Kontrak kuliah

- **KETERLAMBATAN** kehadiran dalam kelas **LEBIH DARI 15 MENIT** setelah jam masuk kelas akan diberikan sanksi **TIDAK DIIZINKAN MENGIKUTI PERKULIAHAN** kepada mahasiswa yang bersangkutan.
- **KETERLAMBATAN** kehadiran dosen lebih dari 10 menit setelah jam masuk kelas maka kelas pada hari itu ditiadakan namun mahasiswa dianggap hadir.
- **KECURANGAN** yang meliputi kegiatan plagiat, curang, dan/atau menyontek dalam setiap **EVALUASI** (**UJIAN TULIS**) akan diberikan sanksi **NILAI 0 ATAU E** kepada mahasiswa yang bersangkutan.
- **KETIDAKHADIRAN** pada waktu tugas kelompok (presentasi) akan diberikan sanksi nilai 0 kepada mahasiswa yang bersangkutan.
- **KETERLAMBATAN** pengumpulan tugas individu dan tugas kelompok akan diberikan sanksi **PENGURANGAN NILAI EVALUASI** sebesar **5 POIN PER HARI** (maks 20 poin) kepada mahasiswa atau kelompok tugas mahasiswa yang bersangkutan.

Kontrak kuliah

- Jika ada laporan **KEKURANG-AKTIFAN / KETIDAK-AKTIFAN** satu atau lebih mahasiswa dalam satu kelompok oleh pimpinan kelompok (kepada dosen pengajar) maka akan diberikan sanksi pengurangan nilai tugas kelompok sebesar maksimal 50% kepada mahasiswa yang bersangkutan.
- Mahasiswa yang **TIDAK MEMENUHI SYARAT KEHADIRAN 80%** akan mendapat **NILAI E**.
- Mahasiswa yang melakukan **KECURANGAN DALAM PENGISIAN DAFTAR HADIR** akan diberikan sanksi **TIDAK LULUS**.
- Mahasiswa yang membantu mahasiswa lain untuk melakukan **KECURANGAN DALAM PENGISIAN DAFTAR HADIR** akan diberikan sanksi **PENGURANGAN 20% SELURUH NILAI EVALUASI**.
- Mahasiswa yang **TIDAK HADIR** pada waktu kuliah maupun presentasi tugas karena alasan yang jelas harus membawa surat keterangan dari instansi yang berwenang. Surat ijin harus diserahkan kepada Tata Usaha paling lambat 1 (satu) minggu sejak ketidakhadiran mahasiswa yang bersangkutan.

RENCANA PEMBELAJARAN

MINGGU KE	MATERI	METODE
1	Kontrak Perkuliahan dan Pengenalan Komponen-Komponen Sistem Hidrolik	Kuliah
2 – 3	Komponen-komponen Sistem Hidrolik	*Problem Based Learning*
4 – 6	Desain dan Analisis Sistem Hidrolik	*Tugas Besar*
7	Perawatan Sistem Hidrolik	Kuliah
8	Ujian Tengah Semester	Tes Tulis

RENCANA PEMBELAJARAN

MINGGU KE	MATERI	METODE
9 – 11	Komponen-komponen Sistem Pneumatik	Kuliah (9); *Problem Based Learning(10-11)*
12 – 14	Desain dan Analisis Sistem Pneumatik	Tugas Besar
15	Perawatan Sistem Pneumatik	Kuliah
16	Ujian Akhir Semester	Tes Tulis

PENILAIAN

1. Tugas Kelompok : 30%
2. Tugas Besar : 40%
3. Ujian Tengah Semester : 15%
4. Ujian Akhir Semester : 15%

CPMK

Mampu menerapkan prinsip dasar hidrolik dan pneumatik dalam pemanfaatannya di industri

Referensi

Utama :

Esposito, A., (2000). Fluid Power with Applications, New York : Prentice Hall

Pendukung :

1. Rabie, M. Galal, (2009). Fluid Power Engineering, New York : Mc Graw Hill
2. Drs. Wirawan, M.T . Bahan Ajar Pneumatik – Hidrolik. Universitas Negeri Semarang
3. Watton, John, (1997). Modelling, Monitoring and Diagnostic Techniques for Fluid Power Systems London : Springer
4. Barber, A. (1997). Pneumatic Handbook 8th Edition. Elsevier Science & Technology Books

Minggu 9

Pneumatic System

Basic components are required for pneumatic systems:

1. **An air tank** to store a given volume of compressed air
2. **A compressor** to compress the air that comes directly from the atmosphere
3. **An electric motor** or other prime mover to drive the compressor
4. **Valves** to control air direction, pressure, and flow rate
5. **Actuators**, which are similar in operation to hydraulic actuators
6. **Piping** to carry the pressurized air from one location to another

Figure 1-18. Portable pneumatic power unit with a gas engine-driven air compressor. *(Courtesy of Ingersoll-Rand Corp., Davidson, North Carolina.)*

(a) Impact wrench.

(b) Impact wrench in action.

