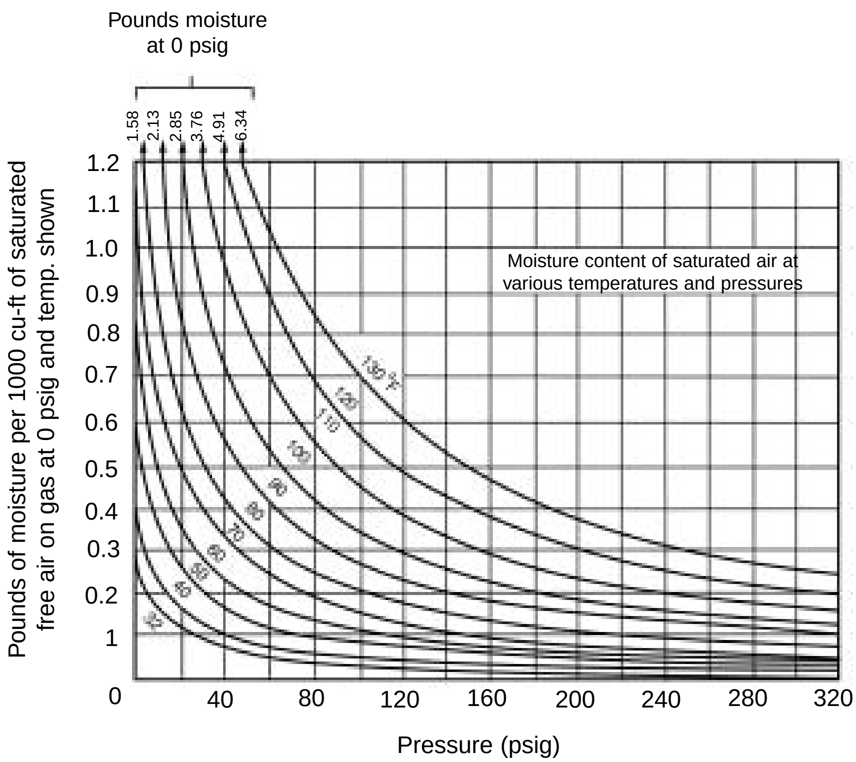


Fig. 10. Moisture content of saturated air at various temperatures and pressures - Reprinted from The Compressed Air and Gas Handbook.

The amount of moisture contained

in air is commonly determined from graphs like the one shown in Fig. 10. To use the graph, find the pressure to which the air has been compressed across the bottom, and the temperature of the compressed air on one of the curved lines in the graph. Then follow the curved line to determine the pounds of moisture for each 1000 cubic feet of air at zero psi gauge, which is the free air pressure. If the graph line intersects with the left margin, read the closest number directly from the margin.

Review: 14.1.
From Fig. 10, approximate how much moisture would 2000 cu-ft of free air contain at 90°F at its dew point.

a. 3.16 lbs
b. 4.26 lbs
c. 5.70 lbs
d. 7.52 lbs
e. 9.82 lbs

Review: 14.2.
If 1000 cubic feet of saturated air at atmospheric pressure and 80 °F is drawn into the inlet of a compressor and compressed to 100 psig, approximately how much water could be expected to be removed from the compressed air if the temperature is restored to 80 °F?

a. 0.20 lbs
b. 1.38 lbs
c. 1.58 lbs
d. 2.13 lbs
e. 2.85 lbs

The amount of humidity in air compared to the amount of moisture that air will hold at saturation (dew point) is called the relative humidity. It is calculated as the ratio of the absolute humidity to the humidity at saturation. That is:

$$\text{Relative Humidity}_{\%} = (\text{Actual Humidity}_{\text{lbs/cu-ft}} \times 100) / (\text{Humidity at Saturation}_{\text{lbs/1000 cu-ft}} \times 0.001)$$

$$RH = (AH \times 100) / (SH \times 0.001) \qquad \text{(Eq. 5)}$$

The amount of water vapor in lb/cu-ft at saturation for any given temperature can be determined from Fig. 10. Remember that the numbers given along the left margin and at the top for the temperature curves are for 1000 cu-ft, and to determine the amount of water vapor for 1 cu-ft, the decimal point must be moved three places to the left. For example, 1000 cu-ft of air at saturation and 90 °F contains 2.13 lbs of moisture, and 1 cu-ft of air at saturation and 90 °F would contain 0.00213 lbs of water vapor.

Review: 15.1.
At 80 °F, at saturation, air contains 1.58 lb/1000 cu-ft of water vapor. If a sample contains 0.00079 lb/cu-ft at 80°F, what is its relative humidity?

a. 20%
b. 30%
c. 40%
d. 50%
e. 60%

Outcome 16. **Understands the relationship between gauge pressure and compression ratio.**

The relationship between gauge pressure and compression ratio is given by:

Compression Ratio = (Pressure$_{psig}$ + 14.7) / 14.7 CR = (PSIG + 14.7) / 14.7 (Eq. 6)

If the output pressure of a single-stage compressor is given, the effective compression ratio can be computed by solving Eq. 6 for CR. As another practical example, if the compression ratio of a piston or diaphragm compressor is given, the maximum pressure that the compressor can develop is computed by solving Eq. 6 for psi. Maximum pressure in Eq. 6 occurs at 100% volumetric efficiency.

Review: 16.1.
A single-stage piston compressor develops 100 psi. Assuming 100% volumetric efficiency, what is the compression ratio of the compressor?

a. 5.8 to 1
b. 6.8 to 1
c. 7.8 to 1
d. 8.8 to 1
e. 9.8 to 1

Review: 16.2.
A compressor developes a pressure of 120 psig. What is the compression ratio?

a. 8.2:1
b. 9.2:1
c. 10.2:1
d. 11.2:1
e. 12.2:1

Outcome 17. **Understands the relationship between height of a column of mercury and negative psig (gauge) reading.**

Positive pressures above zero psi gauge are read in psig. Pressures below zero psig are read in inches of mercury (in. Hg.) or negative psig. In pneumatic systems, vacuum is used to power suction cups and vacuum shrink packing equipment.

The relationship between the negative head (suction) to lift a column of mercury and negative psi gauge reading is given by:

Pressure_{psig} = Height of mercury_{inches} x 0.4912   PSIG = in-Hg x 0.4912   (Eq. 7)

Which is derived from:

Negative Pressure_{psig} = (-height of mercury_{ft}/12”) x 13.56 x (62.4 lbs/gal-H_2O/144 sq-in/sq-ft)

13.56 is the specific gravity (SG) of mercury.

1 psig = 2” Hg (a good avgerage)   1” Hg = 0.4912 psi   1 psi = 2.04 in-Hg

Remember that the height of a column of mercury for pneumatic vacuum lifting or packaging purposes is caused by a vacuum or negative gauge pressure. It is a positive absolute pressure, but negative (below zero) gauge pressure. This is why the value of the psi gauge pressure reading in Eq. 7 is negative.

Review: 17.1.
For vacuum packaging purposes, what is the negative psig gauge reading of a column of mercury of 19 inches?

a. -4.55 psig
b. -8.10 psig
c. -9.33 psig
d. -11.91 psig
e. -19.91 psig

Outcome 18. **Determines the force and area relationships for vacuum pad applications.**

Vacuum pad lifting devices work the same as pressure lifting devices except that the gauge pressures are negative instead of positive. Negative gauge pressures available from vacuum pumps are also small in comparison to positive gauge pressures available from air compressors. This means that the cross-section areas of vacuum pads will be relatively large, compared to cylinders, to provide significant lifting forces.

The force available from a vacuum pad is determined from:

$\text{Vacuum Force}_{lbs} = \text{Negative Pressure}_{psig} \times \text{Area}_{sq\text{-}in}$ $\qquad VF = -P \times A \qquad$ (Eq. 8)

Review: 18.1.
How much vacuum would be required to give a 3 inch diameter vacuum pad application a lifting force of 50 pounds?

a. 11.5 in-Hg
b. 14.4 in-Hg
c. 15.2 in-Hg
d. 17.3 in-Hg
e. 19.6 in-Hg

Outcome 19. **Knows that flexible couplings are used to isolate compressor vibration from air piping system.**

There are a number of sources of noise associated with the compressor and piping system, including drive motor and frame vibration, compressor running noise, cooling fan, inlet and outlet air column vibration, relief valve noise, and whole system resonance. The remedy most often suggested is to mount the compressor in an enclosure designed to deaden the sound. This will suppress compressor noise, but will not isolate the noise from the air piping system.

One authority reports that the noise radiating from pipes can exceed the noise radiating from the compressor and drive motor. A major source of this noise is where metal pipes attach to metal building supports. Here misalignment and movement of the compressor transmit the noise to the building structure. Heavy wall pipes are less prone to vibration, but still transmit compressor noise to the building at the place of attachment, where they will resonate. Pipes can be mounted rigidly in cushions where they attach to the building, but this does not eliminate the noise. One way to isolate compressor noise from the building structure is to connect a flexible coupling between the compressor and the piping system. The coupling compensates for minor misalignment and isolates the compressor, because it will not transmit the vibration.

Outcome 20. **Computes cost of cfm leakage in a compressed air system.**

Air leaks are costly because the compressor must be operated to replenish the loss. Experience tells us that most air systems leak at several connections and at a few components. The question of how much air should be allowed to leak before the system is repaired varies by industry, the cost of isolating and fixing the leak, and the cost of shutting down the system to make repairs, if this is required. One source reports that when the loss exceeds 10% of the of the compressed air produced, the source of the leaks should be found and repaired.

The amount of air lost through a leak is computed as if the leak were passing air through an air line to the atmosphere without doing useful work. The cost equals the product of the volume, in cubic feet, times the cost to produce the air. That is:

$$\text{Air Leakage Cost}_{\$/min} = \text{Flow}_{cu\text{-}ft} \times \text{Time}_{min} \times \text{Electricity Used}_{kWh/cu\text{-}ft} \times \text{Electricity Cost}_{\$/kWh}$$

$$\$ = \text{cfm} \times \text{min} \times (\text{kWh/cu-ft}) \times (\$/\text{kWh}) \qquad \text{(Eq. 9)}$$

Review: 20.1.
A compressed air system leaks at the rate of 3 cfm. If it requires 0.02 kWh/cu-ft to compress the air, and the cost of electrical power is 0.04$/kWh, how much would the air leak cost per week if the system operated 24 hrs/day?

a. $3.46
b. $8.06
c. $12.10
d. $16.87
e. $24.19

Outcome 21. **Calculates inch drop per length of run from the percent grade for an air line.**

Air lines are sized to carry the required flow of air with less than a 10% pressure drop. They are also pitched downward 1% to 2% to drain moisture in the direction of flow to a moisture trap. The downward pitch away from the compressor allows the air flow to sweep away moisture that will settle out of the air stream to moisture traps at various drops.

The measured drop in an air line is computed from

$$\text{Line Drop}_{in} = \text{Line Run}_{ft} \times \text{Grade}_{\%} \times 0.12 \qquad LD = R \times G \times 0.12 \qquad \text{(Eq. 10)}$$

where the drop is measured in inches, the run is measured in feet, and the constant 0.12 converts inches to feet and percent drop to a decimal fraction.

Notice in Fig. 11 that the vertical leg to a pressure drop is taken off the top of the horizontal main line, and that the air tool connection is taken off the drop leg above the moisture trap. Moisture traps use manual or automatic valve drains to remove the moisture from the trap.

A 1% to 2% drop in an air main line is a 1.2 to 2.4 inch drop for a 10 foot section of pipe, or 0.12 to 0.25 inches per foot of pipe run.

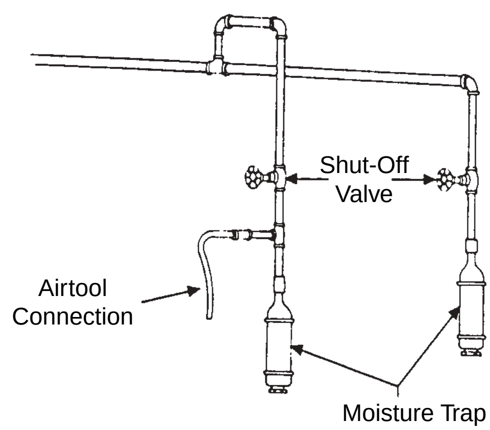


Fig. 11. Downward pitch in air piping system.

Review: 21.1.
How many inches will an air piping run with a downward pitch of 1.5% drop in 75 feet?

a. 11.25 inches
b. 13.50 inches
c. 22.25 inches
d. 26.00 inches
e. 41.75 inches

Outcome 22. **Associates methods of removing moisture from compressed air with costs.**

Compressed air can be dried by absorption, adsorption, and refrigeration.

Compressed air dryers are used to remove moisture from air, lowering the dew point of the air. The dew point is the temperature at which the air becomes 100% saturated with water vapor, at which point the water condenses out of the air to form liquid water.

The main methods used to dry air are absorption, adsorption, and refrigeration.

Deliquescent dryers contain a salt-based chemical which absorbs both vaporous water as well as liquid water from the air stream as the air flows through a bed where the salt is located. The resulting condensate and dissolved chemical is then drained off periodically. Generally, one pound of salt can absorb ten to fifteen pounds of water. Deliquescent dryers are capable of producing 25˚ dew point suppression air. This means that the dew point of the air exiting the dryer is 25˚ F lower than the temperature of the air entering the dryer. If the temperature of the air entering the dryer is 80˚ F, moisture will not form in the dried air as long at the air temperature remains above 55˚ F. For this reason, it is important to supply the dryer with the coolest possible air.

Desiccant dryers remove water by adsorbing moisture onto the surface of a desiccant such as silica gel or activated alumina. Silica gel is generally used in small housings located downstream of a filter-regulator assembly and serves just one machine. Typically, as silica gel adsorbs moisture, it turns from pink to blue so that its condition may be checked. Silica gel may be regenerated by heating it to drive off the moisture. Activated alumina is used in heatless twin-tower regenerative dryers. When one tower is drying the air, the other tower is being regenerated. This is achieved by directing a small amount of the dry air that exits the active tower into the other tower a reverse flow direction over the tower, regenerating it. The dry air flowing backwards through the saturated tower picks up moisture from the activated alumina. The moisture laden air is then vented to atmosphere. This operation is called purging. Heated regenerative (regen) dryers use heating coils or heated air when drying the inactive tower. Regenerative dryers are capable of producing air with a -40˚ F (or C) dewpoint.

Refrigeration dryers remove moisture by lowering the dew point. Remember that the dew point is the temperature at which moisture will condense out of the air. Thus, lowering the temperature, reduces the capacity of the air to hold moisture.

The refrigeration cycle lowers the temperature of moist air from the compressor to remove the moisture. The air is then reheated before leaving the outlet of the dryer by a heat exchanger that recovers heat from the warm moist air entering at the inlet. This also reduces the temperature of the inlet air. The heat exchanger that recovers heat for the outlet air, and reduces the temperature of the inlet air, reduces the required heat sink capacity by 60%.

Excluding initial investment, refrigeration is the least expensive method of drying compressed air. Typical operating costs are less than 15% of the most expensive method. Adsorption drying is the most expensive method of drying cold air because of the cost of regenerating the desiccant. Adsorption drying and absorption drying costs are comparable for warm air.

Review: 22.1.
Which method of removing the moisture from compressed air has the lowest operating cost?

a. Adsorption.
b. Absorption.
c. Refrigeration.
d. Silica gel attachment.
e. Water separation sieves.

Components

Outcome 23.	**Knows that compressor delivery is expressed in cfm at <u>ambient conditions</u>, or scfm at <u>standard conditions</u> of 14.7 psia, 68 °F, and relative humidity of 36% (0.0750 density).**

Compressor delivery is given by manufacturers in cfm at ambient conditions, or scfm at standard conditions. These two measures of flow rate have different meanings.

Ambient conditions describe the pressure caused by elevation, barometric conditions, and relative humidity as they exist at a particular location. They are measured with instruments. Standard conditions describe a pre-determined set of conditions. They are computed by correcting ambient conditions. A review of standard conditions will help to understand the difference between the two.

Air has mass and exerts pressure on the surface of the earth. A barometer, consisting of an inverted tube closed at the top, will support a column of mercury (Hg) at exactly 760 mm (29.92 inches) at sea level when measuring standard conditions at °F. Since mercury has a specific gravity of 13.6, this is the equivalent of (29.92 in-Hg x 13.6/12")= 33.897 feet of water or (0.433 x 33.8971)= 14.677 psia. Thus, standard pressure is usually taken to be 14.7 psia, or 0 psi gauge.

Gauge pressures (psig) above atmospheric conditions are read as positive gauge pressures, whereas gauge pressures below atmospheric conditions are read with a negative sign. By convention it is understood that positive gauge pressures do not include local atmospheric conditions, and when absolute pressure is used to solve problems, it is signified as psia or P absolute.

While barometric changes caused by altitude, weather conditions and relative humidity affect atmospheric conditions only slightly (about 2.5% per 1000 ft), this too must be considered when computing the air delivery from the compressor.

Standard air and air flow (scfm) are defined at a temperature of 68 °F, a pressure of 14.7 psia, and relative humidity of 36% (0.0750 density). This is in agreement with definitions adopted by ASME, although in the gas industries the temperature of standard air is usually given as 60 °F. Because the size of the relative humidity correction factor is small, it is usually ignored. Thus, most problem solutions correct the pressure to 14.7 psia and the temperature to 60 °F or 68 °F.

Review: 23.1.

Compressor ratings in scfm refer to:

a. free air.
b. displacement.
c. pressurized air.
d. ambient conditions.
e. standard conditions.

Outcome 24. **Understands that compressor cfm is measured flow rate at the intake (ambient conditions), and that scfm is calculated from measured flow rate (to standard conditions from ambient conditions).**

Air volume flow in cfm is free air at ambient conditions at the compressor intake. This means that cfm always refers to free air, no matter at what pressure it is given. Remember that free air is air at local atmospheric conditions. For example: if the delivery of a compressor is given to be 10 cfm at 100 psig, it means that 10 cfm of free air is entering the inlet of the compressor at ambient atmospheric conditions, even though the compressor is raising the pressure to 100 psig in the receiver. Knowing the delivery at a given pressure is useful because as pressure increases, the loss in volumetric efficiency of the unit will cause the delivery to decrease. The unit just described, for example, may deliver 11 to 12 cfm if the pressure is reduced to 50 psig, or 8 to 9 cfm if the pressure is increased to 125 psig.

Air volume flow in scfm is free air at standard conditions of 14.7 psia, 68 °F, and a relative humidity of 36% (0.0750 density). This is the ASTM standard, although many manufacturers use a temperature of 60 °F. Scfm is not measured directly, rather, cfm is measured at ambient conditions, and then corrected to standard conditions mathematically.

Therefore, scfm is defined as being measured at 14.7 psia (0 psig). In contrast, cfm may exist at any pressure, for example, 20 cfm at 100 psig. To convert cfm to scfm, calculate the compression ratio and multiply it by scfm (CFM = CR x SCFM)

Review: 24.1.
Which of the following is measured at the compressor inlet?

a. rpm
b. scfm
c. delivery in cfm
d. pressure in psig
e. displacement in cubic inches.

Outcome 25. **Recognizes rule of thumb that for continuous demand sytems, receiver capacity equals free cfm delivery from the compressor at working pressure and ambient conditions.**

Outcome 26. **Computes air receiver capacity from the constant (K), cfm delivery from the compressor, working pressure, and ambient conditions**

The size of the air receiver is determined from the compressor output, the volume flow required by the system, and the air demand cycle.

Remember that the receiver dampens out pressure pulsations, cools the air, which separates out condensation, and provides storage capacity for periods of high use or even power failure. The receiver does not create air, however, so that, over time, the compressor must produce as many or more scfm than the system consumes.

One common rule of thumb is to size the receiver for a continuous demand cycle to equal the scfm (free air delivery) capacity of the compressor at working pressure and ambient conditions. If a compressor delivers 25 scfm, the size of the receiver equals 25 cubic feet of free air, corrected to the absolute working pressure of the compressor. This would result in a reduction of 25 cubic feet by a factor equal to the compression ratio.

For intermittent demand cycle systems, the rule of thumb is to size the receiver to equal three times the delivery of the compressor at working pressure and ambient conditions.

Combining both rules of thumb to size an air receiver,

$$\text{Receiver Volume}_{gal} = (K \times scfm \times 7.48) / CR \qquad VR = (K \times SCFM \times 7.48) / CR \qquad \text{(Eq. 11)}$$

Use: K=1 if the demand is continuous, and K=3 if the demand is intermittent. The factor 7.48 converts cubic feet to gallons (1728 cu-in / cu-ft / 231 cu-in / gal).

Review: 26.1.

An air compressor that operates intermittently delivers 25 scfm compressed to 115 psig. If receiver size equals three times compressor delivery, what gallon size is the receiver?

a. 21.2 gal.
b. 36.4 gal.
c. 48.8 gal.
d. 63.6 gal.
e. 75.0 gal.

Outcome 27. **Associates friction factors with pressure losses in pneumatic valves.**

Outcome 28. **Associates friction factors with pressure losses in pneumatic fittings.**

Flow losses through valves and fittings are determined by manufacturers for each configuration. These friction factors are sometimes called K-values, and have been found to be relatively independent of valve and fitting size.

The significance of friction factors in pneumatic fittings and valves is that flow losses in the piping system represent wasted power at the compressor. Some losses are unavoidable, but using the right valve or fitting can keep flow friction losses to a minimum. Figure 12 lists the friction factors for common valves and fittings.

Shut-off valves are always positioned fully-open or fully-closed. This is done to reduce friction to a minimum and to prevent leaks around the valve stem. Never use a shut-off valve to regulate flow. Gate valves, for example, have a lower flow friction loss than either plug cock or globe valves in the full-open position, but have a higher flow friction loss when 3/4 closed. Some gate and globe valves seal the stem against leaks in the full open position. There is also a packing around the stem, but this is prone to leaks when the valve is left partially open.

Valve	**K-Value (friction factor)**
gate valve, fully open	0.19
gate valve, 3/4 open	1.15
gate valve, 1/2 open	5.60
gate valve, 1/4 open	24.00
globe valve	10.00
plug cock	0.26
swing check	2.50
Fittings	
45 degree elbow	0.42
90 degree elbow	0.90
standard tee, side outlet	1.80
close retun bend	2.20

Fig. 12. Friction factors for valves and fittings

Review: 27.1.
Which one of the following valves has the most friction in the full-open position?

a. Globe.
b. Angle.
c. Gate.
d. Plug cock.
e. Swing check.

Outcome 29. **Predicts directional control valve operation from performance curves.**

Manufacturers commonly include flow characteristic graphs with directional control valve literature so that performance can be predicted for different operating pressures.

The graph in Fig. 13 relates the operating pressure, scfm flow rate, and pressure drop for a specific valve. There are a number of ways to read the graph.

To determine the flow scfm, first locate the curve that represents the ideal operating pressure, and then move along the curve, up and to the right, until the curve intersects with the horizontal line leading to the left margin that gives the required air flow. Then look along the bottom margin to determine the pressure drop. If the pressure drop is greater than allowed, the next higher operating pressure is selected, and the process is repeated. To determine available scfm from a given valve, locate the operating pressure along the curves, and then the allowable pressure drop across the bottom. The available scfm flow rate is then given along the left margin.

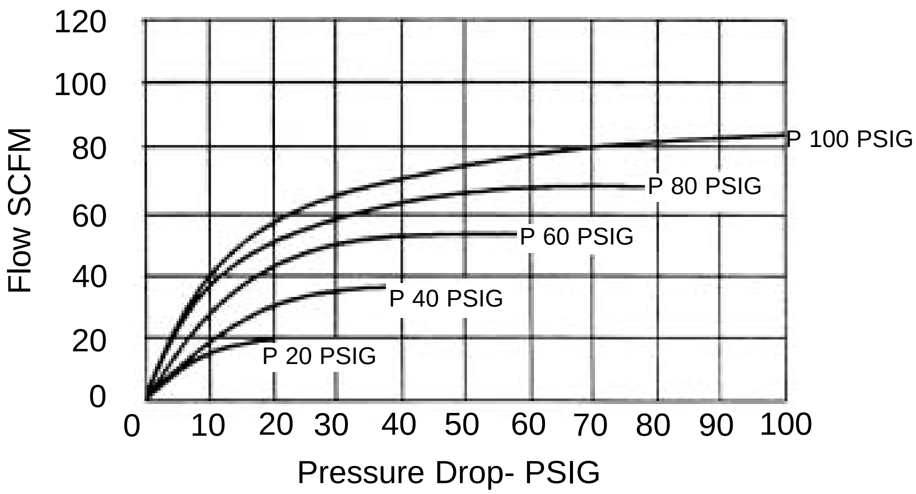


Fig. 13. Flow graph for directional control valve.

Review: 29.1.
Using the performance curve shown in Fig. 13, determine how many scfm the valve would deliver at an operating pressure of 100 psig, and still keep the pressure drop to less than 25 psig.

a. 80 scfm
b. 70 scfm
c. 60 scfm
d. 50 scfm
e. 40 scfm

Outcome 30.	**Understands that the flow capacity of directional control valves is in direct proportion to the C_V factor.**
Outcome 31.	**Calculates C_V, and flow rates for pneumatic valves.**

Traditionally, directional control air valves have been sized by port size, but this has been shown to be inaccurate from size to size, and from manufacturer to manufacturer. Consequently, this practice made it difficult to predict how much air a particular valve size would flow, and it did not allow comparisons between valves from different suppliers.

Flow coefficients standardize the flow capacity of air valves. This means that air valves from two manufacturers that have the same C_v will flow the same scfm of air under the same conditions.

C_v values are also proportional to the scfm that an air valve will flow. This means that an air valve with a $C_v = 2$ will flow twice the scfm that a valve will that has a $C_v = 1$.

Valve applications can be made from flow charts that solve for the C_v when the inlet port pressure and air flow are known, or from orifice formulas that have been modified to include C_v. Arriving at computed valves of C_v is slower because calculations are required, but they are more accurate because values for the inlet pressure, pressure drop, flow rate, and temperature approximate existing conditions, rather than the conditions given by the manufacturer.

Review: 30.1.

A flow control valve with a C_v rating of 0.2 will flow 7 scfm at 80 psi with a 10 psi pressure drop. What C_v rating would flow 14 scfm under the same conditions?

a. 0.1
b. 0.2
c. 0.3
d. 0.4
e. 0.5

There are a number of formulas that generate approximately the same results for the C_v of a directional control valve. The prefered formula is:

(Eq. 12)

$$C_V = Flow_{scfm} / 22.67 \times \sqrt{T_{\circ Rankine} / [(P\ in_{psia} - P\ out_{psia})K]} \qquad Cv = Q/22.67 \sqrt{T / [P_{in} - P_{out}) K}$$

Where: $K = P\ out_{psia}$ if $\Delta p <= 10\%$ of $P\ max_{psia}$

$K = (P\ in_{psia} + P\ out_{psia}) / 2$ if $\Delta p = 10$ to $< 25\%$

$K = P\ in_{psia}$ if $\Delta p >= 25\%$

Note: ˚Rankine = ˚Fahrenheit

Review: 31.1.

An air valve delivers 35 scfm at 70 °F with a supply pressure of 80 psig. If the valve has an 8 psig pressure drop, what is the C_v for the valve?

a. 1.30
b. 1.33
c. 1.35
d. 1.42
e. 1.46

Outcome 32. **Understands how pressure, air consumption rate, and time relate to air receiver size.**

The time that a receiver can supply air between a maximum operating pressure (P_{max}) and minimum acceptable pressure (P_{min}) is computed from

Receiver Supply Time_{min} = [Receiver $\text{Volume}_{cu\text{-}ft}$ x (P max_{psia} – P min_{psia})] / (Flow Rate_{scfm} x 14.7)

$$T = [V \times (P_{max} - P_{min})] / (Q \times 14.7) \qquad \text{(Eq. 13)}$$

Equation 14 is useful to verify that a receiver has sufficient capacity. It can also be used to determine how much air is lost from a system due to leaks.

The time that a receiver can supply air between a maximum and minimum pressure determines how often the compressor will switch on and off to replenish the air supply. Compressors of less than 25 hp that operate less than 50% of the time and cycle less than 5 to 7 times per hour typically use automatic stop-start controls. A cycle rate of 5 to 7 times per hour is about once every 10 minutes. Compressors that operate more than 50% of the time with a pressure control cycle rate of more than 5 to 7 times per hour normally use a constant speed pressure control. This allows the motor to run continuously, with pressure control provided by an unloading valve.

Review: 32.1.
Leakage causes the pressure in a 60 gallon receiver to drop from 140 psia to 110 psia in 10 minutes. How many cfm is the air leak?

a. 1.22 cfm
b. 1.64 cfm
c. 2.08 cfm
d. 3.57 cfm
e. 4.63 cfm

Outcome 33. **Calculates the pressure drop in an air line.**

When air flows from the receiver to an air tool there is always some pressure drop caused by flow friction through the pipe, fittings, valves, and hose. For a given air line size, the pressure drop increases as the flow rate increases. For a given flow rate, the pressure drop increases as line size decreases.

It is common practice to keep the pressure drop between the receiver and actuator to 10 percent of the pressure at the outlet of the receiver. If the pressure drop exceeds this maximum, the air tool is being starved, maximum power cannot be developed, and the line size should be increased. This could include increasing the size of the main line, branch line, or line between the branch line and the air tool. The pressure drop in smaller lines near the air tool should be checked first because the smaller the air line, the higher the pressure drop for a given flow.

The pressure drop to an air tool is given by:

$$\text{Pressure Drop}_{psid} = (\text{Receiver Pressure}_{psig} - \text{Tool Pressure}_{psig}) / \text{Line Distance}_{ft}$$

$$PSID = (RP - TP) / D \qquad \text{(Eq. 14)}$$

Review: 33.1.
If the pressure at the receiver is 125 psia, and the pressure at the air tool is 110 psia, what would be the maximum distance between the receiver and air tool to keep the pressure drop to 0.1 psid/foot?

a. 10 ft
b. 15 ft
c. 75 ft
d. 100 ft
e. 150 ft

Outcome 34. **Understands pressure and area relationships as they affect cylinder output force.**

Pascal's law states that static pressure in a confined space acts undiminished and at right angles to the walls of the container. This means that the pressure acts in all directions against the inside of the cylinder. The output force, however, results only from the positive pressure that acts on the movable area of the cylinder, which is the piston.

Neglecting friction, the output force available from a cylinder equals the product of the positive gauge pressure and moveable area. That is:

$$\text{Force}_{\text{lbs}} = \text{Pressure}_{\text{psig}} \times \text{Area}_{\text{sq-in}} \qquad P = F \times A \qquad \text{(Eq. 15)}$$

Variations on Eq. 15:

$$\text{Area}_{\text{sq-in}} = \text{Force}_{\text{lb}} / \text{Pressure}_{\text{psig}} \qquad A = F / P$$

$$\text{Pressure}_{\text{psig}} = \text{Force}_{\text{lb}} / \text{Area}_{\text{in}} \qquad P = F / A$$

Knowing two of three variables in Eq. 16 allows for the solution of the third. Typical problems are:

1. Given the cylinder bore, rod diameter size, and air pressure, solve for the maximum force available from the cylinder, both extending and retracting.

2. Given the air pressure and required extension and retraction forces, solve for the bore of the cylinder and rod diameter.

3. Given the required extension or retraction forces, and bore and rod diameters of the cylinder, solve for the air pressure to extend and retract the cylinder.

To solve for the bore area and the annular area of a cylinder:

$$\text{Area}_{\text{sq-in}} = \text{Diameter}^2 \times 0.7854 \qquad A = D^2 \times 0.7854 \qquad \text{(Eq. 16)}$$

$$\text{Annular Area}_{\text{sq-in}} = \text{Piston Area}_{\text{sq-in}} - \text{Rod Area}_{\text{sq-in}} \qquad AA = PA - RA \qquad \text{(Eq. 17)}$$

Review: 34.1.
A 1.5 inch bore single rod air cylinder has 105 psig at the inlet port. Neglecting friction, what is the maximum force available from the cylinder when the rod extends?

a. 46.7 lb
b. 59.4 lb
c. 85.2 lb
d. 157.5 lb
e. 185.6 lb

Outcome 35. **Computes the scfm required to power an air cylinder.**

The air flow required to power an air cylinder is computed as free air (scfm) at 14.7 psi absolute pressure and ambient atmospheric conditions. Cylinder rod volume is ignored since the rod size for air cylinders is usually small compared to the bore.

Delivery of free air volume from the receiver to power an air cylinder is given by:

SCFM = (Compression Ratio x $Area_{sq\text{-}in}$ x $Stroke^{in}$ x Strokes/Cycle x Cycles/Minute) / 1728

SCFM = (CR x A x S x SPC x CPM) / 1728 (Eq. 18)

Review: 35.1.
A 1.5 inch bore single-acting cylinder that extends through a 3 inch stroke, cycles at 15 cpm on 85 psig air. How many cfm will the cylinder displace?

a. 0.27 cfm
b. 0.31 cfm
c. 0.48 cfm
d. 0.53 cfm
e. 0.62 cfm

Outcome 36. **Associates pneumatic valve type with operation.**

Knowing how a component operates by looking at the graphic symbol was discussed in Outcome 7. In this outcome, we are interested in associating the type of valve with how it operates in a circuit. There is some overlap between the two outcomes which bears repeating.

Air valves are designed to serve specific purposes. This gives them unique operational characteristics. Following are common examples that illustrate how the type of valve is derived from the function that the valve performs.

Shuttle valves can be used for two station control or priority station control. The control signal is provided from one of two input sources, whichever has the higher pressure. Supplying an air signal at either port 1 or port 2 will result in a signal at the outlet port. If air is applied to both port 1 and port 2 at the same time, the signal with the highest pressure will shift the shuttle valve and exit the outlet port. Thus, priority is given to the signal with the highest pressure. If the pressure of the two sources is equal, the shuttle valve will remain actuated in the original position.

Two pressure valves, while not available from all manufacturers, also provide control from two input sources. They are used to interlock controls. Two input sources are necessary to have a signal at the output. Supplying an air signal to only one inlet closes the valve and there is no output signal. If two input signals of the same pressure are not received at the same time, the output will receive the last signal. If two input signals are received that have different pressures, the valve will permit passage of the signal with the lower pressure. Thus, two signals are required to achieve an output, with the lower pressure signal receiving priority. This feature interlocks the valve to provide a two-pressure control function. These valves are often termed two-hand anti-tie-down valves. They are frequently used on presses and other machinery where there is a need to ensure that both of the operator's hands are not in danger of being injured as the machine members close.

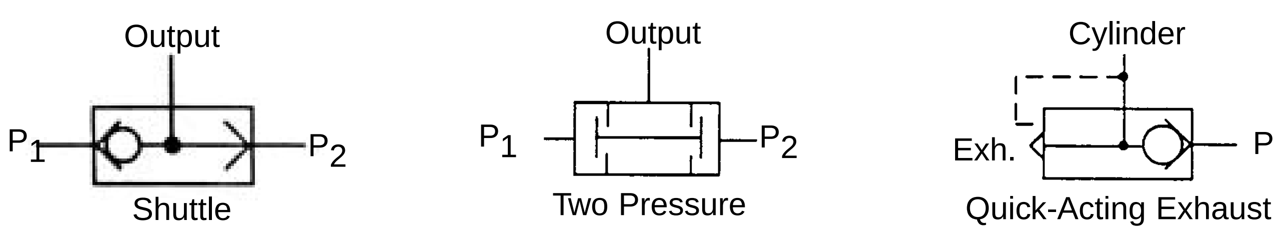


Fig. 14. Shuttle valve, two-pressure valve, and quick exhaust valve symbols compared.

Quick exhaust valves relieve cylinder back-pressure on the retraction stroke of a cylinder to permit rapid return. The symbol for a quick exhaust valve incorporates the action of a shuttle valve, but operates as a three way valve, pressurizing and exhausting an actuator port.

Three common ways to actuate (operate) directional control valves are by manual or mechanical force, by pilot actuation, and by the use of solenoids. Examples of a manual input are hand levers and foot treadles. Cam operators are an example of a mechanical operator. Pilot operation is achieved by using a pressurized fluid, generally air, to work against the movable element of the valve. In a direct solenoid operated valve, the solenoid armature (plunger) acts directly on the spool or poppet. In a solenoid pilot operated valve, a 3/2 pneumatic valve alternately directs pressurized air against, or vents the pressurized air away from, the movable element of the valve. The use of solenoid pilot operators helps keep the solenoid assembly small, saving electrical power, yet the main section of the directional valve can be of a large size in order to control large flow rates of air. All three types of operators are typically used with spool and poppet style valves because the required motion is linear. Some valves, such sliding shear, butterfly, and ball valves, all of which require a rotary motion to operate, are generally equipped with manual or mechanical, fluid, or electrical operators.

Review: 36.1.
Which of the following statements is true for the two pressure valve shown in Fig. 14?

a. The output signal requires one input signal.
b. The lowest pressure input flows to the outlet.
c. The first pressure input flows to the outlet.
d. The valve works the same as a shuttle valve.
e. The valve checks reverse flow.

Outcome 37. **Understands that pneumatic signal output units (valves) must match working units (cylinders and motors).**

A pneumatic circuit contains 1. working units (actuators), 2. signal output components (directional control valves), 3. signal processing components, 4. signal input components (pilot valves), and 5. supply components (service unit, shut-off valve, and reversing valve).

The signal output from the directional control powers the actuator. This requires that the directional control valve must match the requirements of the actuator. For example, a 3/2 (three port, two position) directional control valve is used to power and exhaust a single-acting, spring returned, cylinder. And a 4/2 (four port, two position) valve is used to power a double-acting cylinder. Applying this requirement to rotary actuators, a 3/2 directional control valve would operate a unidirectional air motor, allowing it to coast to a stop, and a 4/3 (four port, three position) directional control valve would operate a bi-directional air motor forward and reverse, with a free-wheeling center position.

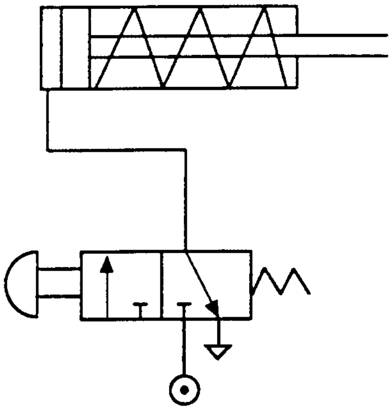


Fig. 15. 3/2 valve connected to operate a single-acting cylinder.

Review: 37.1.
Which directional control valve would be used to extend, hold and retract the single-acting air cylinder shown in Fig. 15?

a. 1/1
b. 2/2
c. 3/2
d. 3/3
e. 4/2

Outcome 38: **Recognizes that various signal output units (valves) can alter operating characteristics of working units (actuators).**

The types of directional control valves used, and how they are connected in the circuit, affect the operating characteristics of the actuator.

For example, the circuit in Fig. 16 uses a four port, three position directional control valve with a closed center. This valve would allow the cylinder to have three positions: full extension when the valve is shifted to the left, full retraction when the valve is shifted to the right, or some intermediate position when the valve is centered at mid-stroke.

Fig. 17 illustrates the use of two three-way valves to make up a four way valve. The circuit has four possible operating positions. With the valves in the positions shown, air will enter the rod end, exit the blind side, and cause the cylinder to retract. Depressing both valves will permit air to enter the blind side, exit the rod end, and extend the cylinder. Depressing only valve A will cause air to enter the blind side, but not to exit the rod side which is already pressurized. Because the blind side of the cylinder has a larger area, the cylinder will extend at reduced force. The rod will stop moving when the combined force of the load on the rod and the force of the intensified air trapped in the rod end equal the force developed by the air acting on the blind side of the piston, unless of course, the rod fully extends first. Depressing only valve B will exhaust the rod end of the cylinder, allowing the cylinder to float.

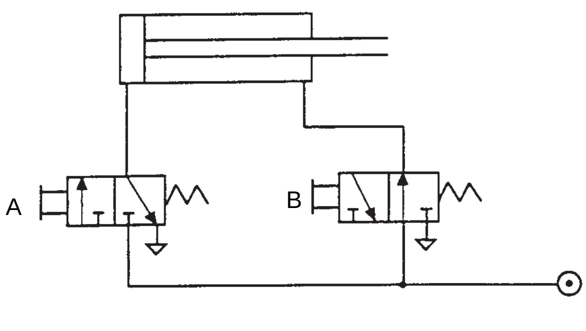


Fig. 17. Two three-way valves operating a cylinder.

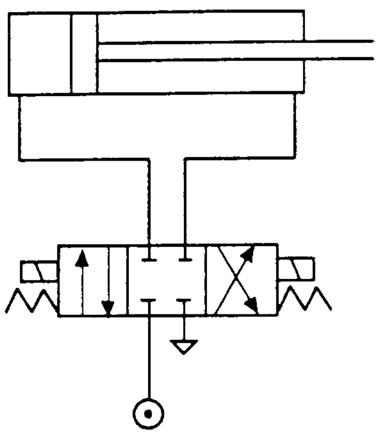


Fig. 16. Double-acting cylinder with three position valve.

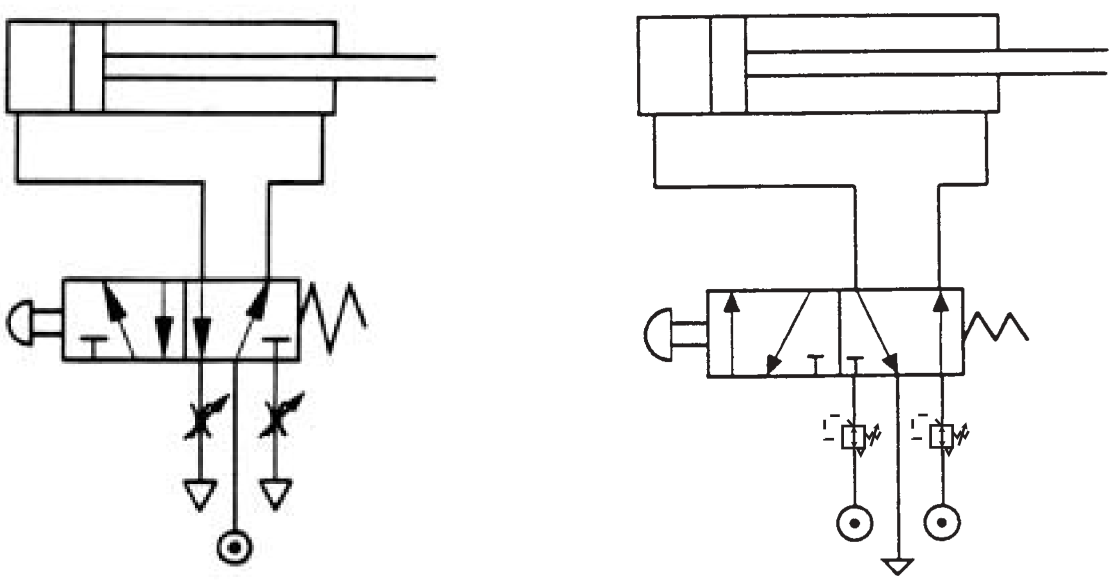
Review: 38.1.
Which valve position in Fig. 17 would cause the cylinder rod to extend at a reduced force from the retracted position?

a. Valve A actuated, valve B actuated.
b. Valve A deactuated, valve B actuated.
c. Valve A deactuated, valve B deactuated.
d. Valve A actuated, valve B deactuated.
e. None of the above.

Outcome 39. **Distinguishes between four-way and five-way plumbing of a four-way directional control valve.**

Four-way and five-way, two-position and three-position valves are used to pressurize and exhaust both ends of a double-acting cylinder. A center position can be used to allow the cylinder to coast if the valve has an open center, or to lock the cylinder if the valve has a closed center. Smaller valves can be operated directly by solenoid, but larger valves use solenoid valves to pilot operate the main spool because increased shifting forces are required.

Both valves in Fig. 18, are four-way valves. Valve A has one pressure port, two outlet ports that connect to the cylinder, and two exhaust ports. Installing a flow control valve in each exhaust port permits meter-out control of the extension and retraction strokes to meet specific conditions. For example, the cylinder can extend under load at one speed and retract under no load at another. Even though the valve has five ports, it is still classified as a four-way valve because both exhaust ports count as one return flow path.



A. Four Way

B. Five Way

Fig. 18. Four-way and five-way plumbing of a five-ported valve.

Valve B in Fig. 18 is a four-way valve plumbed as a five-way valve. It has two pressure ports, two cylinder ports, and one exhaust port. By having two pressurized ports, the valve can supply air at one pressure to extend the cylinder during the work portion of the cycle, and at another pressure to retract it, thus varying the force applied in each direction.

Review: 39.1.

A four-way directional control valve plumbed as a five-way directional control valve has:

a. two exhaust ports.
b. one pressure port.
c. one cylinder port.
d. two pressure ports.
e. three exhaust ports.

Outcome 40. **Recognizes that pneumatic limit valves signal the control system when an event has taken place.**

Limit valves are operated by a cam plate on the actuator, or by a machine member, to signal when an operation has been completed, or the machine has reached a given position. They are position sensitive input components. Examples of mechanically operated valves are: cam, plunger, roller, and one-way trip valves.

Mechanically operated limit valves pilot operate the directional control valve. This requires that the limit valve be located closely to the directional control valve, usually within a few feet, because there is a lag time associated with a moving column of air in a pilot circuit.

Another method used to signal the control system that a position has been reached, or that an event has taken place, is to open or close an electrical circuit to a solenoid operated directional control valve with a limit switch. The distance between the limit switch and directional control valve is usually not a factor in the control process because electrical signals are instantaneous.

Review: 40.1.

Which one of the following valves is used to signal the position of a linear actuator?

a. Limit.
b. Shuttle.
c. Directional.
d. Flow control.
e. Pressure sequence.

Outcome 41. **Identifies single-phase, single-phase two speed, and three-phase AC motor symbols.**

Electric motors are used as prime movers to drive compressors and vacuum pumps. Basic electrical motor symbols identify current, winding, and phase characteristics for replacement and wiring purposes.

Figure 19 illustrates electric motor symbols for three AC motors. Illustration 19A is an AC, single phase, single-speed motor. Figure 19B is an AC, three phase, single-speed motor.

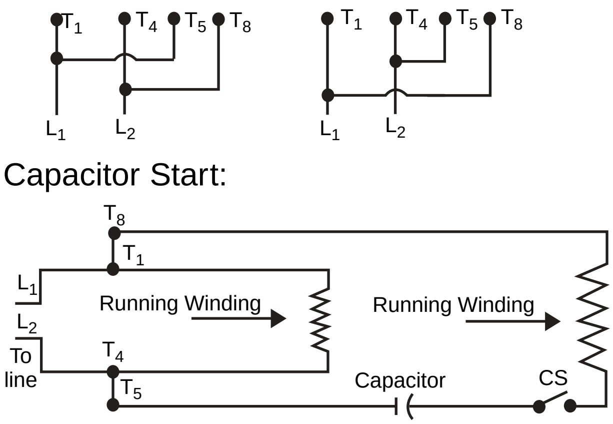


Fig. 19a. Single-phase capacitator start motor.

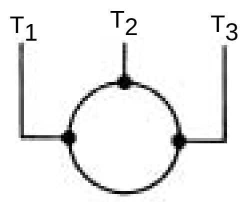


Fig. 19b. Three-Phase motor

To reverse the rotation of a single-phase motor, reverse T5 and T8. To reverse the rotation of a three-phase motor, swap the connection of any two of the three leads.

Outcome 42. **Recognizes that air logic systems control the sequence of operations.**

A pneumatic circuit requires an air signal and/or power input, a process function, and an output power function. The power input is the pressure source. The process function is in the valving. The output function consists of movement provided by cylinder and motor actuators.

The logic circuit is part of the process function. Within the process function, information is acquired using sensing components, processed using logic control components, and transmitted using rigid and flexible air lines. The word "logic" in this context simply means that the flow of information within the process function is in sequence. Air logic systems, then, control the sequence of operations as the pneumatic circuit operates.

Review: 42.1.
An air logic system is used to control:

a. actuator force.
b. actuator speed.
c. operation sequence.
d. actuator limit switches.
e. actuator stroke/rotation.

Outcome 43. **Recognizes various air logic circuits.**

The basic logic control functions are AND, OR, and NOT.

The AND function requires two inputs to generate an output. The three-way valve in Fig. 20, for example, requires an input at A and B to generate a signal at S.

The OR function generates an output signal when at least one input signal is present. The shuttle valve shown in Fig. 20 will generate an output signal at S if there is an input signal at A or at B.

The NOT function generates an output when there is no input signal. The three-way valve shown in Fig. 20 is spring loaded to direct an output signal to S when there is no signal at A. The NOT function is also known as an inverter function, since when there is no input signal there is an output signal, and when there is an input signal there is no output signal.

An inverted AND function is called a NAND. That is, NAND stands for the contraction Not-AND. Notice in Fig. 20 that the NAND function generates an output when there is no input at A and no input at B. If either three way valve is actuated, thereby providing an A or B input signal, the output signal will still be present from the other three way valve. For example actuating three-way valve A will block the air supply from the left leg of the circuit and also vent that side of the circuit. This causes the shuttle valve to shift to close the left leg of the circuit, but still provides a closed passage for the supply of air from three-way valve B through the shuttle valve to the outlet. Negating the output requires inputs from both A and B. If either input to the shuttle valve is present, there will be an outputted OR function is called a NOR, which stands for the contraction Not-OR. The NOR function in Fig. 20 produces an output when there is no input from A or B. If either A or B, or both, receives an input, the shuttle valve will send a pilot signal to shift the three-way valve and negate the output.