Figure 1-19. Pneumatic impact wrench. *(IR logo is a registered trademark of Ingersoll-Rand Company. Courtesy of Ingersoll-Rand Company, Montvale, New Jersey.)*

Pneumatic System

- Pneumatic systems use pressurized gases to transmit and control power.
- As the name implies, pneumatic systems typically use air (rather than some other gas) as the fluid medium, because air is a safe, low-cost, and readily available fluid.
- pneumatics are confined to low-power applications.

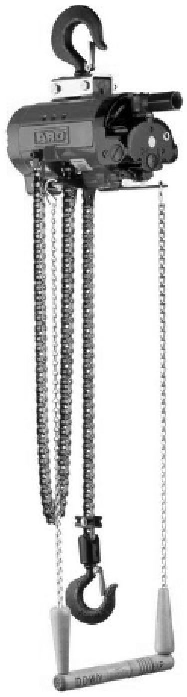


Figure 13-1. Pneumatically powered hoist. *(Courtesy of Ingersoll-Rand Corp., Southern Pines, North Carolina.)*

PROPERTIES OF AIR

- Air is actually a mixture of gases containing about 21% oxygen, 78% nitrogen, and
- 1% other gases such as argon and carbon dioxide.The

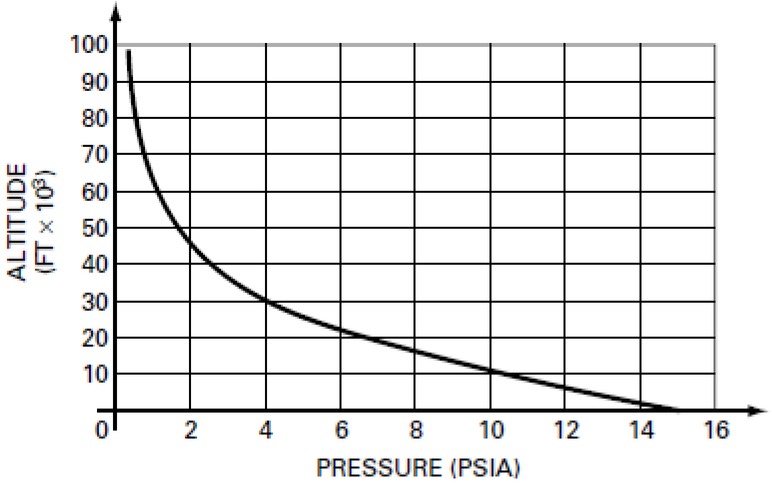


Figure 13-3. Pressure variation in the atmosphere.

Absolute Pressures and Temperatures

$$\text{absolute pressure (psia)} = \text{gage pressure (psig)} + 14.7$$

$$\text{absolute pressure (Pa abs)} = \text{gage pressure (Pa gage)} + 101{,}000$$

$$\text{absolute temperature } (^\circ\text{R}) = \text{temperature}(^\circ\text{F}) + 460$$

$$\text{absolute temperature (K)} = \text{temperature } (^\circ\text{C}) + 273$$

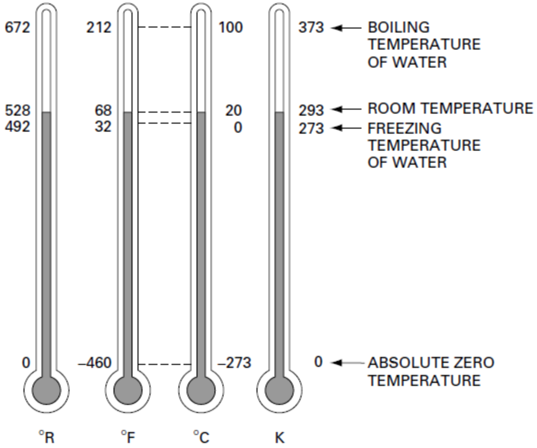


Figure 13-4. A comparison of the Fahrenheit (°F), Celsius (°C), Rankine (°R), and Kelvin (K) temperature scales.

Boyle's Law

$$\frac{V_1}{V_2} = \frac{p_2}{p_1}$$

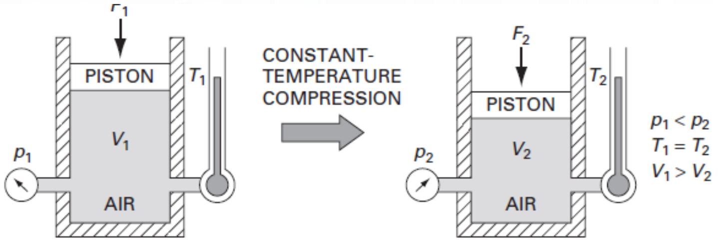


Figure 13-5. Air undergoing a constant-temperature process.

Example 13-1

The 2-in-diameter piston of the pneumatic cylinder of Figure 13-6 retracts 4 in from its present position ($p_1 = 20$ psig; $V_1 = 20$ in³) due to the external load on the rod. If the port at the blank end of the cylinder is blocked, find the new pressure, assuming the temperature does not change.