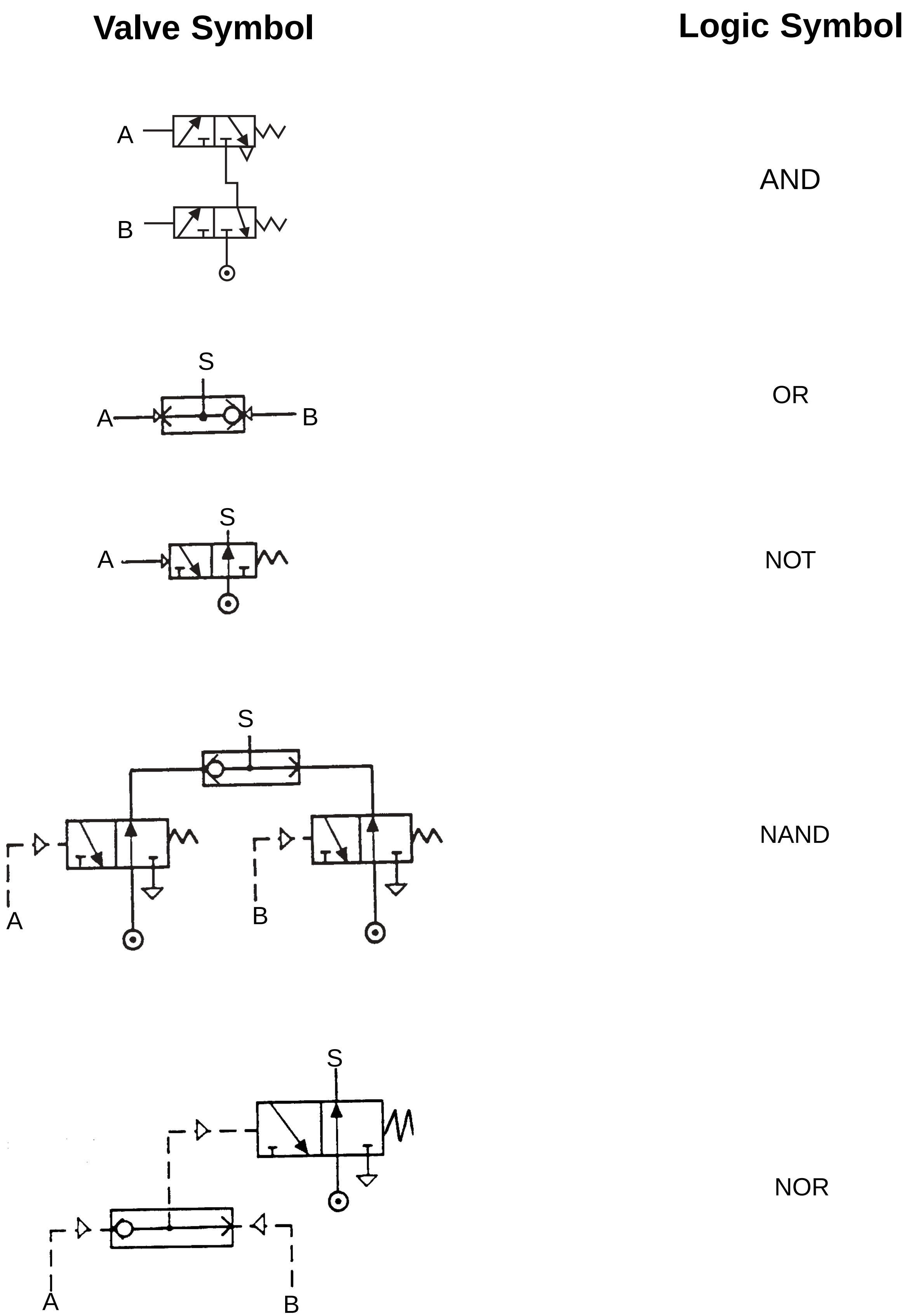


Fig. 20. Air logic functions.

Review: 43.1.
What kind of logic signal will the circuit shown in Fig. 21 produce?

a. AND
b. OR
c. NOT
d. NOR
e. NAND

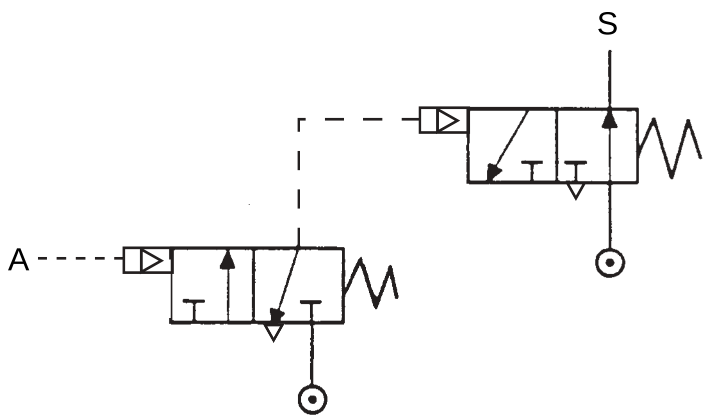


Fig. 21. Circuit for review question 43.1.

Outcome 44. **Identifies logic controls with logic circuits.**

The logic control functions illustrated by components such as those in Fig. 20 are applied to air circuits. Figure 22 illustrates a single-acting cylinder connected to a pilot operated, normally closed, spring return, four-way, two-position, directional control valve, labeled A. Valve A is a four-way valve, but it is connected as a three-way valve to power and exhaust a single-acting cylinder. Pilot valve B, below and to the left of the four-way valve, is a normally closed, three-way, two position, manually operated valve. However, notice that valve C to the right of the pilot operated valve is a normally open, three-way, two-position power valve in series with the four-way valve. The cylinder will extend when pilot valve A is piloted operated by manually controlled pilot valve B, as long as power valve C is not operated and remains in the normally open position.

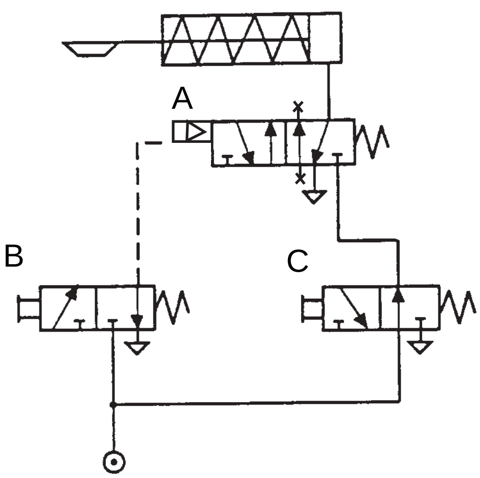


Fig. 22. Air circuit logic control.

Review: 44.1.
Which of the following logic statements best describes the circuit shown in Fig. 22?

a. B OR C = extend.
b. B AND C = extend.
c. B and NOT C = extend.
d. NOT B OR C = extend.
e. NOT B AND C = extend.

Outcome 45. **Identifies basic electrical symbols from ladder diagrams.**

Six basic symbols are found on ladder diagrams: switches, relay coils, relay contacts, signal lights, solenoids, and limit switches. In addition, the bus lines are shown to the left and right of the ladder rungs, with the left bus being positive, and the right bus negative or common (Fig. 23).

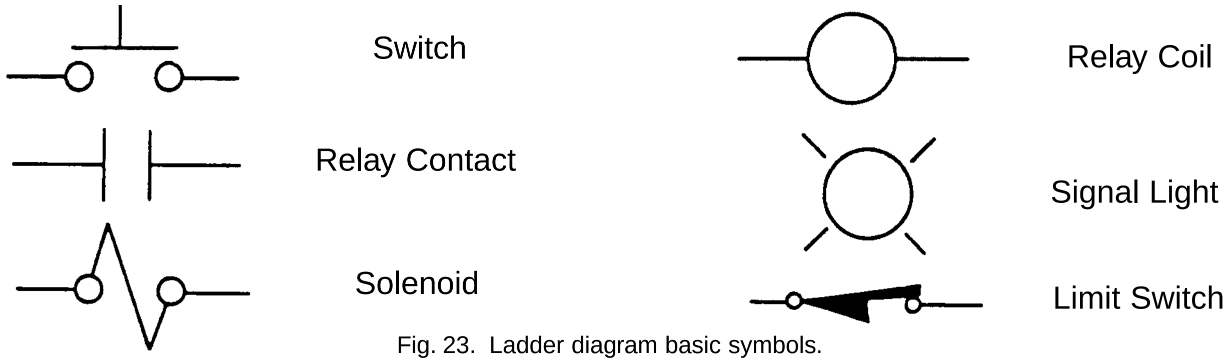


Fig. 23. Ladder diagram basic symbols.

Relay contacts can be shown:

1. Normally open.
2. Normally closed.
3. Normally open, held closed.
4. Normally closed, held open.

Relay contacts in ladder diagrams are shown in their normal position when the machine is in the OFF or AT REST position.

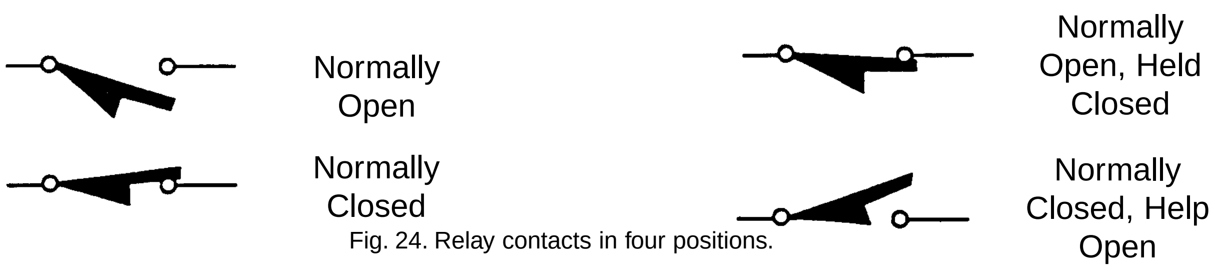


Fig. 24. Relay contacts in four positions.

A basic ladder diagram for a double-acting pneumatic cylinder with a four-way, two position directional control valve is shown in Fig. 25. The push button switch on the first rung of the ladder initiates the start process. The control relay is energized, and both relay contacts close, the top one to hold the circuit latched when the push button is released, and the bottom one to energize the solenoid, which shifts the solenoid valve to extend the cylinder. At the end of the stroke, the cylinder rod opens the limit switch LS 1 to interrupt the circuit and both relay contacts open. The solenoid on the directional control valve is then de-energized and the return spring reverses the valve to retract the cylinder.

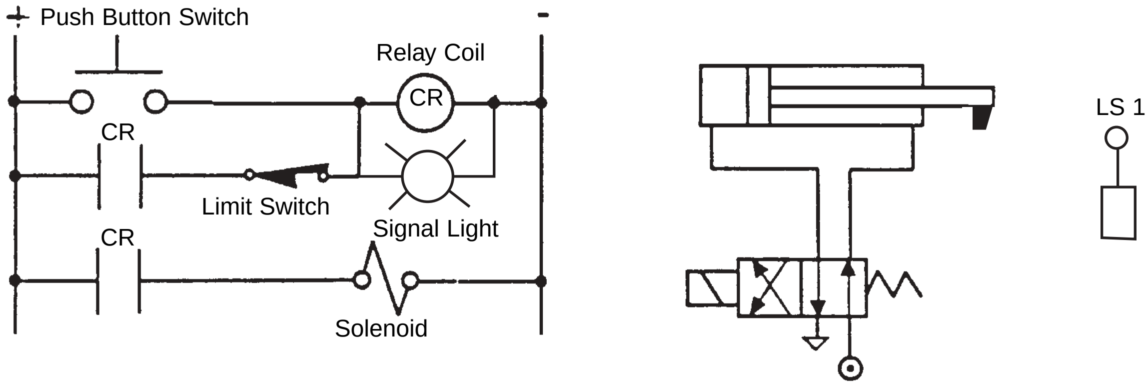


Fig. 25. Ladder diagram for double-acting pneumatic cylinder.

Outcome 46. **Understands that electrical contacts have negligible electrical resistance, whereas output elements have appreciable electrical resistance.**

There are two types of ladder diagram elements: electrical contacts, and output elements. In addition, there are conductors which are the positive bus on the left and negative or common bus on the right, and wiring to connect the elements between the busses.

Electrical contacts consist of push button switches, sensors, and relay contacts. Electrical contacts are always placed on the left side of the diagram. Push button switches are hand operated to start operations, and for safety reasons, to stop operations. A relay contact is an electro-magnetic switch. A small switching current through an electromagnet in the relay closes the contacts that will carry the main load. Sensors are also switches that respond to changes in such system indicators as pressure, temperature, and fluid level. Electrical contacts have low resistance when closed.

Output elements consist of resistance loads, such as relays, solenoids, signal lights, and motors. Relays close the relay contacts. For purposes of explaining ladder diagrams, the resistance load of the relay is kept separate from the relay contact. The relay and relay contact are shown separate on the ladder diagram, with the relay placed on the right and relay contact placed on the left, even though both are incorporated within the same component. Solenoids are used to operate directional control valves and are resistance loads that generate heat. Signal lights indicate which rungs on the ladder diagram and components in the system are energized. Signal lights do not consume much energy, but they are still resistance elements. Electric motors have a lower resistance than signal lamps, which causes them to draw more current. Thus, all output elements have more resistance than electrical contacts. Remember that electrical contacts are designed to carry current, but not to draw current and consume power.

Review: 46.1.
Which one of the following ladder diagram elements would not consume power?

a. Solenoid.
b. Relay coil.
c. Signal light.
d. Electric motor.
e. Pressure switch.

Outcome 47. **Understands the interaction between a ladder diagram and a directional control valve shifting mechanism.**

Ladder diagram circuits are used to connect electrical components, and to show how the control circuit operates. The ladder diagram can also be related directly to the pneumatic schematic.

The ladder diagram and pneumatic schematic in Fig. 26 show how the two are related to shifting the directional control valve. The same components, for example, solenoids and limit switches, are labeled on both drawings.

When the push button switch is depressed momentarily, control relay 1 is energized momentarily, closing control relay 1 contacts momentarily. This energizes solenoid 1 momentarily and the directional control valve shifts to direct air to the blind side of the cylinder, and the cylinder rod extends. At the end of the stroke, the cylinder rod closes limit switch 2, energizing control relay 2 momentarily. This energizes solenoid 2 momentarily, which reverses the direction of the directional control valve and directs air to the rod end of the cylinder, and the cylinder rod retracts. The cylinder will remain at rest until the push button switch is actuated again. Notice that both the air circuit and ladder diagram use the same designations for the limit switch and solenoids. Also notice that the push button switch should not be held actuated because this would cause the cylinder to stall in the extended position, overheating both solenoid coils.

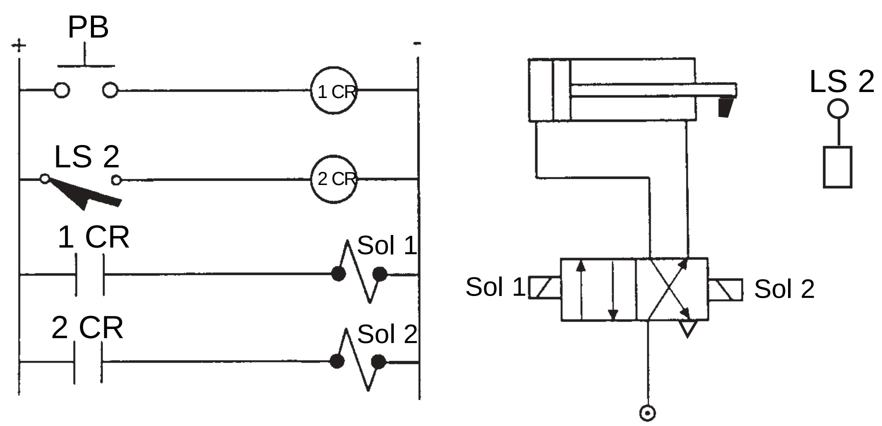


Fig. 26. Ladder diagram and pneumatic circuit schematic.

Review: 47.1.
Which electrical element in the ladder diagram shown in Fig. 26 signals the cylinder to retract?

a. Solenoid 2.
b. Limit switch 2.
c. Control relay 1.
d. Control relay 2.
e. Push button switch.

Outcome 48. **Recognizes logic statements that describe ladder diagrams.**

The operation of a ladder diagram circuit can be represented by a logic statement, which uses letters and symbols to express the input and output functions of the circuit.

The letters A and $\underline{A}$ (not A), B and $\underline{B}$ (not B), C and $\underline{C}$ (not C), and so on, are used to represent input functions, while the word "output" or "X" is used to represent an output. A dot between two letters is used to represent the AND function, and a plus sign is used to represent the OR function. In combination, these symbols are used to write logic statements that describe the operation of a ladder diagram circuit.

The logic statement A OR B equals an output is written as

A + B = Output

The statement expresses the condition that either of two inputs are necessary to accomplish an output. The ladder diagram in Fig. 27 represents the inputs, A OR B, as two push button contact symbols connected in parallel, and both contacts are connected in series with a signal light symbol to represent the output.

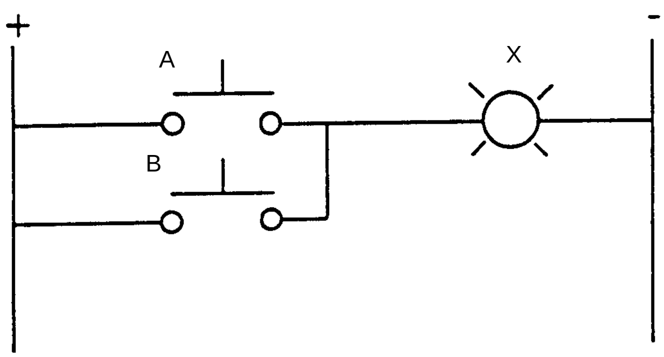


Fig. 27. Ladder logic diagram.

Review: 48.1.
Which of the following logic statements is represented by the logic diagram shown in Fig. 27?

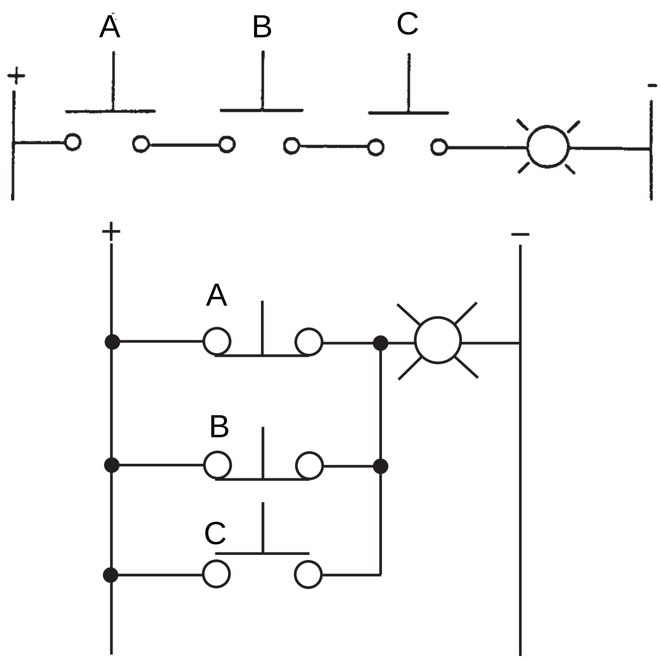
a. A ● B = Output.
b. A + B = Output.
c. $\underline{A}$ ● $\underline{B}$ = Output.
d. $\underline{A}$ + $\underline{B}$ = Output.
e. $\underline{A}$ ● B = Output.

Outcome 49. **Identifies equivalent logic statements from a truth table.**

Logic statements that represent the operation of a ladder diagram circuit can also be represented by a truth table. Truth tables are used to predict the operation of an air circuit, and to design in interlocks that guard against unintended outputs.

The presence of an input is indicated by a 1, while the absence of an input is indicated by a 0. Notice that these are discrete binary signals with fixed values of 1 and 0, which makes them well suited to describe the control and operation of most air circuits for example "on", "off", "pressurized", "bleed", "extend", "retract", and so on.

The truth table in Fig. 28. shows all possible combinations of input signals from A, B, and C. In the way the ladder diagram is constructed, however, only the last combination of all three inputs will result in an output.



Row	A	B	C	X
1.	0	0	0	0
2.	1	0	0	0
3.	0	1	0	0
4.	0	0	1	0
5.	1	1	0	0
6.	1	0	1	0
7.	0	1	1	0
8.	1	1	1	1

Fig. 28. Logic statement and truth table.

Review: 49.1.
A parallel circuit ladder diagram has three contacts connected as follows:

A - normally closed.
B - normally closed.
C - normally open.

Which row in the truth table given in Fig. 28 would generate an open condition (no output)?

a. 1
b. 2
c. 4
d. 5
e. 6

Outcome 50. **Matches cylinder motion sequences with motion diagrams.**

Motion diagrams, also called function diagrams or travel-step diagrams, identify the relative positions of the actuators as the circuit executes each step of the operating sequence. For example, in a three cylinder circuit, a motion diagram would show when each cylinder was extended, when each cylinder was retracted, and the relative positions of all three cylinders with respect to each other.

Cylinder motion sequences can be written out by using letters to identify each cylinder, and a plus or minus sign to indicate its position, where (+) means that the cylinder rod is extended, and (-) means that the cylinder rod is retracted. For example, the motion sequence given by:

A +, B +, A-, B-

means that cylinder A extends in the first sequence step, cylinder B extends in the second sequence step, cylinder A retracts in the third sequence step, and cylinder B retracts in the fourth sequence step.

A motion diagram typically identifies individual cylinders down the left side with numbers 1, 2, or 3; or letters, A, B, C, etc., and steps in the sequence of circuit operations numbered across the top. Figure 29 shows such a motion diagram. Notice that during the first step, cylinder A is in the retracted position. At step 2, cylinder A extends. At step 3 cylinder A retracts. And at step 4, cylinder A remains retracted.

Combining the written motion sequence with the motion diagram is simply a matter of matching the correct cylinder sequence with the motion diagram.

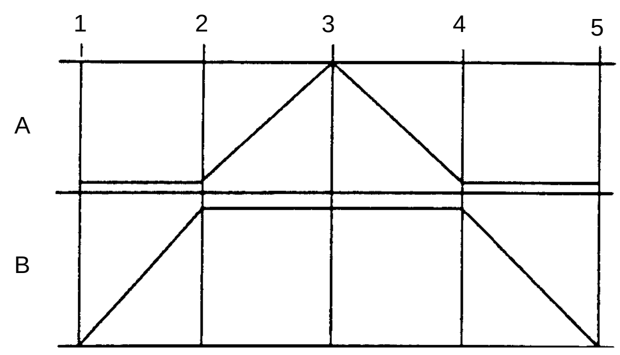


Fig. 29. Motion diagram for 50.1.

Review: 50.1.
Which of the following written motion sequences matches the motion diagram shown in Fig. 29?

a. B +, A -, B -, A +
b. B -, A +, A +, B +
c. B -, A -, B +, A +
d. B +, A +, A -, B -
e. B -, A +, B +, A -

Outcome 51. **Determines a cylinder operation sequence from a motion diagram.**

If the directional valves are controlled by limit switches, or by limit valves that are actuated by the cylinders when they extend and retract, the control sequence can also be identified from the motion diagram. Fig. 30 shows a motion diagram for four cylinders that extend and retract. Notice that the position for each cylinder is indicated down the left margin. The retracted position for each cylinder is indicated by a 0, and the extended position for each cylinder is indicated by a 1. The sequence of operations is given across the top of the graph. By looking at each step number in the sequence, and then reading down the graph, the relative positions of all cylinders can be identified. For example, in sequence step #1, Cylinders No. 1, No. 2, No. 3, and No. 4 are in the retracted position. In sequence step #2, Cylinder No. 1 is extended, while Cylinders No. 2, No. 3, and No. 4 are retracted.

Limit switches and valves are typically mounted so as to be tripped when the cylinder is fully extended or retracted. This allows one sequence to be completed before the next begins. Limit switches can be mounted to control the directional valve for the cylinder in operation, or connected to control other cylinders in the operation. For example, in the motion control diagram shown in Fig. 30, Cylinder No. 1 extends, followed by the extension of Cylinder No. 2. This indicates that the limit switch or valve that extends Cylinder No. 2 is tripped at the end of the extension stroke of Cylinder No. 1. A similar situation exists for Cylinders No. 3 and No. 4. Notice that Cylinders No. 2, No. 3, and No. 4 retract at the same time. This indicates that the limit switches or valves to retract all three cylinders are tripped when Cylinder No. 4 fully extends.

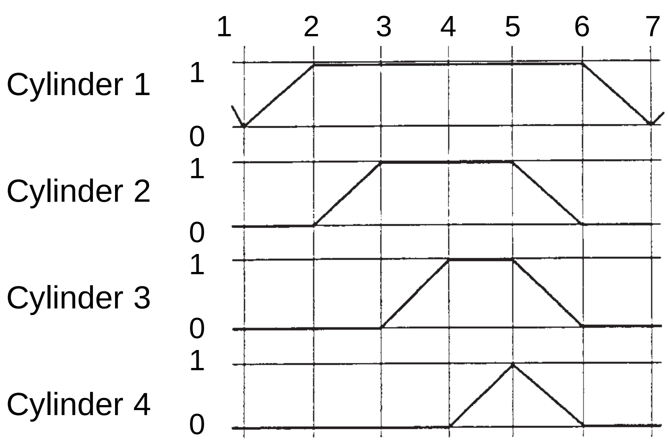
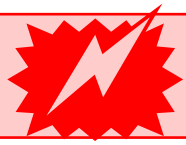


Fig. 30. Motion control diagram.