Solution

$$V_1 = 20 \text{ in}^3$$

$$V_2 = 20 \text{ in}^3 - \frac{\pi}{4}(2)^2(4) = 7.43 \text{ in}^3$$

$$p_1 = 20 + 14.7 = 34.7 \text{ psia}$$

Substituting into Eq. (13-3), which defines Boyle's law, we have

$$\frac{20}{7.43} = \frac{p_2}{34.7}$$

$$p_2 = 93.4 \text{ psia} = 78.7 \text{ psig}$$

Charles' Law

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

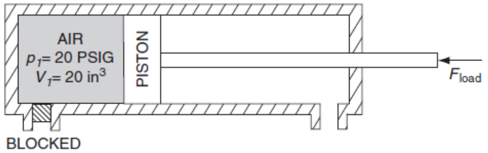


Figure 13-6. System for Example 13-1.

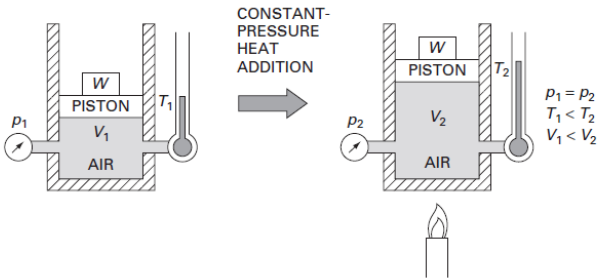


Figure 13-7. Air undergoing a constant-pressure process.

Example 13-2

The cylinder of Figure 13-6 has an initial position where p_1 = 20 psig and V_1 = 20 in^3 as controlled by the load on the rod. The air temperature is 60°F. The load on the rod is held constant to maintain constant air pressure, but the air temperature is increased to 120°F. Find the new volume of air at the blank end of the cylinder.

Solution

$$T_1 = 60 + 460 = 520°\text{R}$$

$$T_2 = 120 + 460 = 580°\text{R}$$

Substituting into Eq. (13-4), which defines Charles' law, yields the answer:

$$\frac{20}{V_2} = \frac{520}{580}$$

$$V_2 = 22.3 \text{ in}^3$$

Gay-Lussac's Law

$$\frac{p_1}{p_2} = \frac{T_1}{T_2}$$

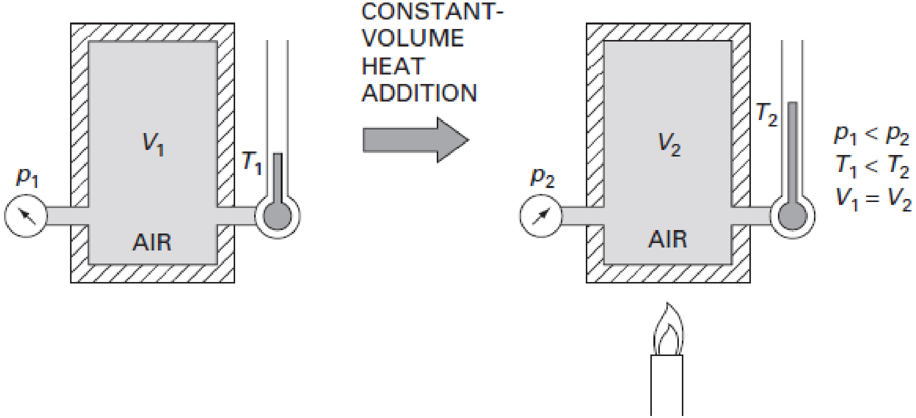


Figure 13-8. Air undergoing a constant-volume process.

EXAMPLE 13-3

The cylinder in Figure 13-6 has a locked position (V_1 = constant). $p_1 = 20$ psig, and $T_1 = 60°F$. If the temperature increases to 160°F, what is the new pressure in the blank end?

Solution

$$p_1 = 20 + 14.7 = 34.7 \text{ psia}$$

$$T_1 = 60 + 460 = 520°R \text{ and } T_2 = 160 + 460 = 620°R$$

Substituting into Eq. (13-5), which defines Gay-Lussac's law, we obtain

$$\frac{34.7}{p_2} = \frac{520}{620}$$

or

$$p_2 = 41.4 \text{ psia} = 26.7 \text{ psig}$$

General Gas Law

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

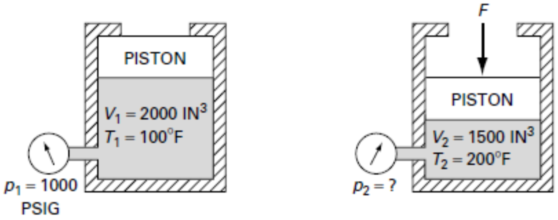


Figure 13-9. System for Example 13-4.

Example 13-4

Gas at 1000 psig and 100°F is contained in the 2000-in³ cylinder of Figure 13-9. A piston compresses the volume to 1500 in³ while the gas is heated to 200°F. What is the final pressure in the cylinder?

Solution Solve Eq. (13-6) for p_2 and substitute known values:

$$p_2 = \frac{p_1V_1T_2}{V_2T_1}$$

$$= \frac{(1000 + 14.7)(2000)(200 + 460)}{(1500)(100 + 460)} = \frac{(1014.7)(2000)(660)}{1500(560)}$$

$$= 1594.5 \text{ psia} = 1579.8 \text{ psig}$$

Example 13-5

Gas at 70 bars gage pressure and 37.8°C is contained in the 12,900-cm³ cylinder of Figure 13-9. A piston compresses the volume to 9680 cm³ while the gas is heated to 93.3°C. What is the final pressure in the cylinder?