Review: 51.1.
In the motion diagram shown in Fig. 30, where is the limit switch (valve) actuated to retract cylinder No. 2?

a. Cylinder No. 1 extended.
b. Cylinder No. 2 extended
c. Cylinder No. 3 extended.
d. Cylinder No. 3 retracted.
e. Cylinder No. 4 extended.



Outcome 52. Understands the function of the Graetz rectifier.

A Graetz rectifier directs all flow in one direction through the center section of the component. A typical application is a one-way flow control valve on a double-acting cylinder. The Graetz rectifier eliminates the need for a second flow control to serve the same function in the opposite direction.

Notice in Fig. 31 that flow from the cylinder enters the flow control through the upper left check valve, travels through the flow control from left to right, and exits the bottom through the lower right check valve. When the direction of flow is to the cylinder, air enters from the bottom left check valve, again the air flows from left to right through the flow control, and exits out the top through the upper right check valve. Whether the flow is to or from the cylinder through the rectifier, flow is always left to right through the center section of the component.

To equalize the extension and retraction rates of a double-acting cylinder, flow controls are normally installed at each port. If the cylinder has a single rod, each flow control must be adjusted separately because the flow rates at the blind and rod ends of the cylinder are unequal. A Graetz rectifier solves this problem with one component, and this can be installed in either port.

A typical example would be a vertically mounted cylinder that extends to lift the load and retracts to lower the load. By installing the Graetz rectifier at the blind end port, air is metered into the blind end as the load is lifted, and metered out of the blind end as the load is retracted. The direction of flow through the flow control is the same whether the cylinder is extending or retracting.

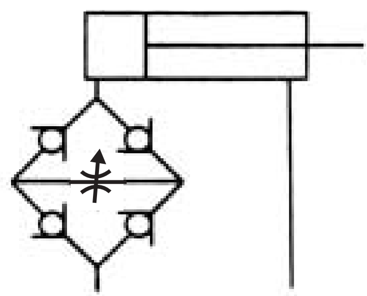


Fig. 31. Graetz rectifier.

Review: 52.1.

The function of the check valves in Fig. 31 is to:

a. divide the flow
b. amplify the flow.
c. rectify the flow.
d. reverse the flow.
e. flip-flop the flow.

Outcome 53. **Identifies the function of electrical components in a circuit.**

A commonly used electrical circuit energizes a throttle solenoid that increases engine rpm to drive an air compressor when the pressure falls to a predetermined lower limit. The pressure switch completes the circuit through a DC solenoid coil, which pulls the plunger in the magnet field, and in doing so, holds the engine throttle partially open to increase the rpm of the compressor. When the pressure in the receiver increases to a predetermined upper limit, the switch opens and the solenoid coil becomes de-energized, releasing the throttle. The purpose of the capacitor in the circuit is to protect the switch from arcing when it opens, by storing electrical energy that would otherwise bridge the gap of the contacts just when they open. Several types of switching circuits use capacitors to protect contacts.

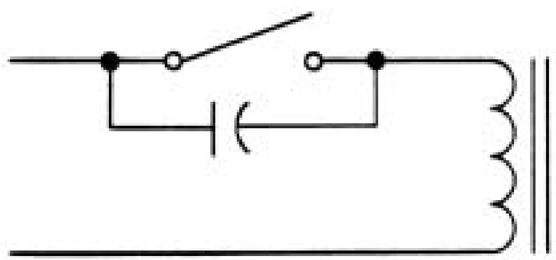


Fig. 32. Application of a capacitor.

Another common purpose for a capacitor is in the starting winding of single-phase motors. When the capacitor is wired in series with the starting winding, it gives the motor a high starting torque characteristic. Single-phase motors that are designed to start against a load are equipped with capacitors.

Review: 53.1.
Which electrical component listed protects a switch against arcing?

a. Coil.
b. Capacitor.
c. Relay contact.
d. Pressure switch.
e. Circuit breaker.

Outcome 54. **Understands that solenoid coil hum is caused by alternating current and the bias spring.**

Outcome 55. **Associates a loud AC solenoid hum with failure of the armature, or failure of the plunger to seat.**

Outcome 56. **Understands that a solenoid shading coil sets up an auxiliary magnetic attraction which is out of phase with the main coil such that it helps to hold the armature as the main magnetic coil attraction drops to zero.**

In North America, the standard frequency for AC current is 60 cycles per second. This means that the voltage increases and decreases 60 times each second. The magnetic field that pulls a solenoid in is strongest during the alternating cycle when the voltage peaks, and as the voltage drops to zero the magnetic field becomes weak. This causes the solenoid to produce a 60 Hertz hum.

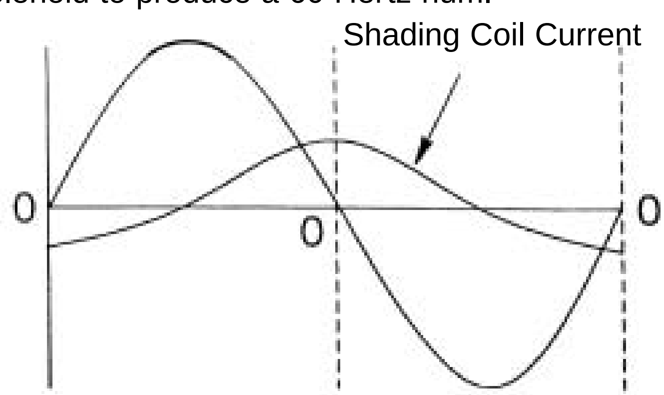


Fig. 33. Solenoid and shading coil current.

One way to maintain the magnetic field as the AC voltage fluctuates is to mount a shading coil, which consists of a single turn winding of heavy copper, in the face of the laminated iron core magnet assembly. The shading coil, sometimes called a shading ring, cuts flux lines to produce its own magnetic field, but is mounted so that the field is 90 degrees out of phase (1/4th of the cycle) with the main winding. This causes the shading coil magnetic force to be maximum when the main winding magnetic force is zero. The relationship of the shading coil, (sometimes called a shading ring) in the solenoid not only increases the force of the solenoid as the voltage fluctuates through zero, but reduces the hum that accompanies alternating current.

As an AC solenoid cycles, most of the heat per unit of time is generated by the high inrush current as the solenoid pulls the plunger into the coil. For example, the inrush current when the solenoid begins to close could be six or seven times the current when the solenoid is holding closed.

Other factors that increase the heat buildup in AC solenoids are high cycle rates, high line voltage, and not allowing the solenoid to completely close. Remember that inrush current is higher as the solenoid closes, so that if an obstruction or debris prevents full closure, the current and heat build-up will continue to

Review: 54.1.
AC directional control valve solenoid hum is reduced by:

a. reducing solenoid inrush current.
b. lowering solenoid line voltage.
c. reducing solenoid shifting rate.
d. reducing solenoid return spring force.
e. Installing a solenoid with a shading coil.

Review: 55.1.
Which one of the following would determine if AC directional control valve solenoid hum were caused by incomplete motion of the plunger?

a. Shift the manual override.
b. Disconnect the solenoid.
c. Increase the line voltage.
d. Decrease the line voltage.
e. Increase air line pressure.

Review: 56.1.
If the shading coil (shading ring) in, an AC directional control valve was left out when the solenoid was assembled, the valve will:

a. fail to shift at all.
b. make a louder hum.
c. cause the plunger to seize.
d. burn out the solenoid winding.
e shift at a lower air line pressure

be higher than the solenoid coil can tolerate and it will overheat, causing an internal short or burnout.

If the plunger is not seating, or the coil is shorted internally, the solenoid will make more noise than is normal as it vibrates with a 60 hertz hum. Debris could prevent the plunger from seating, but so too could incomplete shifting of the valve spool, or even a broken part in the solenoid. The best way to find out if the noise is a shorted coil or a valve spool that has not completely shifted is to shift the valve with the manual override to see if the noise is reduced. If it is, the problem is probably a stuck spool or solenoid. If seating the solenoid does not reduce the noise, the solenoid probably has an internal short.

Outcome 57. **Understands the relationship given by Ohm's law.**

Ohm's Law describes the relationship among the voltage, amperage, and resistance in a DC circuit such that:

$$\text{Electromotive Force}_{volts} = \text{Current}_{amps} \times \text{Resistance}_{Ohms} \qquad E = I \times R \qquad \text{(Eq. 19)}$$

Ohm's Law is applied when checking the continuity and resistance of directional control valve solenoids.

Safety caution: Before making continuity and resistance checks, make sure that the machine is turned off, and that the electrical and air service are locked out.

An electrical test of a component should include a continuity test to verify if the component is burned out, internally shorted, or shorted to ground. To check the continuity of a component, an ohm meter is set to the 100 ohm scale and calibrated to read a full-scale reading with the leads connected. A continuity test of contact elements, such as push button switches, sensors, and relay contacts, should indicate that the resistance is zero.

Following a continuity test, resistance loads, such as relay coils, solenoids, signal lights, and motors, are checked to determine if they have the proper resistance value as given by the specifications for the component. For example, knowing the resistance specifications for a solenoid is helpful when replacements are selected, and checking the resistance of both solenoids on a two solenoid directional control valve will verify that the right replacement is being made. To measure the resistance,

Review: 57.1.
What is the resistance of a 32 volt DC solenoid that has a holding current of 3.5 amperes?
a. 0.11 ohms
b. 2.61 ohms
c. 3.50 ohms
d. 9.14 ohms
e. 94.81 ohms

Review: 57.2.
A DC solenoid has a resistance of 12 ohms. How much current would the coil draw at 32 volts DC.
a. 0.4 amperes
b. 1.3 amperes
c. 2.7 amperes
d. 5.3 amperes
e. 9.1 amperes

recalibrate the Ohm meter on the appropriate scale, disconnect the solenoid leads, and connect the Ohm meter probes to each of the solenoid leads. A typical 24 volt DC directional control valve solenoid that draws a holding current of 1.8 amperes should have a resistance of approximately 13 Ohms. If the solenoid is shorted or burned out, the replacement solenoid should check out with the specifications, and also have approximately the same resistance as the other good solenoid, if the valve has two solenoids.

Basic Circuits

Outcome 58. **Understands that the spongy nature of air causes "stick slip" (sticktion) when moving heavy loads at slow speeds with air cylinders.**

Air is a spongy fluid. A pressurized cylinder that is not under load will extend or return suddenly if the exhaust air is not controlled.

Air is favored over hydraulics for quick movement of a cylinder for such applications as indexing, where the cylinder extends and retracts through a given complete stroke. However, when a slow controlled movement of the cylinder is required, air has a tendency to produce a jerky motion as the cylinder extends and retracts. As the bore of the cylinder and load are increased, the condition becomes aggravated. This is because cylinders with large bores require more air to fill the volume as the cylinder extends and retracts. As the load is increased, more pressure is required, together with the increased volume, to move the load. The condition where an air cylinder produces a jerky motion as compressed air builds pressure in the cylinder and produces a partial motion, followed by a reduction in pressure, is called "stick slip". The cycle keeps repeating as the cylinder continues to compensate for changes in pressure. For this reason, air cylinders are typically not used for slow or controlled motion of heavy loads, particularly where large bore cylinders are required. For these applications, hydraulic cylinders with meter-out control are used, or an oil cylinder is used, in conjunction with the air cylinder, to control the speed of the air cylinder. Some circuits, such as automotive air hoists, combine the air and oil circuit.

Basic Circuits

Outcome 59. **Recognizes basic air circuits from circuit diagrams.**

Air circuits use single-acting or double-acting cylinders, and air motors, to accomplish the work of the circuit. The force exerted by cylinders is determined by the bore and pressure. Speed is controlled by a flow control, which is usually placed at the outlet port. The sequence of operations is determined by control valves that shift the power valve. Control circuits use operator controls, position controls, sequence controls, pressure controls, and programmed controls to establish the sequence of operation. Actuation of control valves and the sequence of operations can be made by manual, pneumatic, or electro-pneumatic operators.

Air circuits are given names that describe their function. Typical examples and their functions follow:

1. Meter-in circuits control the flow of air to the cylinder with an in-line throttling restriction.

2. Meter-out circuits control the flow of air from the cylinder with an in-line restriction.

3. Reciprocating cylinder circuits extend and retract automatically after the start valve is actuated.

4. Time delay cylinder circuits extend or retract after a preset time.

5. Quick exhaust circuits direct the return port of the cylinder to atmosphere to relieve back pressure and speed up the return stroke.

6. Two pressure circuits extend a cylinder at high pressure and maximum force, and retract the cylinder at low pressure and minimum force.

7. Sequence circuits order the sequence of operation of two or more cylinders using operator (will), travel time, pressure sequence, or programmed control.

8. Slow forward, fast return circuits typically extend the cylinder slowly during the work portion of the cycle, and retract the cylinder at high speed during the slack portion of the cycle.

9. Switching circuits are logic circuits that incorporate interlocks to operate the work actuator, while preventing unintended movement of actuators that are not performing a work function.

10. Safety circuits are also logic circuits that prevent personnel from being injured. The most common examples are two-hand, anti tie-down, start circuits for presses.

This list of basic circuits includes only a few of the possibilities. Many air circuits are named after they are constructed for the special applications they serve. In addition, several familiar functions are often combined in one circuit. For example, a two-pressure circuit could also have a quick exhaust valve to release pressure at the blank end on the retraction stroke.

Outcome 60. **Analyzes component operation in basic air circuits.**

Air circuits are made up of four categories of components. Each component serves a specific function. The ideal is to build the circuit with no more components than are required to perform all the functions, including interlocks and safety measures to protect the machine and operating personnel.

1. Working components - are energy converters and consist of the various types of cylinders and air motors.

2. Signal output components - are directional control power valves.

3. Signal processing components- include limit valves, shuttle valves, quick exhaust valves, check valves, and flow control valves.

4. Signal input components - include FRL units, start and stop valves, and limit valves that pilot operate the directional control valve.

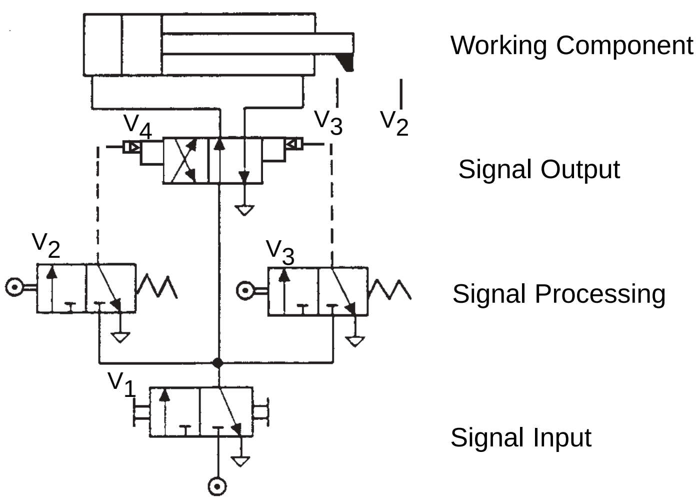


Fig. 34. Air circuit with working, signal output, signal processing, and signal input components

The circuit shown in Fig. 34 shows working components, signal output components, signal processing components, and signal input components. When the three-way start valve is shifted, the cylinder rod will continue to reciprocate until the start valve is shifted to discontinue the signal.

The working component is the air cylinder that moves the load back and forth as the rod reciprocates. Air is received from the directional control valve which is the pilot operated signal output component. Both cam operated limit valves are signal process-

Review: 60.1.

The purpose for valve V_2 in Fig. 34 is to:

a. cause the cylinder to retract.
b. regulate return air pressure.
c. lock the cylinder in position.
d. vent return air from the cylinder.
e. relieve over pressure from the cylinder.

ing components. They are shifted at the end of the extension and retraction strokes by the cylinder rod. The three-way, two position, manually operated start valve is the signal input component.

Outcome 61. **Understands that resistive loads are controlled in pneumatic circuits by meter-in circuits.**

Outcome 62. **Understands that tractive (overrunning) loads are controlled in pneumatic circuits by meter-out circuits.**

Air is a spongy medium, meaning that it compresses and expands to fill the available space. If a cylinder or motor encounters a load that resists movement, the air compresses, and the air pressure in the actuator increases until it is sufficient to move the load, assuming that the required pressure is available from the compressor. If the cylinder or motor is connected to a load that has a tendency to move the cylinder on its own, the air expands, and the air pressure in the actuator decreases. Loads that resist movement are called resistive loads. Loads that tend to move the actuator on their own are called overrunning or tractive loads. Because air is spongy, both resistive and overrunning loads require speed control.

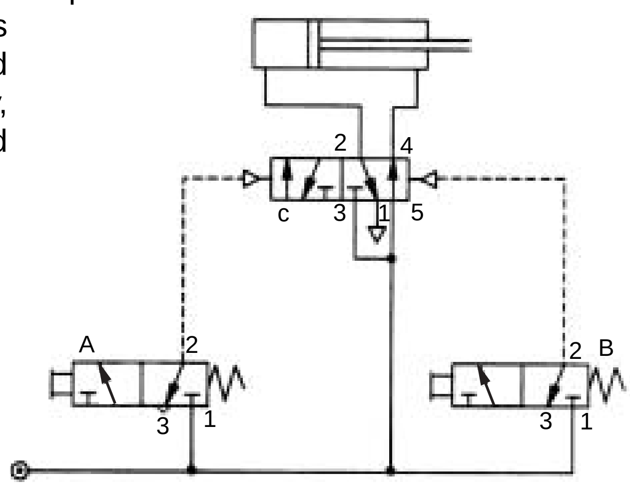


Fig. 35. Meter-in and meter-out flow control options.

Review: 62.1.
Where would a single flow control valve be placed in Fig. 35 to provide meter-out control in both directions?

a. Rod end of the cylinder.
b. Blank end of the cylinder.
c. Left inlet of the control valve.
d. Right inlet of the control valve.
e. Exhaust port of the control valve.

If the load is totally resistive, meter-in control is used. If the load is both resistive and overrunning, or totally overrunning, meter-out control is used. If the load is resistive when the circuit is designed, but at some future time may encounter overrunning loads, meter-out control is used. The "rule of thumb" quoted by some authorities is "when in doubt, meter-out."

Single-acting, spring return cylinders that have the rod end of the cylinder vented, use meter-in control to extend the cylinder. The cylinder is exhausted through the three-way directional control valve when it retracts under the force of the spring.

Figure 35 shows an air circuit that extends and retracts a cylinder. Meter-in control to extend the cylinder could be placed at the cap end port of the cylinder, or at the left inlet port of the directional control valve. When the flow control is placed at the cylinder port, a reverse free-flow check valve is used in parallel with the flow control to prevent metering in both directions. Meter-out flow control to extend the cylinder could be placed at the rod end port of the cylinder with a reverse free-flow check valve. Meter-out control could also be achieved by placing the flow control in the exhaust port of the directional control valve, but this would provide meter-out control in both directions of travel.

Review: 63.1.
Assuming the flow controls are set differently, what effect would reversing the free-flow checks in both flow controls have on the circuit shown in Fig. 36?

a. Reversing both extension and retraction speed.
b. Meter extension speed only
c. Meter retraction speed only.
d. No effect
e. Air would bypass both flow controls.

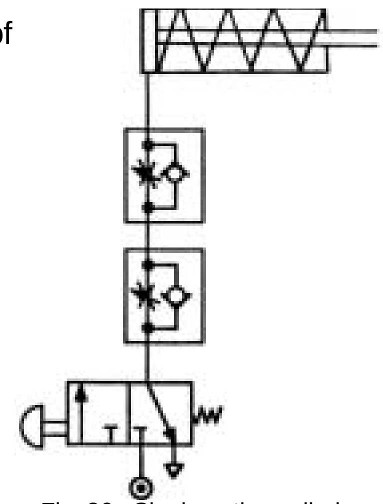


Fig. 36. Single-acting cylinder circuit with flow control.

Outcome 63. **Understands pneumatic speed regulation circuits**.

The single-acting, spring return pneumatic circuit shown in Fig. 36 will meter air flow in both directions. When the start button is depressed and air is directed to the cylinder, air bypasses the lower flow control through the reverse free-flow check valve, but is metered by the upper flow control because the reverse free-flow check valve seats, requiring air to flow through the adjustable restriction. When the start button is released, the air supply is discontinued and the blank side of the cylinder is vented to atmosphere. As the cylinder retracts under the force of the return spring, air passes through the reverse free-flow check valve in the upper flow control, but is metered by the adjustable flow control in the lower flow control because the reverse free-flow check valve seats in the return position.

Review: 63.2.
Reversing the reverse free-flow checks in both flow controls would cause the circuit shown in Fig. 37 to:
a. meter-in, both directions.
b. meter-out, both directions.
c. meter-in, extension only.
d. meter-out, retraction only.
e. have no effect in either direction.

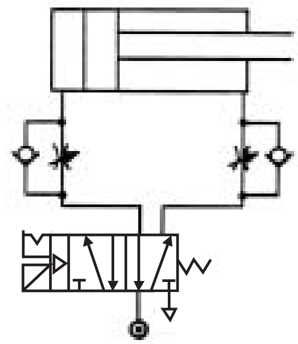


Fig. 37. Double-acting cylinder circuit with flow control.

The double-acting air circuit shown in Fig. 37 has a flow control with bypass check valve mounted at each cylinder port. The circuit regulates the speed of the piston in both directions by throttling the return air. Thus, it is a meter-out circuit.

Depressing the start button directs air through the four-way valve to the blind end of the cylinder through the flow control valve with reverse free-flow check. As the cylinder extends, air returning from the rod end port is throttled by the adjustable flow control, because the check valve is seated. Releasing the start button reverses the four-way directional control valve to retract the cylinder. Air is directed to the rod end of the cylinder through the reverse free-flow check and, as the cylinder retracts, air returning from the blind end port is throttled by the adjustable flow control. Again, notice that the reverse free-flow check valve at the blind end of the cylinder is seated as the cylinder retracts.

Caution must be exercised when using a flow control valve (or a needle valve) to regulate the flow into the pressure port of a pilot operated directional control valve. Assume the source of the pilot pressure that operates the directional valve is downstream of the flow control valve. If the flow control valve is throttled down too much, a great enough pressure drop may develop across the orifice of the flow control valve, and sufficient pilot pressure to control the directional valve may be lost.

Review: 63.3.
Which speed conditions are selected when the speed selector valve in Fig. 38 is in the center position?
a. Fast forward, slow return.
b. Fast forward, fast return.
c. Slow forward, slow return.
d. Slow forward, fast return.
e. No forward, no return.

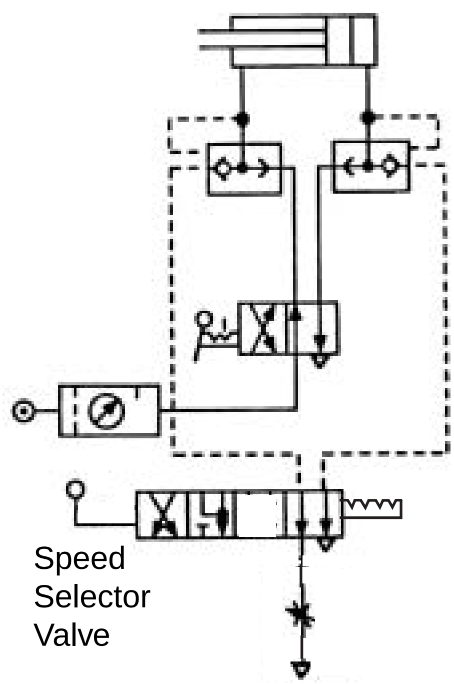


Fig. 38. Speed control circuit.

The double-acting air circuit shown in Fig. 38 incorporates two quick exhaust valves at the cylinder ports, and a speed selector valve at the bottom. The cylinder is extended and retracted by the four-way, two position directional control valve in the center of the circuit. Notice also that the speed selector valve at the bottom has a flow control valve in one of the return ports.

When the directional control valve is shifted to extend and retract the cylinder, return pilot air operates the quick exhaust valves. This directs the exhaust from each port to the speed selector valve, where the position of the valve determines how the circuit will operate. Notice that the speed selector valve has three manually selected positions.

In the position shown, air is directed to the rod side of the piston to retract the cylinder, and air returning from the blank side of the piston is directed by the quick exhaust valve through the speed selector valve to atmosphere. If the directional control valve is shifted to extend the cylinder, the quick exhaust valve directs exhaust air from the rod side of the piston through the speed selector valve to the flow control. This gives the circuit a slow forward, fast return characteristic.

If the speed selector is shifted to the left position (crossed arrows), the circuit will have a fast forward, slow return characteristic.