Solution Solve Eq. (13-6) for p_2 and substitute known values:

$$p_2 = \frac{p_1V_1T_2}{V_2T_1} = \frac{(70 \times 10^5 + 1 \times 10^5)(12{,}900)(93.3 + 273)}{(9680)(37.8 + 273)}$$

$$= 111.5 \times 10^5 \text{ Pa absolute} = 111.5 \text{ bars absolute}$$

Advantages of Pneumatic Systems

Basic Advantages of Pneumatic Systems

(a) Small weight of transmission lines due to

- The small diameter of lines. (Hydraulic losses due to air flow are small, which allows the reduction of the line diameter.)
- The low density of energy transmitting fluid; the air.
- There are no return lines; used air is expelled into the atmosphere.

(b) Availability of the energy transmission fluid, the air.

(c) The system is fireproof.

(d) Pneumatic systems are able to supply a great amount of energy during a short time period, from the compressed air reservoir.

Disadvantages of Pneumatic Systems

Basic Disadvantages of Pneumatic Systems

a. Difficult system tightness.
b. Low working pressure compared with the hydraulic systems due to the tightness problems and compressor design (within 10 bar for industrial systems and more than 200 bar for aerospace systems).
c. Difficulty of holding pneumatic actuators at intermediate positions.
d. Delay of actuators' response due to the time needed for filling the long lines with compressed air.
e. The variation of pressure in air reservoirs with temperature.
f. The possibility of the condensation of humidity and the freezing of condensed water at low temperatures.
g. Special lubricators are needed due to the poor lubricity of air.
h. Danger of explosion.

Minggu 10

COMPRESSORS

Piston Compressors

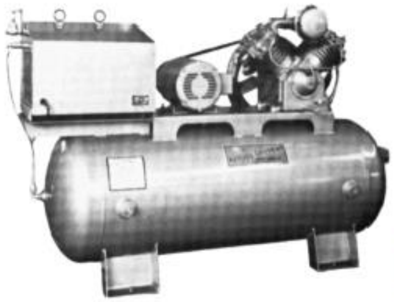


Figure 13-11. Complete piston-type, two-stage compressor unit. *(Courtesy of Kellogg-American, Inc., Oakmont, Pennsylvania.)*

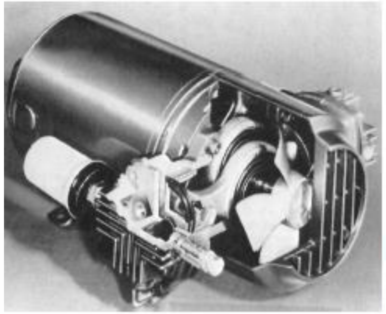


Figure 13-12. Direct-drive, fan-cooled, piston-type compressor. *(Courtesy of Gast Manufacturing Corp., Benton Harbor, Michigan.)*

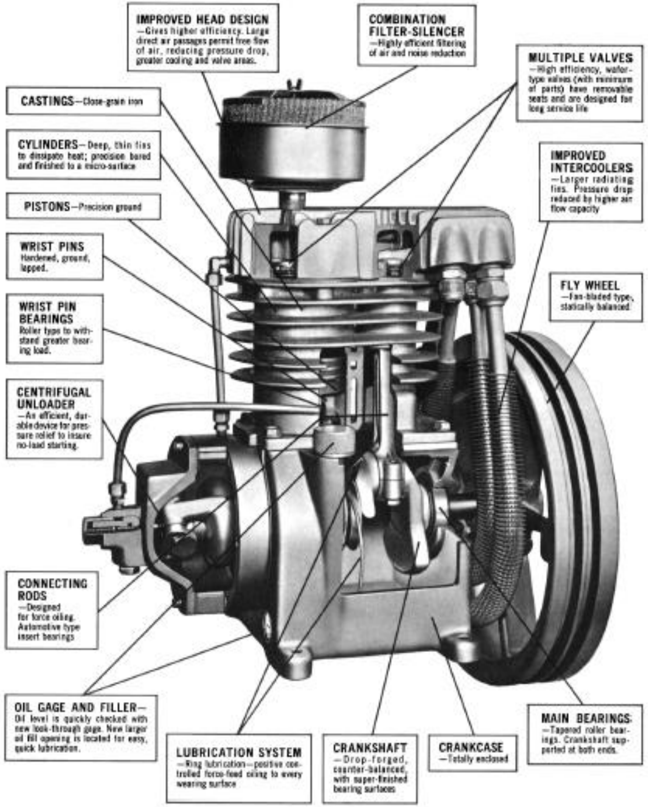


Figure 13-10. Design features of a piston-type compressor. *(Courtesy of Kellogg-American, Inc., Oakmont, Pennsylvania.)*

Screw Compressors

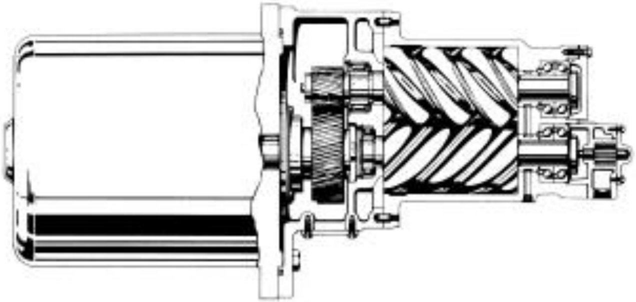


Figure 13-17. Single-stage screw compressor. *(Courtesy of Ingersoll-Rand Co., Washington, New Jersey.)*

Figure 13-18. Unsymmetrical profile of screw rotors. *(Courtesy of Ingersoll-Rand Co., Washington, New Jersey.)*

Vane Compressors

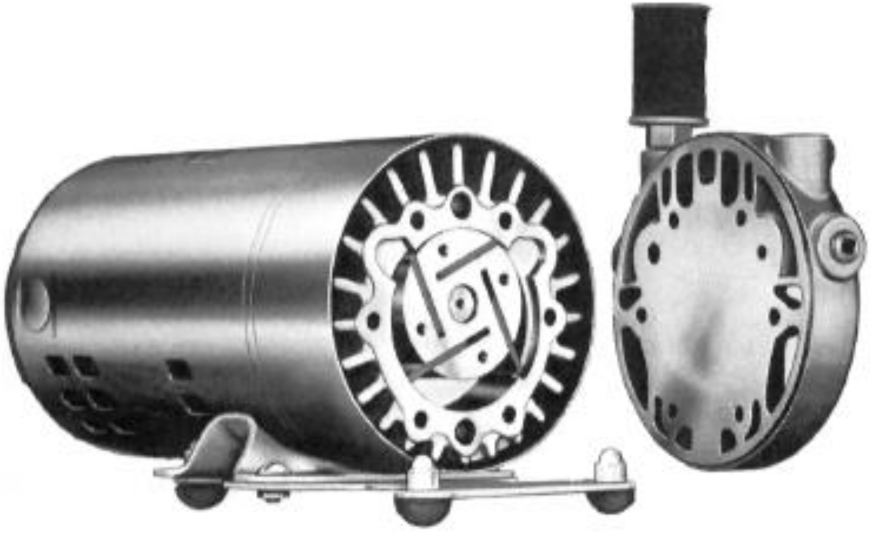


Figure 13-19. Sliding-vane-type rotary compressor. *(Courtesy of Gast Manufacturing Corp., Benton Harbor, Michigan.)*

Air Capacity Rating of Compressors

$$Q_1 = Q_2\left(\frac{p_2}{p_1}\right)\left(\frac{T_1}{T_2}\right)$$

EXAMPLE 13-6

Air is used at a rate of 30 cfm from a receiver at 90°F and 125 psi. If the atmospheric pressure is 14.7 psia and the atmospheric temperature is 70°F, how many cfm of free air must the compressor provide?

Solution Substituting known values into Eq. (13-7) yields

$$Q_1 = Q_2\left(\frac{p_2}{p_1}\right)\left(\frac{T_1}{T_2}\right) = 30 \times \frac{125 + 14.7}{14.7} \times \frac{70 + 460}{90 + 460}$$

$$= 275 \text{ cfm of free air}$$

In other words, the compressor must receive atmospheric air (14.7 psia and 70°F) at a rate of 275 cfm in order to deliver air (125 psi and 90°F) at 30 cfm.

Compressors

Sizing of Air Receivers

$$V_r = \frac{14.7t(Q_r - Q_c)}{p_{max} - p_{min}} \quad \textbf{(13-8)}$$

$$V_r = \frac{101t(Q_r - Q_c)}{p_{max} - p_{min}} \quad \textbf{(13-8M)}$$

where t = time that receiver can supply required amount of air (min),
Q_r = consumption rate of pneumatic system (scfm, standard m³/min),
Q_c = output flow rate of compressor (scfm, standard m³/min),
p_{max} = maximum pressure level in receiver (psi, kPa),
p_{min} = minimum pressure level in receiver (psi, kPa),
V_r = receiver size (ft³, m³).

Example 13-7

a. Calculate the required size of a receiver that must supply air to a pneumatic system consuming 20 scfm for 6 min between 100 and 80 psi before the compressor resumes operation.

b. What size is required if the compressor is running and delivering air at 5 scfm?

Solution

a. $$V_r = \frac{14.7 \times 6 \times (20 - 0)}{100 - 80} = 88.2 \text{ ft}^3 = 660 \text{ gal}$$

b. $$V_r = \frac{14.7 \times 6 \times (20 - 5)}{100 - 80} = 66.2 \text{ ft}^3 = 495 \text{ gal}$$

It is common practice to increase the calculated size of the receiver by 25% for unexpected overloads and by another 25% for possible future expansion needs.

Compressors

Power Required to Drive Compressors

$$\text{theoretical horsepower (HP)} = \frac{p_{in}Q}{65.4}\left[\left(\frac{p_{out}}{p_{in}}\right)^{0.286} - 1\right]$$

$$\text{theoretical power (kW)} = \frac{p_{in}Q}{17.1}\left[\left(\frac{p_{out}}{p_{in}}\right)^{0.286} - 1\right]$$

where p_{in} = inlet atmospheric pressure (psia, kPa abs),
p_{out} = outlet pressure (psia, kPa abs),
Q = flow rate (scfm, standard m³/min).