Outcome 64. **Understands switching circuits for pneumatic branching operations.**

Pneumatic switching circuits can be used for actuator position control. The circuit shown in Fig. 39 has four panel mounted three-way valves to set the four positions of a double cylinder, where both cylinders are double-acting. Notice that both four-way directional control valves are pilot operated, and that the pilot signals are processed through shuttle valves that allow one of two input signals to operate each directional control

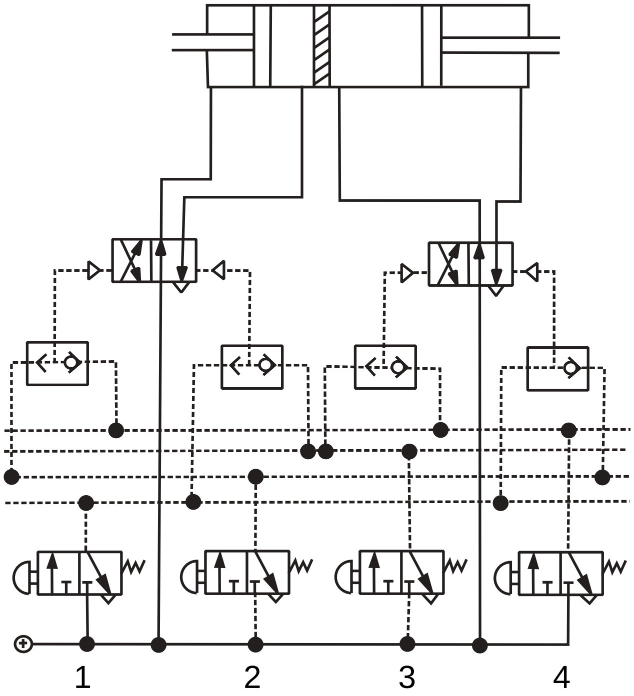


Fig. 39. Pneumatic switching circuit.

Review: 64.1.
Which valve has been depressed in Fig. 39 to shift the directional control valves (not the cylinders) to the positions shown?

a. Valve #1.
b. Valve #2.
c. Valve #3.
d. Valve #4.

valve in either position. The four three-way, two position (Start) valves receive air from a common pressure manifold, and the output from each valve connects to one of four manifold pilot lines. This is how the switching circuit operates.

Depressing panel valve #2 sends an air signal to the second manifold pilot signal line which, in turn, sends the signal to the left and right shuttle valves. The left shuttle valve directs pilot air to shift the left directional control valve, causing the left cylinder to extend; and the right shuttle valve directs pilot air to shift the right directional control valve, causing the right cylinder to extend. Thus, depressing panel valve #2 extends the double cylinder to full stroke length, where it will remain under pressure until one of the other three panel valves is depressed.

Outcome 65. **Distinguishes between will, time, pressure, sequence, and programmed pneumatic circuit control systems**.

Review: 65.1.
Which valve in Fig. 40 is manually operated?

a. 1
b. 2
c. 3
d. 4
e. 5

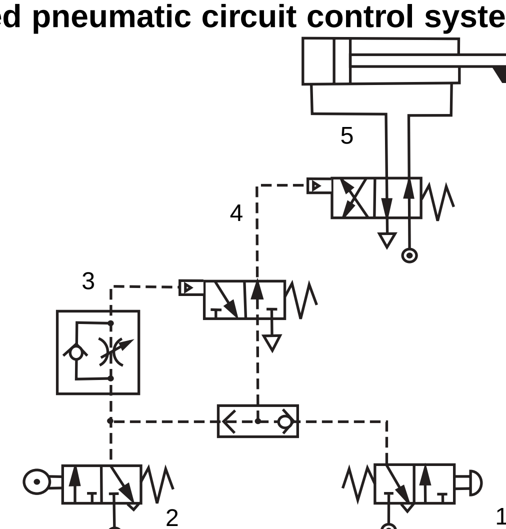


Fig. 40. Circuit for 65.

Pneumatic circuits are controlled by manually (will), time, pressure, sequence, and program operated valves. Most circuits contain more than one type of control, or combined controls.

Manually operated controls are push buttons, lever or pedal operator valves. That is, the operator determines when the valve will be actuated.

Time based pneumatic controls use timing-in and timing-out circuits to determine when the directional control will be actuated. Time based components incorporate flow control valves and accumulators to control the delay time before the signal can operate the directional control valve.

Pressure based pneumatic controls respond to pressure changes. For example, a pressure sequence valve can be used to sequence the operation of clamp and work cylinders connected in parallel. The clamp cylinder extends when the directional control valve is shifted, and the work cylinder extends after the clamp cylinder secures the work piece, causing the pressure level to increase to the shift setting of the pressure sequence valve. In this application, the pressure sequence valve establishes the minimum clamping force on the clamp cylinder before the work cylinder advances.

Sequence based pneumatic controls cause events in the circuit to occur one after the other in sequence. Typical applications would be drilling, grinding, and sawing operations that require a pneumatic cylinder to extend to full stroke and then retract. Circuits that use limit valves to control the length of stroke before sending a control signal to reverse the directional control valve are sequence based controls.

Programmed control is used on automatic machines. A typical program controller consists of a motor driven set of cams stacked on a rotating shaft. The cams operate micro-switches that send electrical signals to solenoid operated directional control valves. The sequence of operation is determined by the position of the cams on the rotating shaft. Programmed controllers of this type are also time dependent because the cam drive is a synchronous electric motor.

Troubleshooting

Outcome 66. **Understands that studying the circuit diagram is necessary to identify component function and sequence of operation.**

The circuit diagram lays out the operation of the pneumatic system. Reading both the symbols and the diagram are necessary to understand how the system operates.

If only a few components are used to construct an air system, for example: a cylinder and manually operated control valve, the symbols and operation of components are obvious because of the simplicity of the system. In more complex systems that have many components, it is common to use a circuit layout that identifies the function of components by their placement, and a numbering system for each component that identifies how that component contributes to the operation of the system.

Circuits are drawn from the top down as follows:

1. Actuators (operating components).

Review: 66.1.
Which component in the air press circuit shown in Fig. 41 is the signal output component?

a. Cylinder.
b. Valve 1.
c. Valve 2.
d. Valve 3.
e. Valve 4.

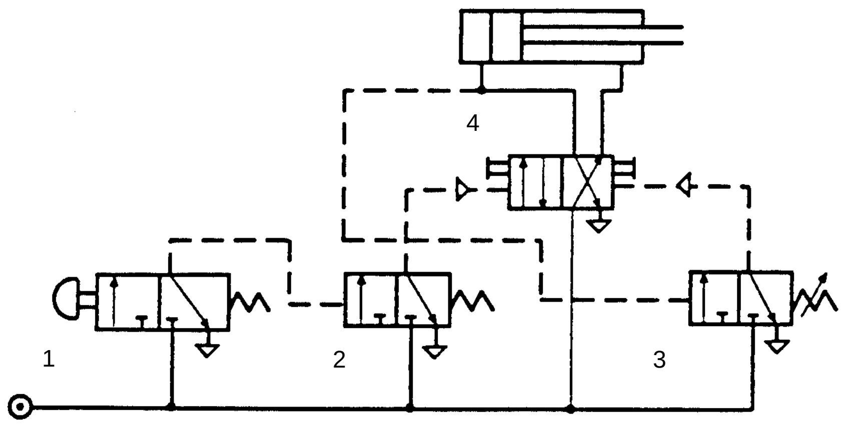


Fig. 41 Air press circuit.

2. Directional control valves (signal output).

3. Limit, shuttle, and restrictor valves that interact with the directional control valve (signal processing).

4. Start and stop valves, and air supply (signal input).

Each component, such as a directional control valve, is also drawn in the normal or neutral position. This alerts the technician to the position of the component when the equipment is turned off. Exceptions to this rule should be noted on the circuit diagram.

The circuit in Fig. 41 shows a double-acting air cylinder, controlled by a pilot operated directional control valve. The pilot valves that shift the directional control valve are also pilot operated. To extend the cylinder, valve 1 is manually operated to shift three-way valve 2, which shifts four-way directional control valve 4 to direct air to the blank side of the piston. When the cylinder extends and stalls, pressure in the pilot line shifts three-way pilot valve 3 to reverse the directional control valve and retract the cylinder. Notice that both pilot valves 2 and 3 are spring returned to the normally non-passing position. The extension, pressurization, and retraction of the air cylinder will repeat each time the hand operated start valve is depressed. Notice that three-way pilot valve 3 is pressure sensitive. That is, when the load on the cylinder as it extends increases the pressure at the cap end of the cylinder sufficiently, it will shift valve 3 which causes the cylinder to retract. Under certain loads, this could cause the cylinder to retract before reaching full-extension.

The general rule for troubleshooting is to study the circuit diagram before attempting to isolate the problem. When approaching the machine, maintaining safe conditions is a must to prevent personal injury and damage to the machine. The problem is identified first as a problem, and then a procedure is followed to pinpoint which component is causing the machine to malfunction.

Outcome 67. **Associates slow air cylinder return with minimum (low) air pressure operating against the rod side of the piston.**

The force exerted by a cylinder is computed from the product of the pressure (psi) and area (square inches). The pressure is created by the resistance to movement offered by the load. On single rod cylinders, the air pressure acts on the blind side end of the piston as the cylinder extends, and the annular area of the rod side of the piston to retract. Because the blind side of the piston has more area,

Review: 67.1.
The air cylinder shown in Fig. 42 has a 2 inch bore and 1 inch diameter rod and extends and retracts, moving a constant load. The cylinder almost stalls retracting. What should be done to increase retraction velocity?

a. Replace the rod seal.
b. Clean the pilot valve.
c. Remove pilot line restriction.
d. Increase the air pressure.
e. Check the start valve.

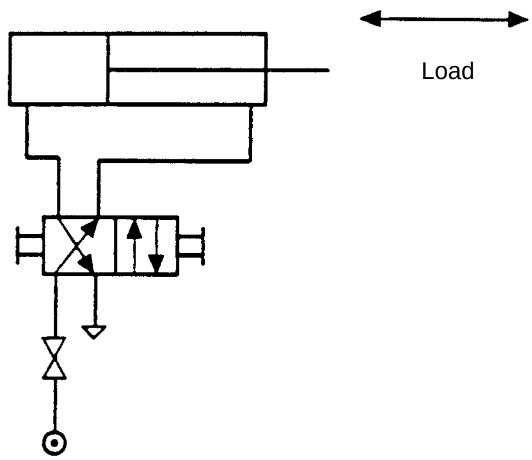


Fig. 42. Circuit for Outcome 67

the static force extending will be greater than the static force retracting. If the load increases to a level above the pressure capacity of the air source, the cylinder will stall.

The operation of an air cylinder differs from its hydraulic counterpart in that the speed of the cylinder can be increased by increasing the air pressure. This occurs because, in addition to the air pressure required to move the load, a portion of the pressure is required to overcome the restriction to flow that slows down the air stream as it fills the cylinder. This does not mean that cylinder speed is controlled by air pressure. Rather, speed is controlled by placing a flow restriction in the air line, usually in the exhaust port, to control how fast air is allowed to leave the cylinder. Unlike hydraulic flow control valves, air flow controls are less accurate because the compressible nature of air is affected by cylinder load, inlet and outlet pressure at the cylinder, and load changes throughout the stroke. Thus, for a given cylinder and flow control setting, increasing the air pressure will increase the speed of the cylinder and cycle rate.

For most air cylinder calculations, the cross-section of the rod can be ignored if the diameter of the rod is small in comparison to the bore of the cylinder. As rod size increases, the retraction force from the cylinder will decrease significantly and must be accounted for. The same is true for cylinder speed. For a given regulator pressure and constant load, a slow down as the cylinder retracts could mean that the pressure to overcome both the load resistance as well as flow losses is approaching the pressure setting of the regulator.

The circuit in Fig. 42 extends and retracts an air cylinder. The manually operated, four-way directional control valve is shifted in one direction to extend the cylinder rod against a constant load, and in the other to retract it. Notice that there is no provision to regulate the speed of the circuit. The two variables in this circuit that affect the force and speed of the cylinder are the areas of the piston (blind and rod side) and air pressure. If the pressure remains constant, flow losses should be approximately the same whether the cylinder is extending or retracting. If the load is increased, or the pressure is decreased, at some point the cylinder will slow down and then stall retracting, indicating that the static pressure is not sufficient to move the load. Since the piston blind side area is larger than the rod side area, the maximum force from the cylinder when the cylinder stalls will be available when the rod is extending rather than retracting.

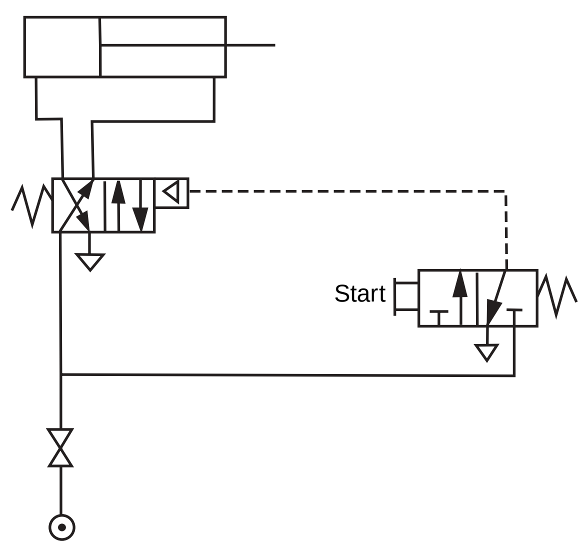


Fig. 43. Figure for Outcome 68

Review: 68.1.

The air cylinder shown in Fig. 43 should extend and retract, moving a constant load, when the start valve is actuated and released. Instead, the cylinder stalls retracting and air can be heard escaping from the exhaust port on the directional control valve. What is the likely cause of the problem?

a. Binding load.
b. Low air pressure.
c. Stuck start valve.
d. Blown piston seal.
e. Stuck directional control valve.

Outcome 68. **Understands that if an air cylinder fails to extend under load, it is still able to retract if a 2 position direction control valve is used, if the directional valve is in the cylinder return position.**

The air circuit shown in Fig. 43 has a single rod which means that the capacity to extend a load will always be greater than to retract it. This assumes that the piston seal on the piston does not leak. To operate the circuit, the start valve is depressed to pilot operate the directional control valve to extend the cylinder. When the start valve is released it vents to atmosphere, allowing the four-way valve to reverse under the force of spring pressure and direct air to retract the cylinder. Notice that both valves are spring returned and that the cylinder should retract when both valves are in the normal (unactuated) position.

If the load will retract the cylinder, but fails to extend it, the problem is not caused by low air pressure. In Fig. 43, for example, if turning on the air shut-off valve at the bottom of the circuit will retract the cylinder, but pushing the start button will not extend it, the problem is probably caused by a stuck directional control valve. The cylinder retracts because the normal (unactuated) position (shown) for the four-way directional control valve will direct air to the rod side of the piston. Notice that depressing the start valve sends a pilot signal to shift the four-way directional control valve. The pilot signal is probably present because pressurized air is available and the start valve is manually actuated. This reduces the fault to the directional control valve which is probably stuck in the normal position. Shifting the valve manually should confirm the diagnosis.

If the cylinder in a circuit like that shown in Fig. 43 is at fault, one would inspect for binding or blown piston seal. If the cylinder is equipped with cup seals, the piston could have two cup seals with the lips facing the cylinder ports. Failure of one of the seals would allow the cylinder to move the load in one direction, but blow past the seal and out the exhaust port in the opposite direction.

Outcome 69. **Traces fault backward from working element (cylinder or motor), to signal input pilot valves.**

The circuit diagram for a particular machine is reviewed to localize the problem to a particular circuit. That circuit is then analyzed to find out which component is causing the problem.

Problems have symptoms that show up at the working element. For example, the cylinder will not move, or the air motor will not rotate. To find the source of the problem, begin with the output device and then check the operation of each component shown in the circuit diagram back to the pressure source.

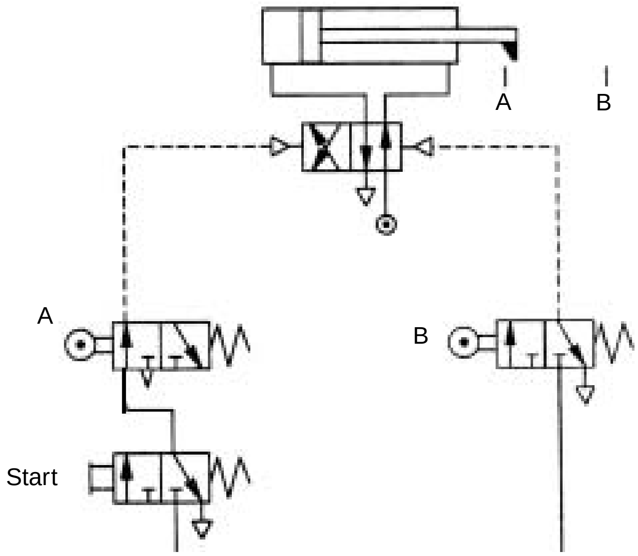
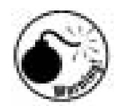


Fig. 44 Circuit for Outcome 69

Before starting the troubleshooting procedure, check to be sure that the air supply is on, and that the pressure is at the correct setting. Tracing faults backward from output components that are not operating properly assumes that pressurized air is available to power the circuit.



Safety at this point is a major concern. Troubleshooting an air circuit that is connected to air and electrical power can be dangerous. One source notes that a machine will "chop a hand off without any show of emotion." The point to be made here is that reaching into the machine, or actuating air valves manually, in an attempt to just "do something" is a serious safety error. The correct method is to think through the problem first, using the circuit diagram to trace back through each component, and then act in a safe and logical manner.

Review: 69.1.
When the air is turned on, the cylinder in Fig. 44 retracts. When the start valve is actuated and released, the cylinder extends and locks up. Which component is causing the problem?

a. Cylinder.
b. Start valve.
c. Control valve.
d. Limit valve B.
e. Limit valve A.

If an actuator will not operate, but it is not binding, or leaking or bypassing internally, the next logical place to check for the problem is the output power signal from the directional control valve. One way to check this safely would be to shutdown and lockout the machine and completley vent the system. Then, tee a pressure gauge into the lines from the directional control valve to the cylinder and restart the machine. A reading on the pressure gauge will indicate that the line is in fact being pressurized, and that the trouble is elsewhere, further back in the circuit. **"Cracking a fitting" in order to check for the presence of pressure in a line that may be, or is, under pressure, is an extremely dangerous practice. Under no circumstance should a pressurized line be vented in this manner, due to the high compressibility of gasses. Though pressurized liquids, such as oil in a hydraulic system, will not expand to the degree that a compressed gas does, in either case, devastating damage can be**

inflicted on both personnel or machinery by improperly vented fluids.

Shifting the directional control valve by hand should be weighed carefully against the possibility that sudden operation of the machine could result in injury or machine damage. Another option is to determine from the circuit diagram if the valve should be receiving an air pilot signal or an electrical signal that is supposed to shift the valve. Again, an air signal can be checked by cracking a fitting. An electrical signal is checked with a volt meter. If the valve is receiving a shift signal, but has not shifted, the problem is likely in the valve. It could be stuck or have a faulty seal. Of course a faulty seal commonly shows up as escaping air at the exhaust port, but so too would a blown piston seal in the cylinder. If there is no signal to the directional control valve, the problem could be in the signal processing part of the circuit.

Limit valves that process the pilot signal to the directional control valve are another source of problems. Mechanically operated limit valves can get out of adjustment in a way that they do not shift fully. They can also stick in the shifted position. For example, if mechanically operated limit valve B in the circuit shown in Fig. 44 were to stick passing, the air cylinder would retract and then remain retracted because of the continuous signal from the passing pilot valve to the directional control valve.

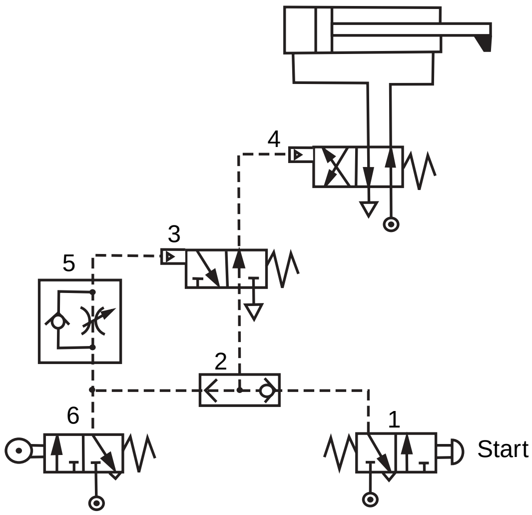


Fig. 45. Circuit for Outcome 70

Review: 70.1.
When the operator depresses the palm button on the start valve in the circuit shown in Fig. 45, the cylinder rod fully extends. After five seconds the cylinder rod retracts a few inches and then extends again. This cycle repeats so long as the air pressure source is maintained. Which component is at fault?

a. Shuttle valve is stuck.
b. Flow control valve is open.
c. Pilot valve spring is broken.
d. Start valve is stuck passing.
e. Directional control valve is sticking.

Outcome 70. **Identifies component malfunction in a pneumatic system.**

Troubleshooting a pneumatic system means identifying the component or components that are causing the problem. Symptoms such as "the cylinder will not extend," or "the cylinder will not retract," provide clues about where the problem lies. The circuit diagram is used to figure out how the circuit operates and the sequence of operations as the machine completes the work cycle. The fault is then traced from the actuator back to the component that is malfunctioning.

To identify how a component malfunctions, one must know what each component is supposed to do in the circuit, and how the component operates. For example, the circuit in Fig. 45 extends and retracts an air cylinder after the start valve is actuated.

When start valve 1 is actuated, an air signal is sent through shuttle valve 2 and then three-way pilot valve 3 to main four-way, spring returned, directional control valve 4. If start valve 1 is released before the cylinder reaches the end of the extension stroke, the return spring will reverse four-way directional control valve 4 to retract the cylinder.

Once the cylinder rod extends and contacts limit valve 6, a second air signal is sent through shuttle valve 2 to maintain the pilot signal at directional control valve 4. At this point in the cycle, the start valve could be released without causing the cylinder rod to retract, because the second signal through the shuttle valve from the limit valve will hold the directional valve in the "extend" position.

Notice that when limit valve 6 shifts, it also directs a pilot signal to restrictor valve 5 that, after a time delay, shifts pilot valve 3 to vent the directional control valve pilot signal. This allows the return spring to reverse the directional control valve, which causes the cylinder to retract.

Thus, the function of shuttle valve 2 is to maintain the pilot signal on the directional control valve

~~after the cylinder rod depresses the limit valve. The function of the restrictor valve is to hold the cycle~~ extended for a preset time, after which the cylinder rod will retract. This gives the circuit the characteristics of "extending," "holding," and then "retracting after a preset time."

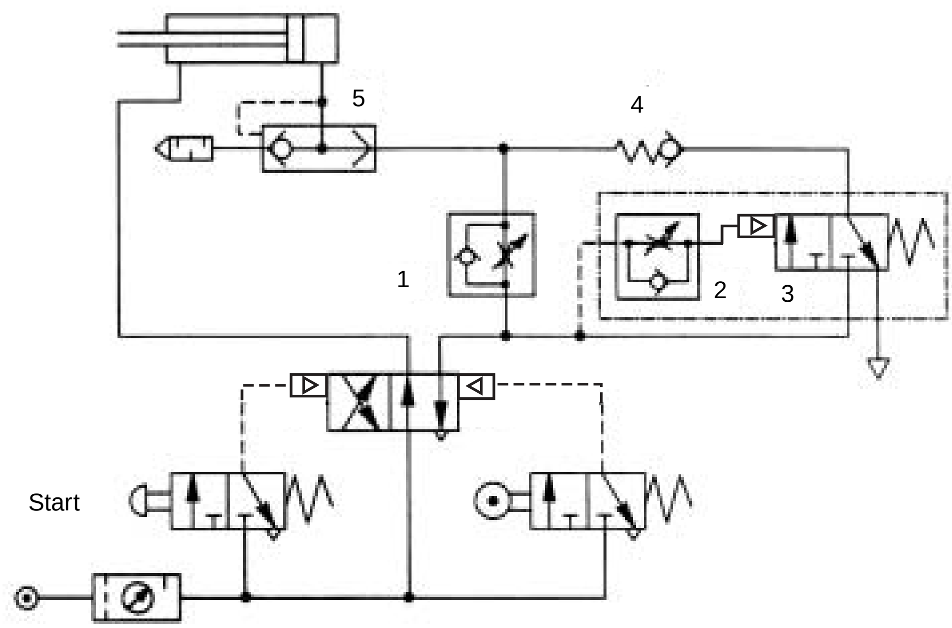


Fig. 46. Circuit for Outcome 71

Review: 71.1.
Which valve in Fig. 46 controls the initial extension speed of the cylinder rod?

a. 1
b. 2
c. 3
d. 4
e. 5

Outcome 71. **Analyzes pneumatic circuits.**

Analyzing pneumatic circuits is a generic process of determining what an air circuit is designed to do by studying the circuit drawing, and then identifying the operational characteristics of individual components within the circuit.

From the previous discussion of individual components and basic circuits, one should be able to identify the basic purpose and operation of a given circuit. Knowing the purpose of a circuit is also helpful in determining the purpose and operation of individual components within the circuit.

The circuit in Fig. 46 contains a start valve, limit valve, directional control valve, restrictor valves 1 and 2 with by-pass checks, three-way pilot operated valve 3, line check 4, and quick exhaust valve 5.

Pneumatic Technician Certification Answer Manual

1.1: d

2.1: c

3.1: d

4.1: a

4.2: a

5.1: c

6.1: d

7.1: a

7.2: d

8.1: b

9.1: d
Solving Eq. 1 for absolute temperature:
˚R = ˚F + 460 = 125 ˚F + 460 = 585 ˚R

9.2. d
Solving Eq. 1 for absolute temperature:
˚K = ˚C + 274 = 93 ˚C + 274 = 367 ˚K

9.3: d
Solving Eq. 1 for absolute temperature:
˚F = ˚R – 460 = 585 ˚R – 460 = 125 ˚F

10.1: e
Solving Eq. 2 for the absolute pressure:
PSIA = PSIG + 14.7 = 110 psig + 14.7 = 124.7 psia

11.1: c
a) Solve for the area of the cylinder bore:
Area = D^2 x 0.7854 = $(2")^2$ x 0.7854 = 4 x 0.7854 = 3.14 sq-in

b) Solve for the swept volume of the cylinder:
$\text{Volume}_{\text{cu-in}}$ = $\text{Area}_{\text{sq-in}}$ x $\text{Stroke}_{\text{in}}$ = 3.14 sq-in x 3" = 9.42 cu-in

c) Add the swept volume to the final volume to determine the initial volume: 9.42 cu-in + 2 cu-in = 11.42 cu-in

d) Solve Eq. 3 for P2, which is the final pressure, and remembering that gas law calculations require the use of absolute valves:
(P1 x V1) = (P2 x V2) → 14.7 psia x 11.42 cu-in = P2 x 2 cu-in → P2 = 83.94 psia À 84 psia

e) Since 84 psia is not one of the answers, calculate the gauge pressure:
PSIG = PSIA – 14.7 = 84 psia – 14.7 = 69.3 psig

11.2: b
Over the two minute time period, the compressor will pump 20 cubic feet of air into the air receiver.

a) Solve for the volume of the air receiver in cubic feet:
1) 50 gal x 231 cu-in/gal = 11,550 cu-in
2) 11,550 cu-in / 1728 cu-in/cu-ft = 6.68 cu-ft

b) Solve Eq. 3, (P1 x V1) = (P2 x V2): 14.7 psia x 20 cu-ft = P2 x 6.68 cu-ft ; P2 = 44 psia

c) Solve Eq. 2 for pressure: PSIG = PSIA – 14.7 = 44 psia – 14.7 = 29.3 psig

12.1: e
a) Solve for the area of the cylinder bore:
Area = D^2 x 0.7854 = $(3")^2$ x 0.7854 = 9 x 0.7854 = 7.07 sq-in
b) Solve for the swept volume of the cylinder:
$\text{Volume}_{\text{cu-in}}$ = $\text{Area}_{\text{sq-in}}$ x $\text{Stroke}_{\text{in}}$ = 7.07 sq-in x 3" = 21.2 cu-in
c) Add the swept volume to the final volume to determine the initial volume:
21.2 cu-in + 3 cu-in = 24.2 cu-in
d) Convert the temperatures from ˚F to ˚R:
˚R = ˚F + 460 = 70 ˚F + 460 = 530 ˚R = T_{initial}
˚R = ˚F + 460 = 120 ˚F + 460 = 580 ˚R = T_{final}
e) Solve Eq. 4 for P2, which is the final pressure:
(P1 x V1) / T1 = (P2 x V2) / T2 → (14.7 psia x 24.2 cu-in) / 530 ˚R = (P2 x 3 cu-in) / 580 ˚R → P2 = 129.8 psia
f) Since 129.8 psia is not one of the answers, calculate the gauge pressure:
PSIG = PSIA – 14.7 = 129.8 psia – 14.7 = 115.1 psig

13.1: d

14.1: b
In Fig. 10, locate the 90˚ F curve on the graph and follow it upward, then to the left, and finally to the top margin where the value 2.13 is found. Since there were 2000 cu-ft, multiply 2.13 x 2 to obtain the value of 4.26 lbs of water.

14.2: b
From Fig. 10, at saturation, free air at 80˚ F contains 1.58 pounds of water per 1000 cu-ft of air. Following the 80˚ F curve from the upper left margin down and to the right until it crosses the 100 psig vertical line, we find that the water remaining in the air at 80˚ F is approximately 0.20 lbs/1000 cu-ft of free air. Thus, the amount of moisture removed is 1.58 – 0.20 = 1.38 lbs of water. This represents approximately 87% of the moisture in the air.

15.1: d

16.1: c
Solve Eq. 6 for the compression ratio: CR = (PSIG + 14.7) / 14.7 = (100 psig + 14.7) / 14.7 = 7.8 → 7.8:1

16.2: b

17.1: c
Solve Eq. 7 for negative gauge pressure: PSIG = in-Hg x 0.4912 = -19 in-Hg x 0.4912 = -9.33 psig

18.1: b
a) Solve for the area of the pad: Area = D^2 x 0.7854 = $(3")^2$ x 0.7854 = 7.07 sq-in
b) Solve for the negative pressure required to lift a 50 pound load using Eq. 15:
P = F / A = -50 lbs / 7.07 sq-in = -7.07 psig
a) Knowing the negative pressure, use Eq. 7 to solve for the amount of vacuum required to lift the load:
in-Hg = psig / 0.4912 = -7.07 psig / 0.4912 = 14.4 in-Hg

20.1: e
Solve Eq. 9 for the cost to compress the air lost to the leak. Remember that the leak operates 60 minutes/hour, 24 hours/day/ 7 days per week.
$ = cfm x min x (kWh/cu-ft) x ($/kWh) = 3 cfm x (60m x 24h x 7d) x 0.02 kWh/cu-ft x 0.04$/kWh = $24.19/week

21.1: b
Solve Eq. 10 for the measured drop in a 75 foot long air line: LD = R x G x 0.12 = 75’ x 1.5% x 0.12 = 13.5 inches

22.1: c

23.1: e

24.1: c

26.1: d
Solve Eq. 6 for the compression ratio, and then Eq. 11 for the volume in gallons where K = 3:
VR = (K x SCFM x 7.48) / CR = (3 x 25 cfm x 7.48) / 8.82 = 63.6 gallons

27.1: a

29.1: c
First, locate the 100 psig pressure curve on the graph. Then move upward and to the right until the curve intersects with an imaginary vertical line that intersects with a pressure drop value of 25 psi. next, read the scfm flow rate along the left vertical axis. The delivery should be approximately 60 scfm. Notice that the pressure drop is slightly less than 25 psi, which is a requirement in the problem.

30.1: d

31.1: c
Since 86.7 psia is 91.5% of 94.7 psia, use K = Pout = 86.7
Solve Eq. 12. $C_v = Q/22.67 \sqrt{T / [Pin - Pout) K} = 35scfm / 22.67 \div 530˚R \sqrt{[(94.7psia - 86.7psia) \times 86.7]} = 1.35$

32.1: b
First, convert 60 gallons into cubic feet: 60 gallons x 231 cu-in/gal / 1728 cu-in / cu-ft = 8.02 cu-ft
Then solve Eq. 13 for the flow rate:

T = [V x (P_{max} – P_{min})] / (Q + 14.7) 10 min = [8 gal x (140 psia – 110 psia)] / (Q x 14.7) → Q = 1.64 cfm

33.1: e
Solve Eq. 14 for distance: PSID = (RP – TP) / D → 0.1 psid/ft = (125 psia – 110 psia) / D → D = 150 feet

34.1: e
Solve Eq. 15 for force: F = P x A = 105 lbs x 1.77 sq-in = 185.9 lbs

35.1: b
Solve Eq. 18: SCFM = (CR x A x S x SPC x CPM) / 1728 = (6.78cr x 1.77sq-in x 3” x 1spc x 15cpm) / 1728 = 0.31 cfm

36.1: b

37.1: d

38.1: d

39.1: d

40.1: a

42.1: c

43.1. c

44.1: c

46.1: e

47.1: b

48.1: b

49.1: d

50.1: d

51.1: e

52.1: c

53.1: b

54.1: e

55.1: a

56.1: b

57.1: d
Solve Eq. 19 for resistance: E = I x R → 32 volts = 3.5 amps x R → R = 9.14 ohms

60.1: a

62.1: e

63.1: a

63.2: a

63.3: b

64.1: a

65.1: a

66.1: e

67.1: d

68.1: d

69.1: d

70.1: d

71.1: a

Pneumatic Technician Certification Pre-Test

Introduction

Pre-tests are used to evaluate candidate preparedness for certification tests. Pre-tests may be either taken individually or in a group setting such as during a Review Training Session (RTS). As a part of an RTS, Pre-tests are used to allow the instructor to tailor the subject matter coverage to the needs of the audience. When a candidate is studying individually or in a small group, pre-tests provide insight into which areas require further study and whether the candidate should consider other study options, such as an RTS.

Included in this manual are three separate pre-tests for the Pneumatic Technician certification test. Each pre-test has its own separate answer sheet which appears at the end of the pre-tests. Individual pre-tests are numbered PT-1, PT-2, and PT-3. The answer key for all three pre-tests appears at the end of the manual.

Candidates are encouraged to take a pre-test early in the study process. Pre-tests should be taken under timed conditions. A maximum of forty-five minutes should be allotted for each pre-test. This should be sufficient time to answer all twenty-five questions on the pre-test. The results of the pre-test will guide the candidate to one of four possible courses of action regarding tests preparation.

1. Take the test: Preparation is sufficient.
2. Study the material using the Study Manual.
3. Attend a Review Training Session (RTS): Preparation is good, but not sufficient to pass the test.
4. Participate in a formal (general) course: A Review Training Session would not provide adequate preparation to pass the test.

Additional pre-tests should be taken after individual study or attendance at an RTS to further evaluate test readiness. In some instances, it may be desirable to take all three pre-tests at different times during the study process to better access preparedness and effectiveness of study.

The answer sheets provided have been developed such that each question is referenced to a particular subject matter area of the study manual and of the test. The candidate is encouraged to fold the answer sheet vertically along the dotted line before taking the pre-test. This will eliminate any bias that may occur by having the appropriate outcome statement appear with the answers and more closely mimics actual test conditions. After checking the answers, the answer sheet may be opened to reveal the areas where further study is needed. This should enable directed study in the areas where a deficiency exists.

Candidates should be advised that each pre-test covers only a representative sample of the types of questions found on the test. Due to the need to keep the pre-test brief, not all subject matter is covered on every pre-test. Thorough preparation for the certification test is strongly encouraged.

The experience of taking pre-tests under timed conditions should reduce test anxiety associated with the actual certification test. If necessary, candidates may wish to retake the pre-tests after some period of time has elapsed to recheck their knowledge.

Suggestions or comments for improvements of these pretests and other certification materials should be sent to:

Fluid Power Certification Board
c/o FPS
3245 Freemansburg Avenue
Palmer, PA 18045-7118
Phone: 610-923-0386,
Fax: 610-923-0389,
E-mail: FPS@IFPS.org.

PNEUMATIC TECHNICIAN CERTIFICATION PRE-TEST

FORM PT-1

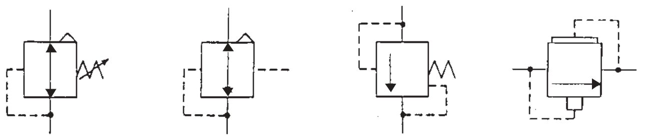
Pre-Test Instructions

Please write your name at the top of the answer sheet and record your answers in the circles provided. Make sure there are no stray marks on the answer sheet and that all erasures are removed completely. Please do not mark on the test. Each test item has only one best answer. There is no correction for guessing, so select the answer you feel is the most correct. Be sure to answer every item. You will have 60 minutes to complete the 25 items. YOU MAY USE A CALCULATOR AND TWO STANDARD REFERENCE GUIDES.

When you have finished, please give the test and your answer sheet to the test proctor.

1. How is the vent (relieving) feature shown on one or more of the regulator symbols shown?

a. Arrow drawn at 45 degrees.
b. Spring shown opposite pilot.
c. Internal line with one arrow.
d. Open triangle attached to the square box.
e. Pilot connected to the downstream line.

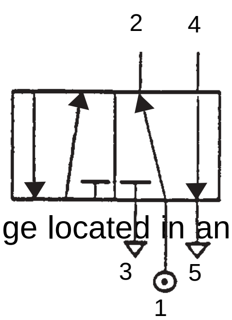


2. A three-position, exhaust center, directional control air valve connects:

a. two cylinder ports to both exhaust ports.
b. one pressure port to both exhaust ports.
c. two cylinder ports to one exhaust port.
d. one pressure port to both cylinder ports.
e. two pressure ports to both cylinder ports.

3. On a five port, two-position air valve, like that shown, if port 1 is connected to port 2 in the normal position, what port is connected to port 1 when the valve is actuated?

a. 1 is connected to 2.
b. 1 is connected to 3.
c. 1 is connected to 4.
d. 1 is connected to 5.
e. None, Port 1 is blocked.



4. Where is the pressure gauge located in an FRL unit?

a. Before the filter element.
b. After the filter element.
c. After the regulator.
d. After the lubricator.
e. At the drain tap.

5. What is the degree Rankine temperature of 125°F?

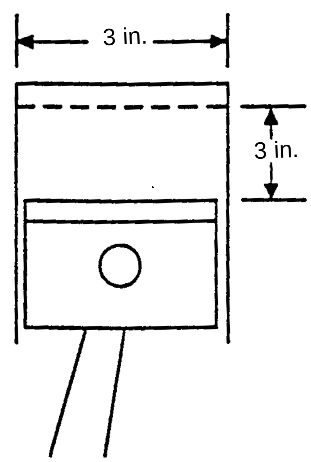
a. 335°R
b. 445°R
c. 485°R
d. 585°R
e. 685°R

6. A pressure gauge reads 0 psig. What is the absolute pressure in psia?

a. 0 psia
b. 7.2 psia
c. 14.7 psia
d. 21.4 psia
e. 28.6 psia

7. If air at the inlet of a cylinder with a 3 inch bore and 3 inch stroke is compressed into a 3.0 cubic inch space at the top of the cylinder, while the temperature increases from 70°F to 120°F, what would be the gauge pressure when the piston is at the top of the cylinder? (Assume 100 volumetric efficiency and adiabatic conditions.)

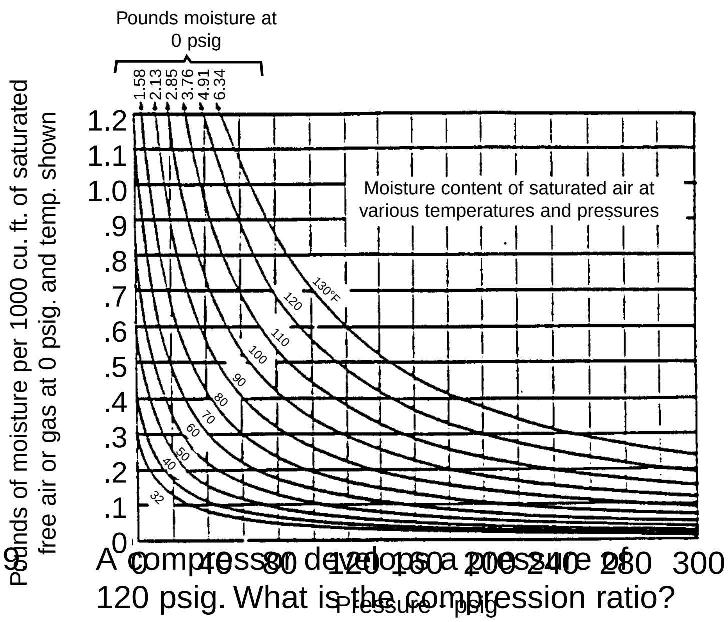
a. 80.3 psia
b. 95.0 psig
c. 99.0 psia
d. 109.7 psig
e. 115.1 psig



8. If 1000 cubic feet of saturated air at atmospheric pressure and 80° F is drawn into the inlet of a compressor and

compressed to 100 psig, approximately how much water could be expected to be removed from the compressed air if the temperature is restored to 80°F?

a. 0.20 lbs
b. 1.38 lbs
c. 1.58 lbs
d. 2.13 lbs
e. 2.85 lbs



9. A compressor develops a pressure of 120 psig. What is the compression ratio?

a. 8.2:1
b. 9.2:1
c. 10.2:1
d. 11.2:1
e. 12.2:1

10. A compressed air system leaks at the rate of 3 cfm. If it requires 0.02 kWh/cu-ft to compress the air, and the cost of electrical power is 0.04$/kWh, how much would the air leak cost per week if the system operated 24 hrs/day?

a. $3.46
b. $8.06
c. $12.10
d. $16.87
e. $24.19

11. Compressor ratings in scfm refer to:

a. free air
b. displacement.
c. pressurized air.
d. ambient conditions.
e. standard conditions.

12. Which one of the following valves has the most friction in the full-open position?

a. Globe.
b. Angle.
c. Gate.
d. Plug cock.
e. Swing check.

13. An air valve delivers 35 scfm at 70°F with a supply pressure of 80 psig. If the valve has an 8 psig pressure drop, what is the C_v for the valve?

a. 1.30
b. 1.33
c. 1.35
d. 1.42
e. 1.46

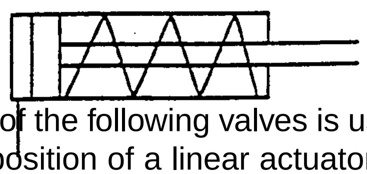
14. A 1.5 inch bore single rod air cylinder has 105 psig at the inlet port. Neglecting friction, what is the maximum force

available from the cylinder when the rod extends?

a. 46.7 lbs
b. 59.4 lbs
c. 85.2 lbs
d. 157.5 lbs
e. 185.9 lbs

15. Which directional control valve would be used to extend, hold, and retract th single-acting air cylinder shown?

a. 1/1
b. 2/2
c. 3/2
d. 3/3
e. 4/2

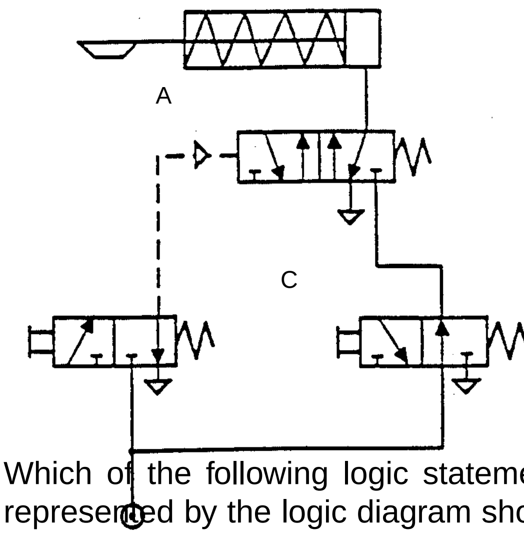


16. Which one of the following valves is used to signal the position of a linear actuator?

a. Limit.
b. Shuttle.
c. Directional.
d. Flow control.
e. Pressure sequence.

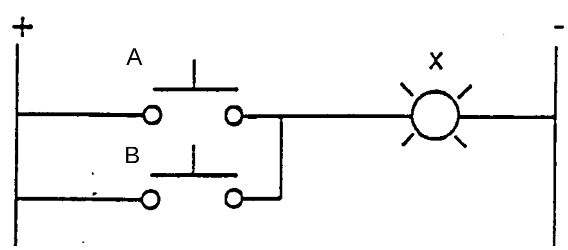
17. Which of the following logic statements best describes the circuit shown?

a. B OR C = extend.
b. B AND C = extend.
c. B and NOT C = extend.
d. NOT B OR C = extend.
e. NOT B AND C = extend.



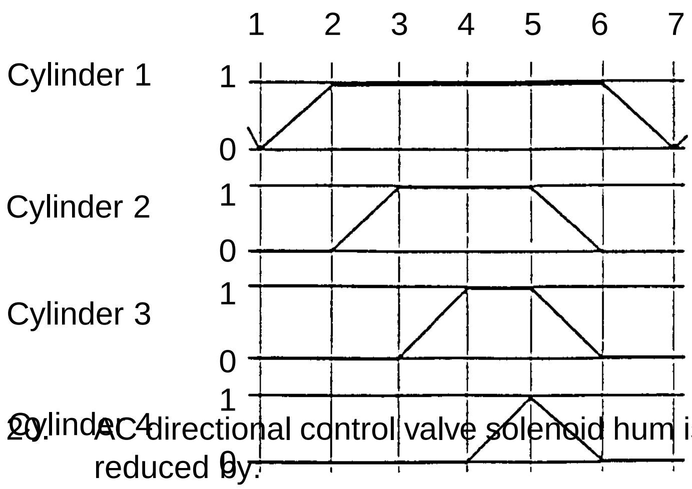
18. Which of the following logic statements is represented by the logic diagram shown?

a. A ● B = Output.
b. A + B = Output.
c. $\underline{A}$ ● $\underline{B}$ = Output.
d. $\underline{A}$ + $\underline{B}$ = Output.
e. $\underline{A}$ ● B = Output.



19. In the motion diagram shown, where is the limit switch (valve) actuated to retract cylinder No. 2?

a. Cylinder No. 1 extended.
b. Cylinder No. 2 extended.
c. Cylinder No. 3 extended.
d. Cylinder No. 3 retracted.
e. Cylinder No. 4 extended.

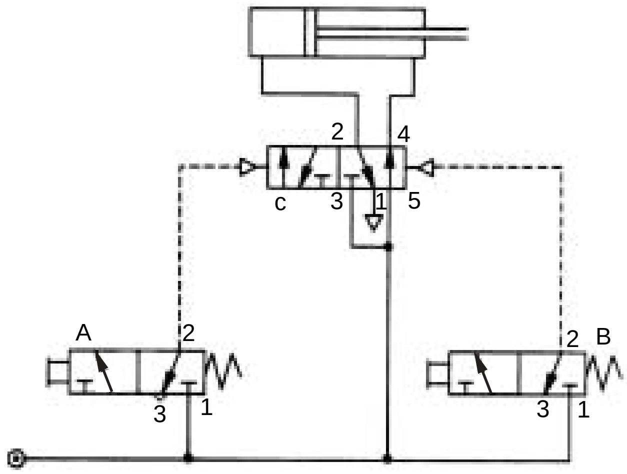


20. AC directional control valve solenoid hum is reduced by:
a. reducing solenoid inrush current.
b. lowering solenoid line voltage.
c. reducing solenoid shifting rate.
d. reducing solenoid return spring force.
e. installing a solenoid with a shading coil.

21. What is the resistance of a 32 volt DC solenoid that has a holding current of 3.5 amperes?
a. 0.11 ohms
b. 2.61 ohms
c. 3.50 ohms
d. 9.14 ohms
e. 94.81 ohms

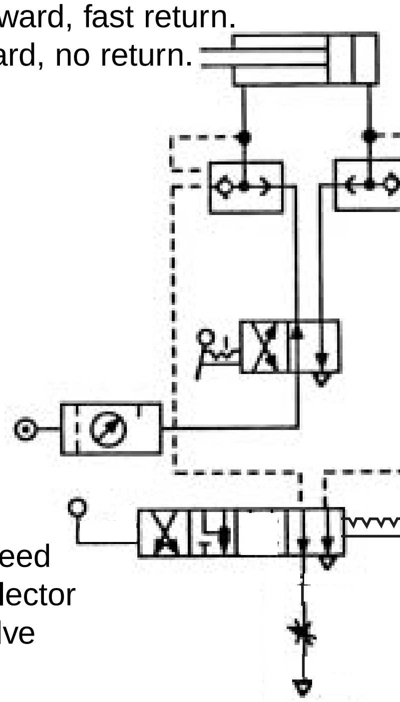
22. Where would a single flow control valve be placed in the circuit shown to provide meter-out control in both directions?

a. Rod end of the cylinder.
b. Blank end of the cylinder.
c. Left inlet of the control valve.
d. Right inlet of the control valve.
e. Exhaust port of the control valve.



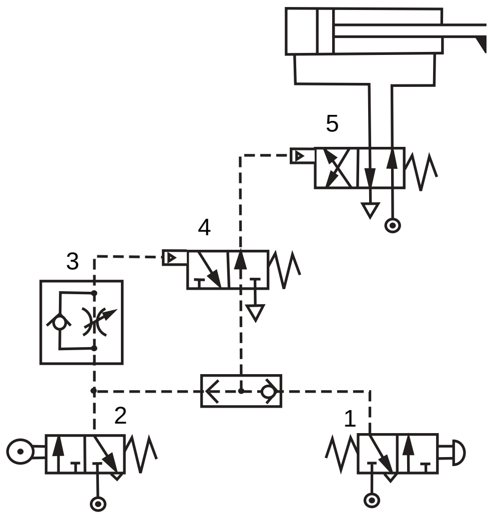
23. Which speed conditions are selected when the speed selector valve in the circuit shown is in the center position?

a. Fast forward, slow return.
b. Fast forward, fast return.
c. Slow forward, slow return.
d. Slow forward, fast return.
e. No forward, no return.