Example 13-8

Determine the actual power required to drive a compressor that delivers 100 scfm of air at 100 psig. The overall efficiency of the compressor is 75%.

Solution Since absolute pressures must be used in Eq. (13-9), we have p_{in} = 14.7 psia and p_{out} = 114.7 psia. Substituting directly into Eq. (13-9) yields the theoretical horsepower required.

$$HP_{theor} = \frac{14.7 \times 100}{65.4}\left[\left(\frac{114.7}{14.7}\right)^{0.286} - 1\right] = 18.0 \text{ hp}$$

The actual horsepower required is

$$HP_{act} = \frac{HP_{theor}}{\eta_o} = \frac{18.0}{0.75} = 24.0 \text{ hp}$$

Actuator

Pneumatic Cylinders

Figure 13-40. Construction of pneumatic cylinder. *(Courtesy of Aro Corp., Bryan, Ohio.)*

Pneumatic Rotary Actuators

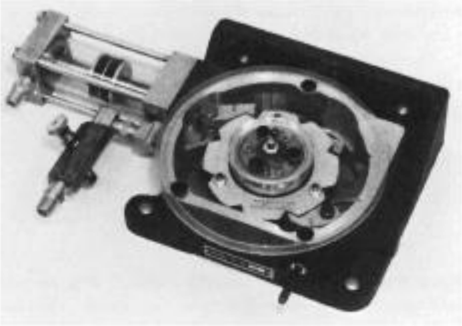


Figure 13-41. Air cylinder-drive rotary index table. *(Courtesy of Allenair Corp., Mineola, New York.)*

Figure 13-42. Pneumatic rotary actuator. *(Courtesy of Flo-Tork, Inc., Orrville, Ohio.)*

Rotary Air Motors

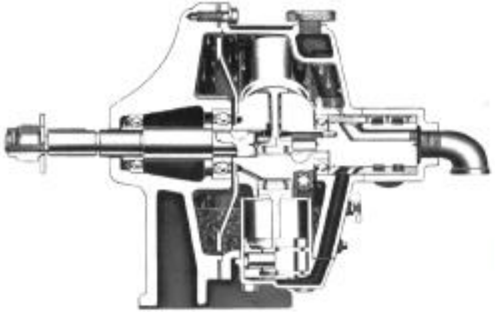
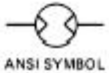


Figure 13-45. Radial piston air motor. *(Courtesy of Gardner-Denver Co., Quincy, Illinois.)*



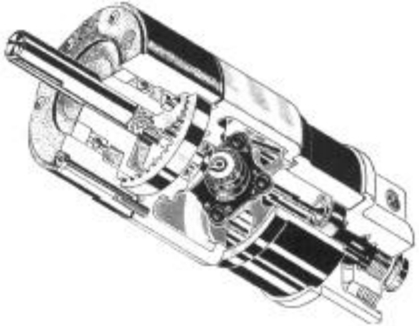
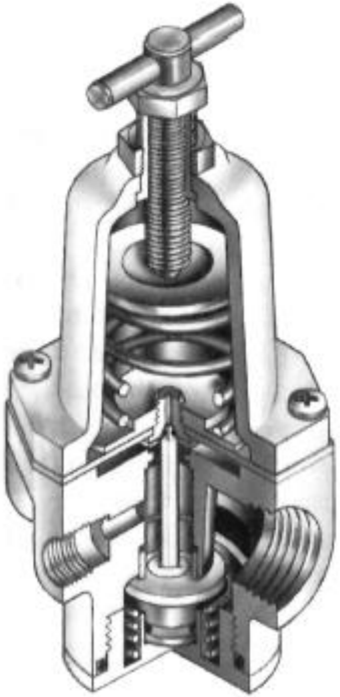


Figure 13-46. Axial piston air motor. *(Courtesy of Gardner-Denver Co., Quincy, Illinois.)*

Figure 13-43. Vane air motor. *(Courtesy of Gast Manufacturing, Inc., Benton Harbor, Michigan.)*

Minggu 11

Pressure Regulators



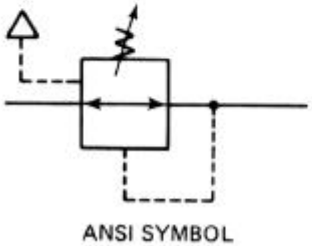


Figure 13-30. Cutaway of pneumatic pressure regulator. *(Courtesy of Aro Corp., Bryan, Ohio.)*

AIR CONTROL VALVES

Check Valves

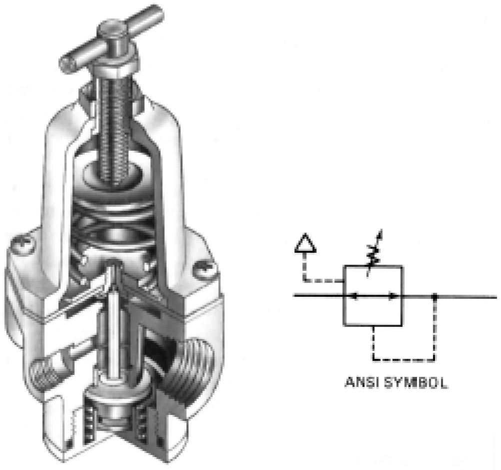


Figure 13-30. Cutaway of pneumatic pressure regulator. *(Courtesy of Aro Corp., Bryan, Ohio.)*

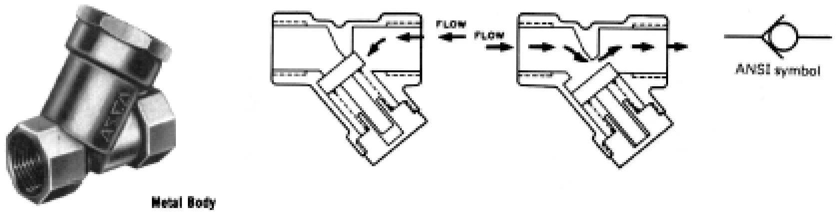


Figure 13-31. Pneumatic check valve. *(Courtesy of Automatic Switch Co., Florham Park, New Jersey.)*

Shuttle Valves

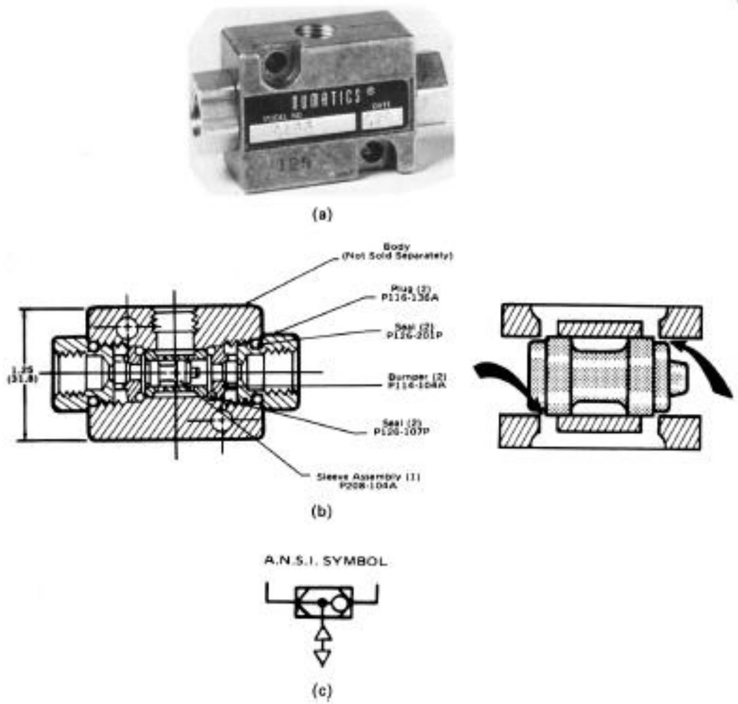


Figure 13-32. Shuttle valve. (a) External view. (b) Internal view and spool-port configuration. (c) ANSI symbol. *(Courtesy of Numatics Incorporated, Highland, Michigan.)*

Two-Way Directional Control Valves

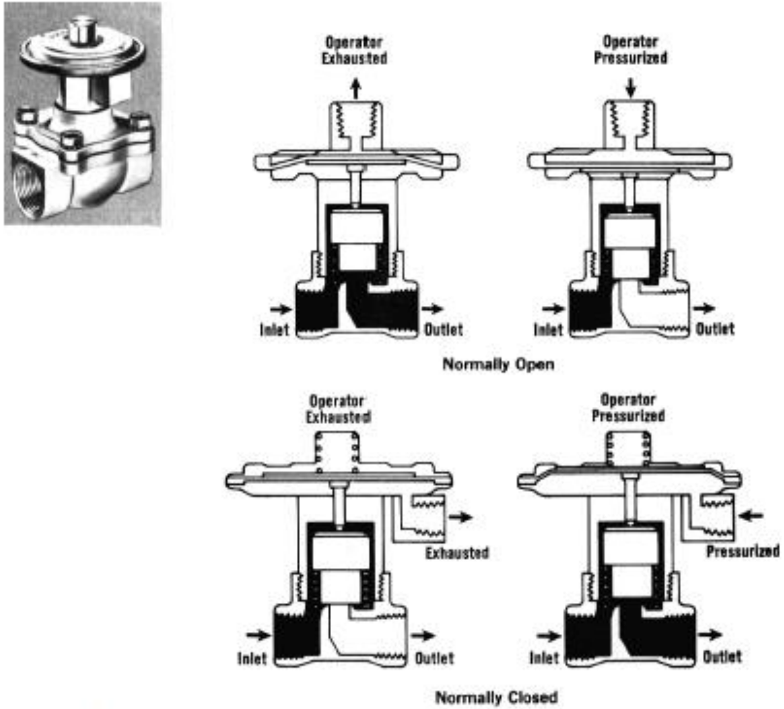


Figure 13-33. Two-way, air-piloted valve. *(Courtesy of Automatic Switch Co., Florham Park, New Jersey.)*