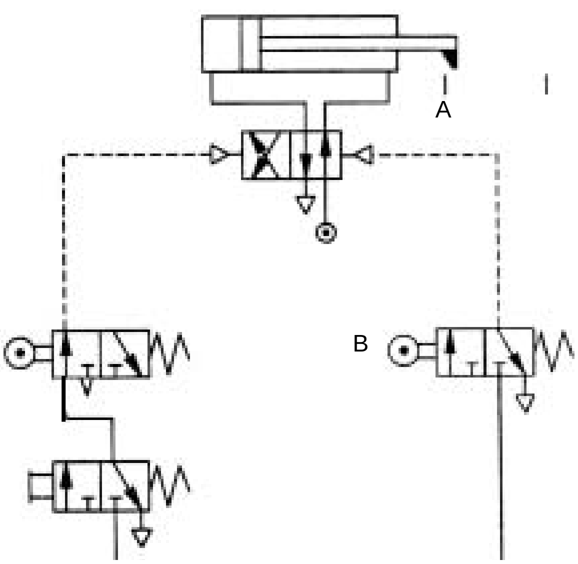
24. Which component in the air press circuit shown is the signal output component?

a. Cylinder.
b. Valve 1.
c. Valve 2.
d. Valve 3.
e. Valve 4.



25. When the air is turned on, the cylinder in the circuit shown retracts. When the start valve is actuated and released, the cylinder extends and locks up. Which component is causing the problem?

a. Cylinder.
b. Start valve.
c. Control valve.
d. Limit valve B.
e. Limit valve A.



PT-1 Pre-Test Answer Sheet

Pneumatic Symbols

Outcome:	Page	Answers
1. Identifies graphic symbols for pressure control and flow valves.	12	1. A B C D E
4. Distinguishes between pneumatic blocked center, pressure center, and exhaust center three-position directional control power valve symbols.	14	2. A B C D E
5. Recognizes flow paths through pneumatic directional control valves in the different positions.	15	3. A B C D E
7. Recognizes component operation from its graphical symbol.	17	4. A B C D E

Gas Laws

9. Converts temperature to absolute values.	20	5. A B C D E
10. Converts pressure measurement between psi (gauge) and psia (absolute).	21	6. A B C D E
12. Understands pressure, volume and temperature relationships given by the general gas law.	23	7. A B C D E
14. Determines the moisture content of air from pressure/temperature graphs.	24	8. A B C D E
16. Understands the relationship between gauge pressure and compression ratio.	26	9. A B C D E

Maintenance

20. Computes the cost of cfm leakage in a compressed air system.	30	10. A B C D E

Components

23. Knows that compressor delivery is expressed in cfm at ambient conditions, or scfm at standard conditions of 14.7 psia, 68 °F, and relative humidity of 36% (0.0750 density).	33	11. A B C D E
27. Associates friction factors with pressure losses in pneumatic valves.	37	12. A B C D E
31. Calculates Cv and flow rates for pneumatic valves.	39	13. A B C D E
34. Understands pressure and area relationships as they affect cylinder output force.	43	14. A B C D E
37. Understands that pneumatic signal output units (valves) must match working units (cylinders and motors).	47	15. A B C D E

Controls

40. Recognizes that pneumatic limit valves signal the control system when an event has taken place.	51	16. A B C D E
44. Identifies logic controls with logic circuits.	57	17. A B C D E
48. Recognizes logic statements that describe ladder diagrams.	62	18. A B C D E
51. Determines a cylinder operation sequence for a motion diagram.	65	19. A B C D E
54. Understands that solenoid coil hum is caused by alternating current and the bias spring.	68	20. A B C D E
57. Understands the relationship given by Ohm’s law.	70	21. A B C D E

PT-1 Pre-Test Answer Sheet

Basic Circuits

62.	Understands that tractive (overrunning) loads are controlled in pneumatic circuits by meter-out circuits.	75	22. A B C D E
63.	Understands pneumatic speed regulation circuits.	76	23. A B C D E

Troubleshooting

66.	Understands that studying the circuit diagram is necessary to identify component function and sequence of operation.	80	24. A B C D E
69.	Traces fault backward from working element (cylinder), to signal input pilot valves.	85	25. A B C D E

PNEUMATIC TECHNICIAN
CERTIFICATION
PRE-TEST

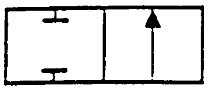
FORM PT-2

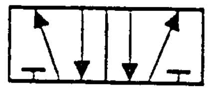
Pre-Test Instructions

Please write your name at the top of the answer sheet and record your answers in the circles provided. Make sure there are no stray marks on the answer sheet and that all erasures are removed completely. Please do not mark on the test. Each test item has only one best answer. There is no correction for guessing, so select the answer you feel is the most correct. Be sure to answer every item. You will have 60 minutes to complete the 25 items. YOU MAY USE A CALCULATOR AND TWO STANDARD REFERENCE GUIDES.

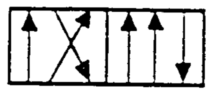
When you have finished, please give the test and your answer sheet to the test proctor.

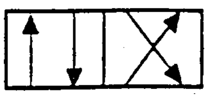
1. Which one of the symbols shown is a four way, two position valve (4/2)?

a. 

d. 

b. 

e. 

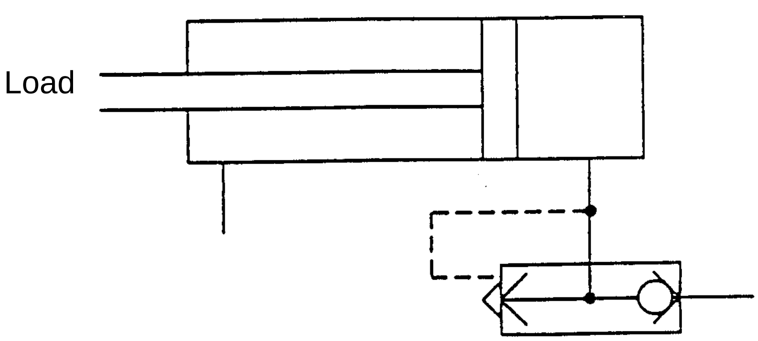
c. 

2. A three-position, pressure center, directional control air valve connects:

a. two pressure ports to both cylinder ports.
b. one pressure port to both cylinder ports.
c. two cylinder ports to one exhaust port.
d. one pressure port to both exhaust ports.
e. two cylinder ports to both exhaust ports.

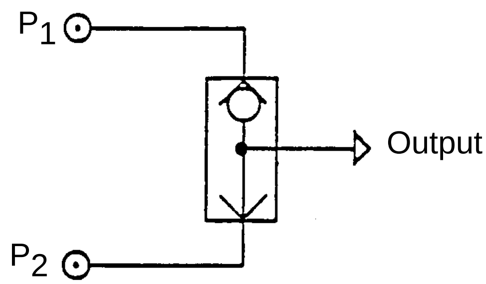
3. The position of the check in the quick-exhaust exhaust valve shown indicates that the cylinder is:

a. holding.
b. extending.
c. retracting.
d. exhausting.
e. decelerating.

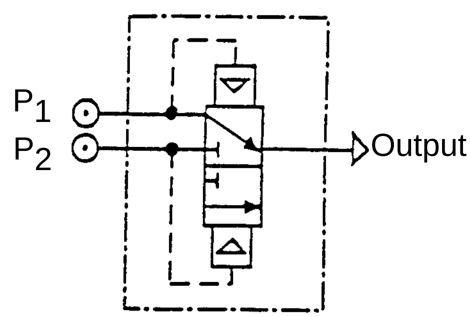


4. Which of the following applications would use a shuttle valve like that shown?

a. Quick exhaust.
b. Safety release.
c. Quick disconnect.
d. Two station control
e. Pressure relief valve.



Simplified



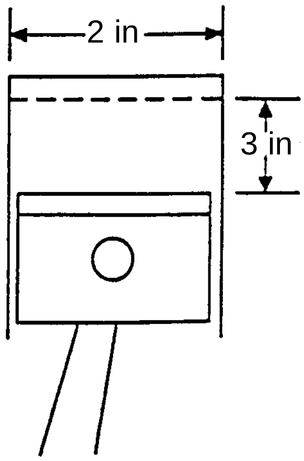
Detailed

5. What is the degree Fahrenheit temperature of 585 °R?

a.   90 °F
b. 110 °F
c. 115 °F
d. 125 °F
e. 140 °F

6. A 2 inch diameter piston with a 3 inch stroke, like that shown in the figure com presses air at atmospheric pressure into a 2 cubic inch space at the top of the cylinder. Use Boyle's law to determine the gauge pressure after the gas has been compressed.

a. 39.9 psig
b. 54.6 psia
c. 69.3 psig
d. 84.0 psig
e. 119.6 psia



7. Dew point must be reported as a given:

a. volume.
b. pressure.
c. humidity.
d. temperature.
e. compression ratio.

8. At 80°F, at saturation, air contains 1.58 lb/1000 cu-ft of water vapor. If a sample contains 0.00079 lb/cu-ft at 80°F, what is its relative humidity? Refer to page 24 for the chart in Figure 10.

a. 20%
b. 30%
c. 40%
d. 50%
e. 60%

9. For vacuum packaging purposes, what is the negative psi gauge reading of a column of mercury of 19 inches?

a. - 4.55 psig
b. - 8.10 psig
c. - 9.33 psig
d. -11.91 psig
e. -19.91 psig

10. How many inches will an air piping run with a downward pitch of 1.5% drop in 75 feet?

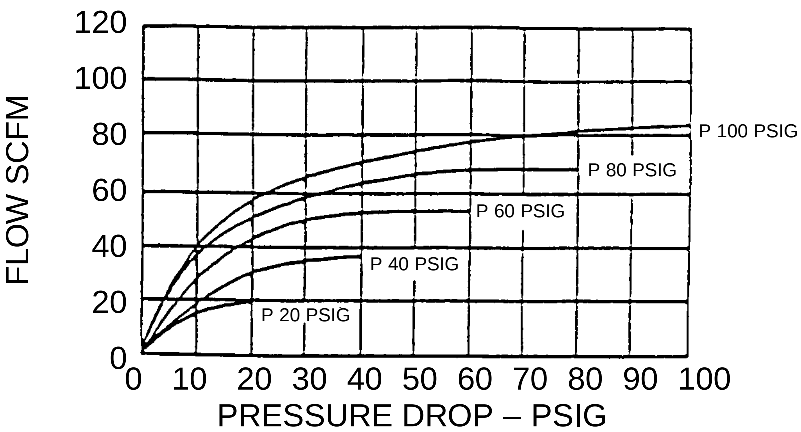
a. 11.25 inches
b. 13.50 inches
c. 22.25 inches
d. 26.00 inches
e. 41.75 inches

11. Which of the following is measured at the compressor inlet?

a. rpm
b. scfm
c. delivery in cfm
d. pressure in psig
e. displacement in cubic inches

12. Using the performance curve shown, determine how many scfm the valve would deliver at an operating pressure of 100 psig, and still keep the pressure drop to less than 25 psig.

a. 80 scfm
b. 70 scfm
c. 60 scfm
d. 50 scfm
e. 40 scfm



13. Leakage causes the pressure in a 60 gallon receiver to drop from 140 psia to 110 psia in 10 minutes. How many cfm free air is the air leak?

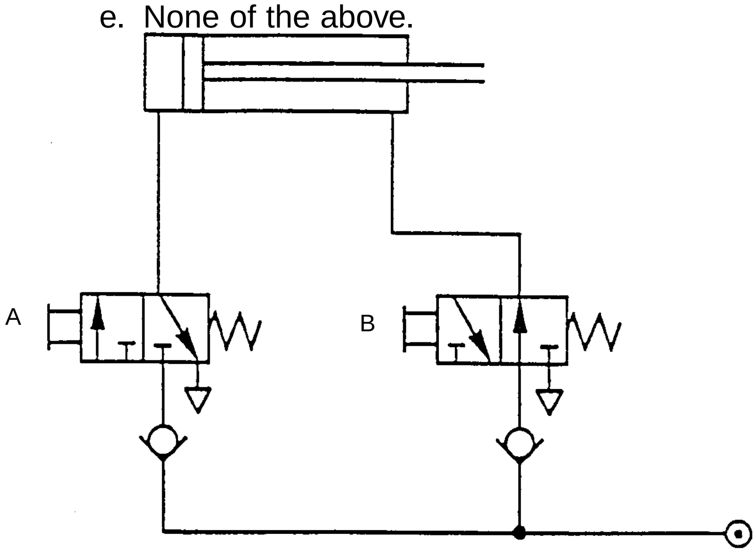
a. 1.22 cfm
b. 1.64 cfm
c. 2.08 cfm
d. 3.57 cfm
e. 4.63 cfm

14. A 1.5 inch bore single-acting cylinder that extends through a 3 inch stroke, cycles at 15 cpm on 85 psig air. How many cfm will the cylinder displace?

a. 0.27 cfm
b. 0.31 cfm
c. 0.48 cfm
d. 0.53 cfm
e. 0.62 cfm

15. Which valve position in the figure shown would cause the cylinder rod to extend at a reduced force from the retracted position?

a. Valve A actuated, valve B actuated.
b. Valve A deactuated, valve B actuated.
c. Valve A deactuated, valve B deactuated.
d. Valve A actuated, valve B deactuated.
e. None of the above.



16. An air logic system is used to control:

a. actuator force.
b. actuator speed.
c. operation sequence.
d. actuator limit switches.
e. actuator stroke/rotation.

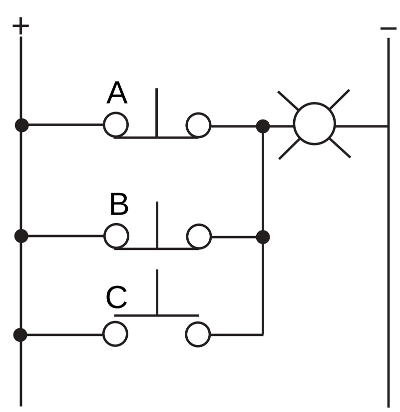
17. Which one of the following ladder diagram elements would consume no power?

a. Solenoid.
b. Relay coil.
c. Signal light.
d. Electric motor.
e. Pressure switch.

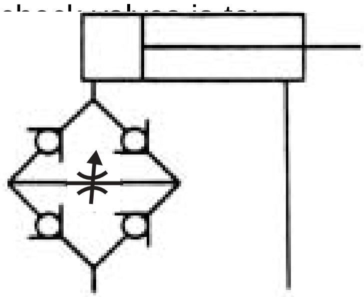
18. A parallel circuit ladder diagram has three contacts connected as follows:
A - normally closed.
B - normally closed.
C - normally open.
Which row in the truth table given in the figure would generate an open condition (no output)?

a. 1
b. 2
c. 4
d. 5
e. 6

Row	A	B	C
1.	0	0	0
2.	1	0	0
3.	0	1	0
4.	0	0	1
5.	1	1	0
6.	1	0	1
7.	0	1	1
8.	1	1	1



19. The function of the



a. divide the flow.
b. amplify the flow.
c. rectify the flow.
d. reverse the flow.
e. flip-flop the flow.

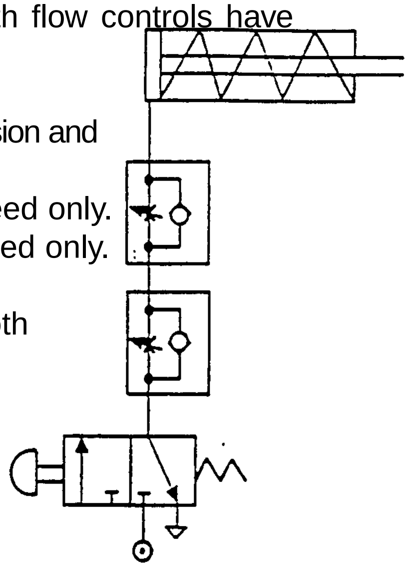
20. Which one of the following would determine if AC directional control valve solenoid hum were caused by incomplete motion of the plunger?

a. Shift the manual override.
b. Disconnect the solenoid.
c. Increase the line voltage.
d. Decrease the line voltage.
e. Increase air line pressure.

21. A DC solenoid coil has a resistance of 12 ohms. How much current would the coil draw at 32 volts DC?

a. 0.4 amperes.
b. 1.3 amperes.
c. 2.7 amperes.
d. 5.3 amperes.
e. 9.1 amperes.

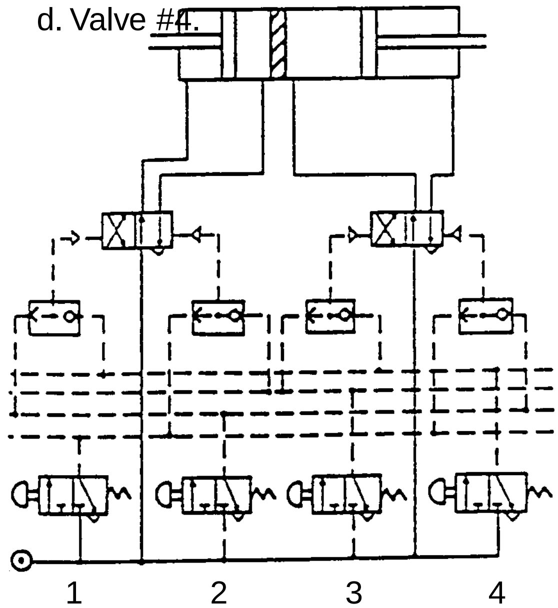
22. Assuming the flow controls are set differently, what effect would reversing the free-flow checks in both flow controls have on the circuit shown?



a. Reversing both extension and retraction speed.
b. Meter extension speed only.
c. Meter retraction speed only.
d. No effect.
e. Air would bypass both flow controls.

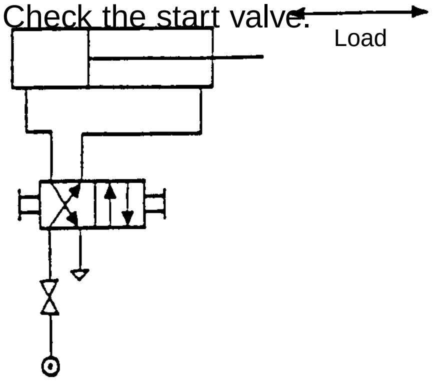
23. Which valve has been depressed in the circuit shown to shift the directional control valves (not the cylinders) to the positions shown?

a. Valve #1
b. Valve #2.
c. Valve #3.
d. Valve #4.



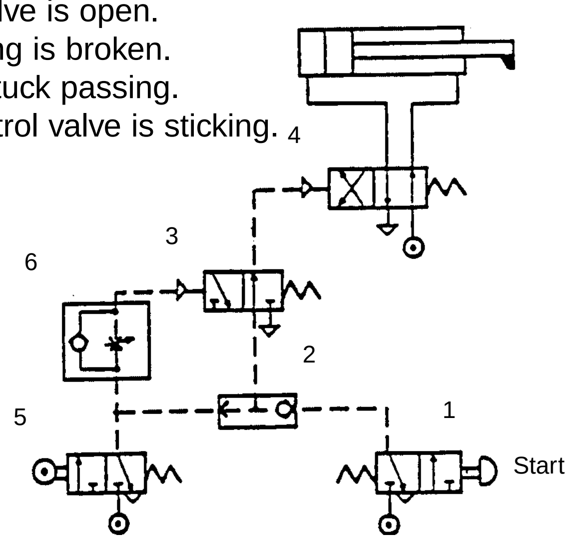
24. The air cylinder shown has a 2 inch bore and 1 inch diameter rod and extends and retracts, moving a constant load. The cylinder almost stalls retracting. What should be done to increase retraction velocity?

a. Replace the rod seal.
b. Clean the pilot valve.
c. Remove pilot line restriction.
d. Increase the air pressure.
e. Check the start valve.



25. When the operator depresses the palm button on the start valve in the circuit shown, the cylinder rod fully extends. After five seconds the cylinder rod retracts a few inches and then extends again. This cycle repeats so long as the air pressure source is maintained. Which component is at fault?

a. Shuttle valve is stuck.
b. Flow control valve is open.
c. Pilot valve spring is broken.
d. Start valve is stuck passing.
e. Directional control valve is sticking.



PT-2 Pre-Test Answer Sheet

Pneumatic Symbols

Outcome:	Page	Answers
2. Understands that port connections in directional control valve symbols count as ways.	13	1. A B C D E
4. Distinguishes between pneumatic blocked center, pressure center, and exhaust center three-position directional control power valve symbols.	14	2. A B C D E
6. Identifies symbols for directional control valves.	15	3. A B C D E
7. Recognizes component operation from its graphical symbol.	17	4. A B C D E

Gas Laws

9. Converts temperature to absolute values	20	5. A B C D E
11. Understands the relationships given by Boyle's Law.	22	6. A B C D E
13. Understands that the dew point of air is the temperature at which air is fully saturated with water.	24	7. A B C D E
15. Understands the relationship between relative humidity, absolute humidity, and humidity at saturation.	24	8. A B C D E
17. Understands the relationship between height of a column of mercury and negative psi gauge reading.	27	9. A B C D E

Maintenance

21. Calculates the inch drop per length of run from the percent grade for air line.	31	10. A B C D E

Components

23. Knows that compressor delivery is expressed in cfm at ambient conditions, or scfm at standard conditions of 14.7 psia, 68 °F, and relative humidity of 36% (0.0750 density).	33	11. A B C D E
29. Predicts directional control valve operation from performance curves.	38	12. A B C D E
32. Understands how pressure, air consumption rate, and time relate to air receiver size.	41	13. A B C D E
35. Computes the scfm required to power an air cylinder.	44	14. A B C D E
38. Recognizes that various signal output units (valves) can alter operating characteristics of working units (actuators).	48	15. A B C D E

Controls

42. Recognizes that air logic systems control the sequence of operations.	53	16. A B C D E
46. Understands that electrical contacts have negligible electrical resistance, whereas output elements have appreciable electric resistance.	60	17. A B C D E
49. Identifies equivalent logic statements from a truth table.	63	18. A B C D E

PT-2 Pre-Test Answer Sheet

52.	Understands the function of the Graetz rectifier.	66	19. A B C D E
55.	Associates a loud AC solenoid hum with failure of the armature, or failure of the plunger to seat.	68	20. A B C D E
57.	Understands the relationship given by Ohm's law.	70	21. A B C D E

Basic Circuits

63.	Understands pneumatic speed regulation circuits.	76	22. A B C D E
64.	Understands switching circuits for pneumatic branching operations.	78	23. A B C D E

Troubleshooting

67.	Associates slow air cylinder return with minimum (low) air pressure operating against the rod side of the piston.	82	24. A B C D E
70.	Identifies component malfunction in a pneumatic system.	87	25. A B C D E

PNEUMATIC TECHNICIAN
CERTIFICATION
PRE-TEST

FORM PT-3

Pre-Test Instructions

Please write your name at the top of the answer sheet and record your answers in the circles provided. Make sure there are no stray marks on the answer sheet and that all erasures are removed completely. Please do not mark on the test. Each test item has only one best answer. There is no correction for guessing, so select the answer you feel is the most correct. Be sure to answer every item. You will have 60 minutes to complete the 25 items. YOU MAY USE A CALCULATOR AND TWO STANDARD REFERENCE GUIDES.

When you have finished, please give the test and your answer sheet to the test proctor.

1. Which center position would allow a reversible air motor to coast in the center position?

   a. Open center.
   b. Closed center.
   c. Tandem center.
   d. Exhaust center.
   e. Pressure center.

2. A three-position, exahust center, directional control air valve connects:

   a. two cylinder ports to both exhaust ports.
   b. one pressure port to both exhaust ports.
   c. two cylinder ports to one exhaust port.
   d. one pressure port to both cylinder ports.
   e. two pressure ports to both cylinder ports.

3. Where is the water separator located in an FRL unit?

   a. Before the filter element.
   b. After the filter element.
   c. After the regulator.
   d. After the lubricator.
   e. At the drain tap.

4. Excess flow control valves are designed to reduce:

   a. costs.
   b. injuries.
   c. air consumption
   d. air hose length.
   e. air line pressure drop.

5. A pressure gauge reads 110 psig. What is the pressure in psia?

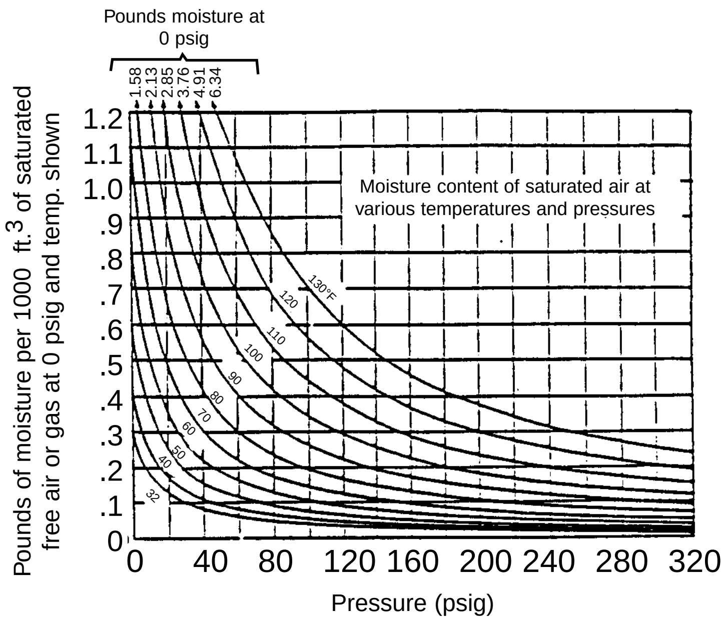
   a. 85.3 psia.
   b. 95.3 psia.
   c. 104.7 psia.
   d. 110.7 psia.
   e. 124.7 psia.

6. A compressor delivers 10 cfm for 2 minutes to a 50 gallon receiver. Assuming no losses, and that the reciever was empty, what is the final receiver gauge pressure at the ambient temperature?

   a. 20 psig
   b. 29 psig
   c. 44 psig
   d. 59 psig
   e. 87 psig

7. From the graph shown, approximate how much moisture would 2000 cu-ft of free air contain at 90°F at its dew point?

   a. 3.16 Ibs
   b. 4.26 Ibs
   c. 5.70 Ibs
   d. 7.52 lbs
   e. 9.82 Ibs



8. A single-stage piston compressor develops 100 psig. Assuming 100% volumetric efficiency, what is the compression ratio of the compressor?

   a. 5.8 to 1
   b. 6.8 to 1
   c. 7.8 to 1
   d. 8.8 to 1
   e. 9.8 to 1

9. How many inches of mercury vacuum would be required to give a 3 inch diameter vacuum pad application a lifting force of 50 pounds?

   a. 11.5 inches
   b. 14.4 inches
   c. 15.2 inches
   d. 17.3 inches
   e. 19.6 inches

10. Which method of removing the moisture from compressed air has the lowest operating cost?

    a. Adsorption.
    b. Absorption.
    c. Refrigeration.
    d. Silica gel attachment.
    e. Water separation sieves.

11. An air compressor that operates intermittently delivers 25 scfm compressed to 115 psig. If receiver size equals three times compressor delivery, what gallon size is the receiver?

    a. 21.2 gal
    b. 36.4 gal
    c. 48.8 gal
    d. 63.6 gal
    e. 75.0 gal

12. A flow control valve with a C_v rating of 0.2 will flow 7 scfm at 80 psig with a 10 psig pressure drop. What C_v rating would flow 14 scfm under the same conditions?

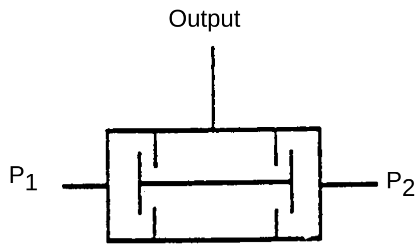
    a. 0.1
    b. 0.2
    c. 0.3
    d. 0.4
    e. 0.5

13. If the pressure at the receiver is 125 psia, and the pressure at the air tool is 110 psia, what would be the maximum distance between the receiver and air tool to keep the pressure drop to 0.1 psid/foot?

    a. 10 ft
    b. 15 ft
    c. 75 ft
    d. 100 ft
    e. 150 ft

14. Which of the following statements is true for the two pressure valve shown?

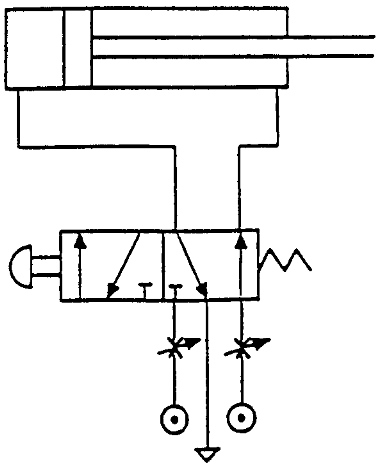
    a. The output signal requires one input signal.
    b. The lowest pressure input flows to the outlet.
    c. The first pressure input flows to the outlet.
    d. The valve works the same as a shuttle valve.
    e. The valve checks reverse flow.



Two Pressure

15. A four-way directional control valve plumbed as a five-way directional control valve has:

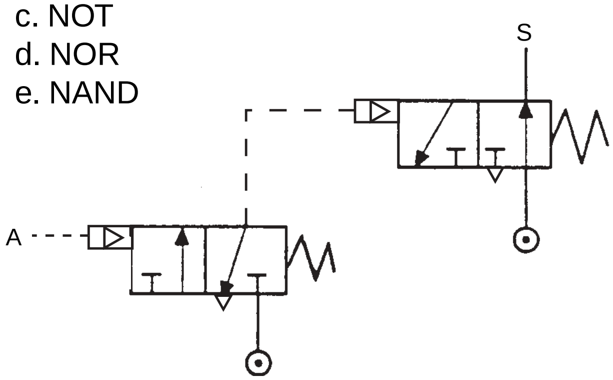
   a. two exhaust ports.
   b. one pressure port.
   c. one cylinder port.
   d. two pressure ports.
   e. three exhaust ports.



Five Way

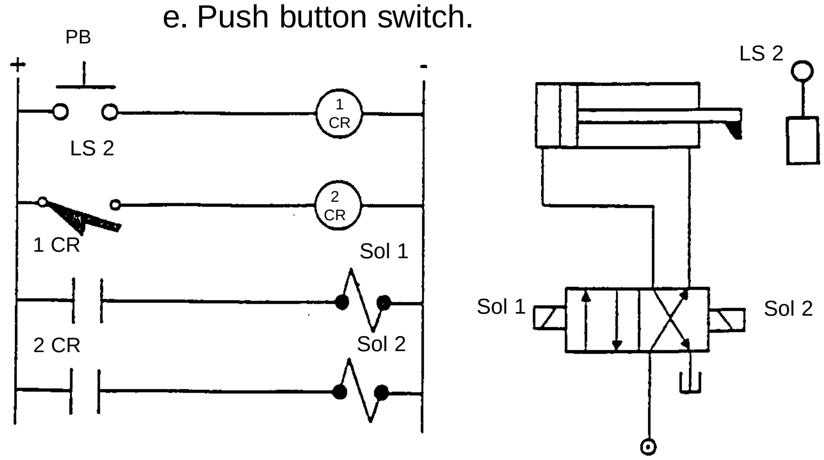
16. What kind of logic signal will the circuit shown produce?

   a. AND
   b. OR
   c. NOT
   d. NOR
   e. NAND



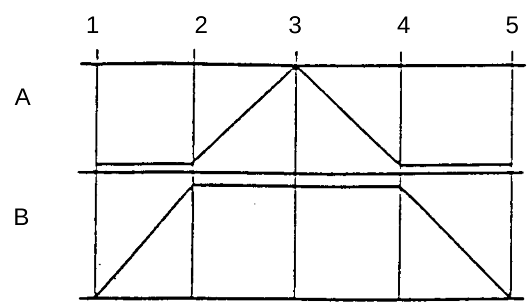
17. Which electrical element in the ladder diagram shown, signals the cylinder to retract?

   a. Solenoid 2.
   b. Limit switch 2.
   c. Control relay 1.
   d. Control relay 2.
   e. Push button switch.



18. Which of the following written motion sequences matches the motion diagram shown?

   a. B +, A -, B -, A +
   b. B -, A +, A +, B +
   c. B -, A -, B +, A +
   d. B +, A +, A -, B -
   e. B -, A +, B +, A -



19. Which electrical component listed protects a switch against arcing?

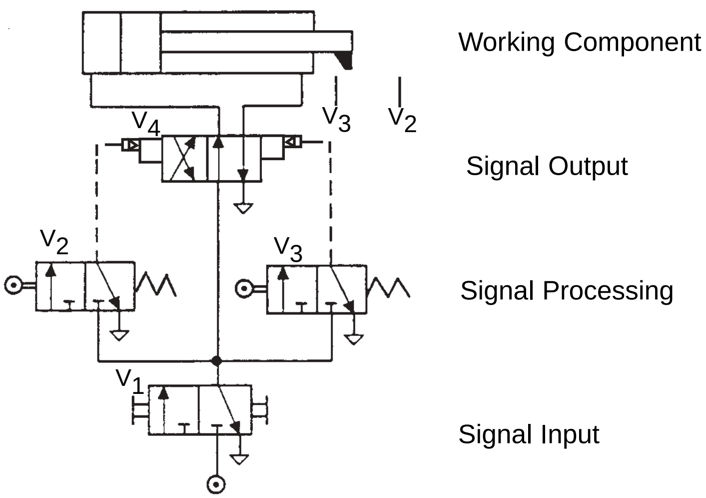
   a. Coil.
   b. Capacitor.
   c. Relay contact.
   d. Pressure switch.
   e. Circuit breaker.

20. If the shading coil (shading ring) in an AC directional control valve was left out when the solenoid was assembled, the valve will:

    a. fail to shift at all.
    b. make a louder hum.
    c. cause the plunger to seize.
    d. burn out the solenoid winding.
    e. shift at a lower air line pressure.

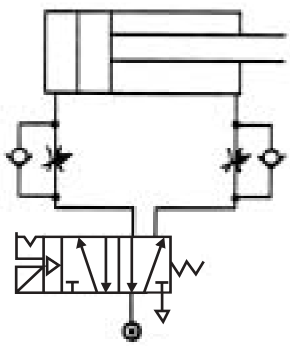
21. The purpose for valve V_2 in circuit shown is to:

    a. retract cylinder direction.
    b. regulate return air pressure.
    c. lock the cylinder in position.
    d. vent return air from the cylinder.
    e. relieve over pressure from the cylinder.



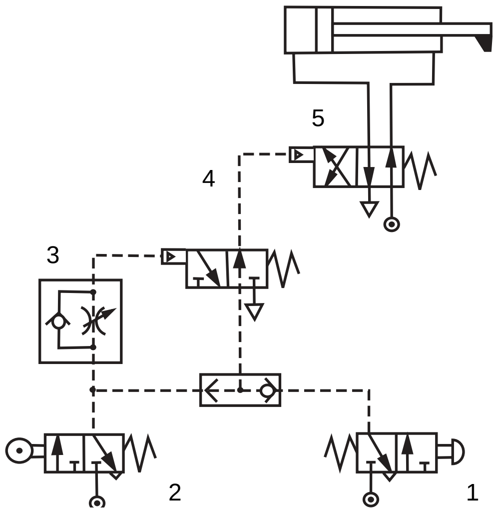
22. Reversing the reverse free-flow checks in both flow controls would cause the circuit shown to:

    a. meter-in, both directions.
    b. meter-out, both directions.
    c. meter-in, extension only.
    d. meter-out retraction only.
    e. have no effect in either direction.



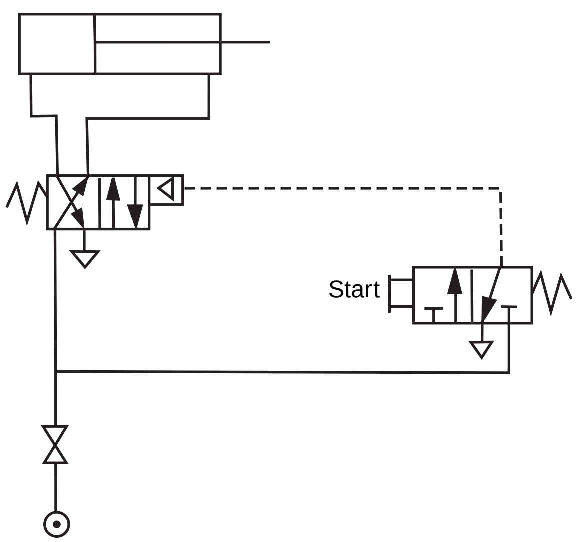
23. Which valve in the circuit shown is manually operated?

    a. 1
    b. 2
    c. 3
    d. 4
    e. 5



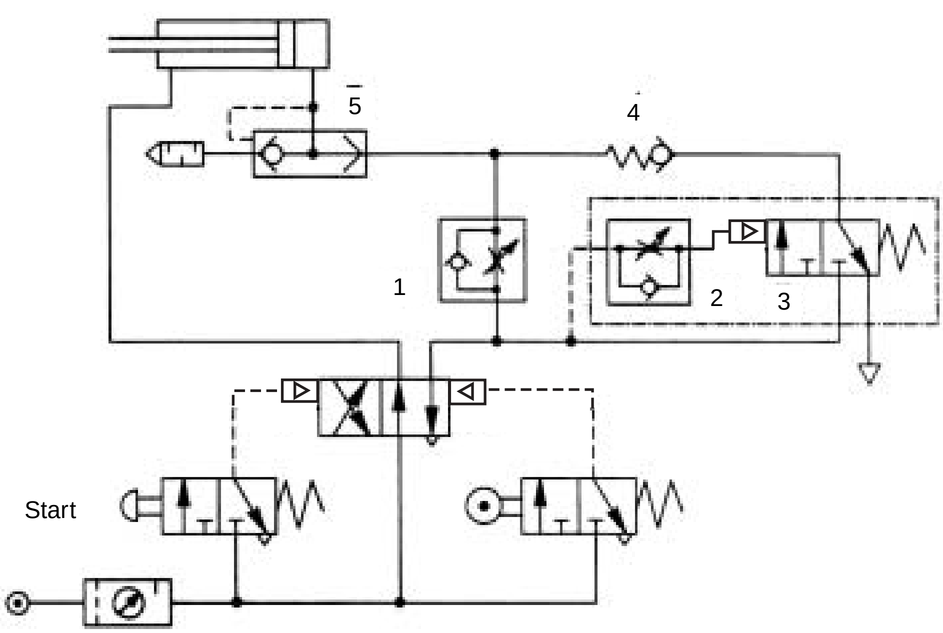
24. The air cylinder shown should extend and retract, moving a constant load, when the start valve is actuated and released. Instead, the cylinder stalls retracting and air can be heard escaping from the exhaust port on the directional control valve. What is the likely cause of the problem?

a. Binding load.
b. Low air pressure.
c. Stuck start valve.
d. Blown piston seal.
e. Stuck directional control valve.



25. Which valve in the circuit shown controls the initial extension speed of the cylinder rod?

a. 1.
b. 2.
c. 3.
d. 4.
e. 5.



PT-3 Pre-Test Answer Sheet

Pneumatic Symbols

Outcome:		Page	Answers
3.	Recognizes that blocked center, pressure center, and exhaust center are the most common center conditions for pneumatic control valves.	14	1. A B C D E
4.	Distinguishes between pneumatic blocked center, pressure center, and exhaust center three-position directional control power valve symbols.	14	2. A B C D E
7.	Recognizes component operation from its graphical symbol.	17	3. A B C D E
8.	Recognizes purpose and function of a pneumatic excess flow control valve (OSHA Regulation for construction. Part 1926.302, April 6, 1979).	19	4. A B C D E

Gas Laws

10.	Converts pressure measurement between psig (gauge) and psia (absolute).	21	5. A B C D E
11.	Understands the relationships given by Boyle's Law.	22	6. A B C D E
14.	Determines the moisture content of air from pressure-temperature graphs.	24	7. A B C D E
16.	Understands the relationship between gauge pressure and compression ratio.	24	8. A B C D E
18.	Determines the force and area relationships for vacuum pad applications.	28	9. A B C D E

Maintenance

22.	Associates methods of removing moisture from compressed air with operating costs.	32	10. A B C D E

Components

26.	Computes air receiver capacity from the constant (K), cfm delivery from the compressor, working pressure, and ambient conditions.	36	11. A B C D E
30.	Understands that the flow capacity of directional control valves is in direct proportion to the C_v factor.	39	12. A B C D E
33.	Calculates pressure drop in an air line.	42	13. A B C D E
36.	Associates pneumatic valve type with operation.	45	14. A B C D E
39.	Distinguishes between four-way and five-way plumbing of a four-way directional control valve.	49	15. A B C D E

Controls

43.	Recognizes various air logic circuits.	54	16. A B C D E
47.	Understands the interaction between a ladder diagram and a directional control valve shifting mechanism.	61	17. A B C D E
50.	Matches cylinder motion sequences with motion diagrams.	64	18. A B C D E
53.	Identifies function of electrical components in a circuit.	66	19. A B C D E

PT-3 Pre-Test Answer Sheet

56.	Understands that a solenoid shading coil sets up an auxiliary magnetic attraction which is out of phase with the main coil such that it helps to hold the armature as the main magnetic coil attraction drops to zero.	68	20. A B C D E

Basic Circuits

60.	Analyzes component operation in basic air circuits.	73	21. A B C D E
63.	Understands pneumatic speed regulation circuits.	76	22. A B C D E
65.	Distinguishes between will, time, pressure, sequence, and programmed pneumatic circuit control systems.	79	23. A B C D E

Troubleshooting

68.	Understands that if an air cylinder fails to extend under load, it is still able to retract if a 2 position direction control valve is used, if the directional valve is in the cylinder return position.	84	24. A B C D E
71.	Analyzes pneumatic circuits.	89	25. A B C D E

Pneumatic Technician Pre-Test Answer Key

PT-1		PT-2		PT-3	
1.	D	1.	C	1.	D
2.	A	2.	B	2.	A
3.	C	3.	D	3.	A
4.	C	4.	D	4.	B
5.	D	5.	D	5.	E
6.	C	6.	C	6.	B
7.	E	7.	D	7.	B
8.	B	8.	D	8.	C
9.	B	9.	C	9.	B
10.	E	10.	B	10.	C
11.	E	11.	C	11.	D
12.	A	12.	C	12.	D
13.	B	13.	B	13.	E
14.	E	14.	B	14.	B
15.	D	15.	D	15.	D
16.	A	16.	C	16.	C
17.	C	17.	E	17.	B
18.	B	18.	D	18.	D
19.	E	19.	C	19.	B
20.	E	20.	A	20.	B
21.	D	21.	C	21.	A
22.	E	22.	A	22.	A
23.	B	23.	A	23.	A
24.	E	24.	D	24.	D
25.	D	25.	D	25.	A

Help Improve This Guide

Updates, corrections and revisions to this Manual are requested and encouraged. This Manual is the second attempt at developing support materials for Certified Fluid Power candidates. It will undoubtedly require improvement. It is up to CFP candidates and Accredited Instructors to provide input and suggestions for improvement. The Fluid Power Certification Board, composed of industry volunteers, is responsible for determining what revisions and improvements are made to this Manual. The Manuals are updated on a regular basis and date stamped on each page.

Please send your suggestions for improvement to Paul Prass who is coordinating input on behalf of the Fluid Power Certification Board.

Thank you very much for helping us improve these materials for future candidates.

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FLUID POWER CERTIFICATION

Setting competitive standards for Fluid Power Professionals

Fluid Power Certification ... How Can I Benefit?

Fluid Power Certification is a fast-growing educational movement in the industry today - and it's not surprising why.

Much of the traditional training from manufacturers, technical schools, and universities has been of high quality, but limited in its availability. Consequently, few of the 350,000 people working in the industry have been able to take full advantage of Fluid Power training. Many of today's fluid power professionals learned about the technology on the job and often did not receive the recognition they deserved for their educational accomplishments.

If the majority of your professional training was on-the-job or limited to short courses and workshops, then fluid power certification may be just what you need to stay competitive in today's marketplace. Fluid power certification gives you an opportunity to demonstrate your extraordinary effort to enhance your professionalism through education, training, and peer review. It may provide you with the credential you need to open the door for career advancement. For fluid power distributors, manufacturers and end-users, certification offers a multitude of benefits:

- Provides another measure with which to assess new employees.
- Establishes a minimal level of Fluid Power knowledge and skills.
- Educates your customers - so you don't have to.
- Helps satisfy requirements for employee qualifications.
- Demonstrates an individual's efforts to achieve and maintain the highest professional proficiency available in the industry.

What's Involved in Certification?

Fluid power certification consists of an optional review session, followed by a three-hour written test and recognition upon successful completion. For Mechanics' and Technicians' certification, an additional three-hour job performance test is also required.

How Many Kinds of Tests Are Offered?

The Fluid Power Certification Board currently offers nine Certification Tests at four levels:

- **Mechanic:** fabricates, assembles, tests, maintains and repairs systems and components, etc.
  - ***Master Mechanic***
    - Mobile Hydraulic Mechanic
    - Industrial Hydraulic Mechanic
    - Pneumatic Mechanic
- **Technician:** troubleshoots systems, tests and modifies systems, prepares reports, etc.
  - ***Master Technician***
    - Mobile Hydraulic Technician
    - Industrial Hydraulic Technician
    - Pneumatic Technician
- **Specialist:** analyzes and designs systems, selects components, instructs others in operations and maintenance, etc.
  - ***Fluid Power Specialist***
    - Hydraulic Specialist
    - Pneumatic Specialist
- **Engineer:** has a technology or engineering degree or is a current Professional Engineer, has eight years of work experience and has passed the Hydraulic & Pneumatic Specialist exams.

What Technologies are Covered by the Tests?

Fluid power and motion control technologies include questions on hydraulics, pneumatics, electronic control, and vacuum.

Who May Organize a Review Training Session?

Educational institutions, end-user companies, fluid power distributors, fluid power component manufacturers, for-profit educational organizations and the Fluid Power Society (local chapters or the national Headquarters), can organize review training sessions.

Who Administers the Tests?

Written testing is conducted under the supervision of local proctors retained by the Fluid Power Certification Board. Job performance testing may only be administered by an FPS Accredited Instructor. Tests are scheduled throughout the world in over 138 cities throughout the year.

How Will My Accomplishments be Recognized?

Certified fluid power professionals are encouraged to include their certification on their business cards and letterhead - even on work vehicle signage. Certification patches are also available for use on uniforms, as well as other promotional items. All Certified Professionals receive a certificate suitable for framing, wallet card, are recognized in the Fluid Power Journal, are listed in the annual Certification Directory, and on the Fluid Power Society's web site.

Will I Have to Renew My Certification?

Yes - Certifications are valid for five years. After that time, you must apply for re-certification based on a point system. On the re-certification form, you will be asked to list job responsibilities, additional educational courses you have taken or taught, and professional involvement in Fluid Power or allied organizations.

What Will This Cost Me?

The Fluid Power Certification Board has made every effort to keep costs low and make Certification available to as many fluid power professionals as possible. Many manufacturers and distributors subsidize or even reward this program because it provides a great return on investment. A contribution to the fluid power certification program helps upgrade the skills of those professionals committed to the industry and elevates the level of professionalism throughout the entire Fluid Power Industry.

How Can I Receive More Information?

For fee schedules, review sessions, manuals and other information, please visit our web site at www.IFPS.org, at 1-800-214-2958, contact Headquarters at 1-800-330-8520 or write to:

Fluid Power Certification Board
3245 Freemansburg Avenue
Palmer, PA 18046-7118
Phone: 800-330-8520, 610-923-0386;
Fax: 610-923-0389 E-mail:
FPS@IFPS.org;
Web: http://www.IFPS.org;

Fluid Power Certification Board

Certification Coordinator c/o FPS, 3245 Freemansburg Ave., Palmer, PA 18045-7118. Phone: 610-923-0386. Fax: 610-923-0389

Certification Test Application

You have three years from date of application to take the test, after which fees are forfeited.

Please fully complete form.

Name

Home Address

City State Zip

Phone Fax

E-mail address

FPS Member I.D. #

Social Security Number **(Serves as your Test ID Number)**

Preferred mailing address: ❑ Home ❑ Work

Employer

Work Address

City State Zip

Phone Fax

E-mail address

Present Job/Title

❑ **Full Time Student**
(Send proof of Full Time status with application - 12 Credits)

Education Information: (Check highest level attained)

Grade School Years ___________

High School Years ___________ Diploma ___________

Technical Institute Years ___________ Degree ___________

College Years ___________ Degree ___________

NOTE
Payment Required with Application for application to be processed

Which test do you intend to take? (Check one)

❑ Mobile Hydraulic Mechanic*
❑ Mobile Hydraulic Technician*
❑ Hydraulic Specialist
❑ Industrial Hydraulic Mechanic*
❑ Industrial Hydraulic Technician*
❑ Pneumatic Specialist
❑ Pneumatic Mechanic*
❑ Pneumatic Technician*
❑ Engineer (separate application required)
❑ Job Performance Only – Hydraulic or Pneumatic (Circle One)

***Requires the Job Performance Test**

Test Date: ___________ Test Site: ___________

Item	Amount
Test Fee	
Full Time Student Test Fee	
Retake Fee — Written Test	
Retake Fee — Job Performance Test	
Certification Manual #	
Test Reschedule Fee (Refer to Policies)	
TOTAL DUE	

For Office Use Only
Member #:
Prior Tests:
Fee Received:

Payment Required with Application for application to be processed.
Payment Type:
❑ Check or Money Order Enclosed (in U.S. funds only)
❑ Credit Card (MasterCard or Visa Only) (Required)
Type of Card: ❑ MC ❑ VISA Credit Card Number ___________ Exp. Date ___________

Signature ___________

Revised 29 March 2000