Three-Way and Four-Way Directional Control Valves

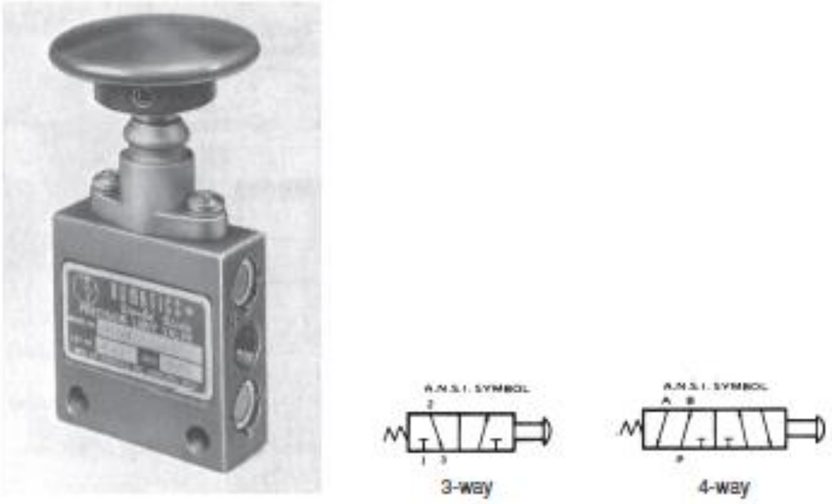


Figure 13-34. Push-button directional control valve. *(Courtesy of Numatics Incorp., Highland, Michigan.)*

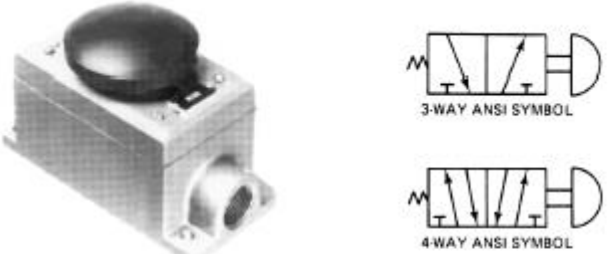


Figure 13-35. Palm-button valve. *(Courtesy of Numatics Incorp., Highland, Michigan.)*

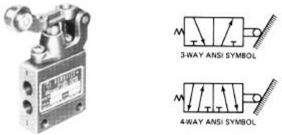


Figure 13-36. Limit valve. *(Courtesy of Numatics Incorp., Highland, Michigan.)*

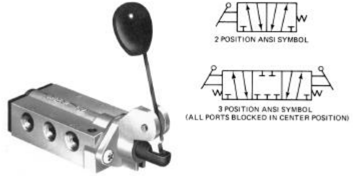


Figure 13-37. Hand-lever-operated, four-way valve. *(Courtesy of Skinner Precision Industries, Inc., New Britain, Connecticut.)*

Flow Control Valves

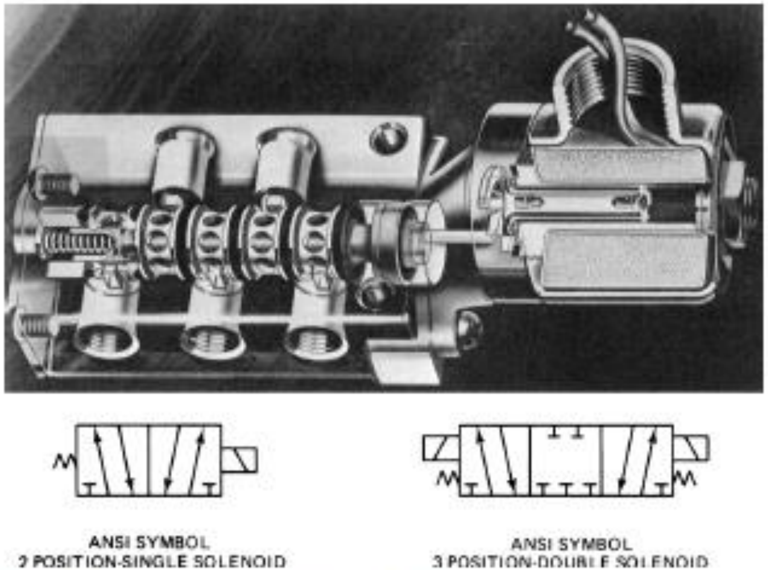


Figure 13-38. Solenoid-actuated directional control valve. *(Courtesy of Skinner Precision Industries, Inc., New Britain, Connecticut.)*

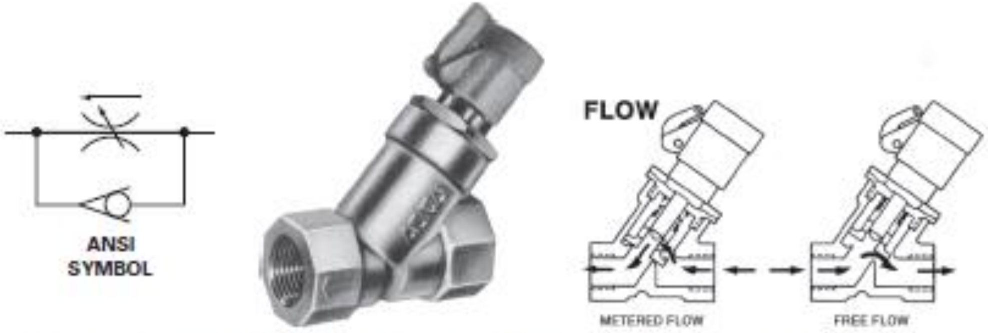
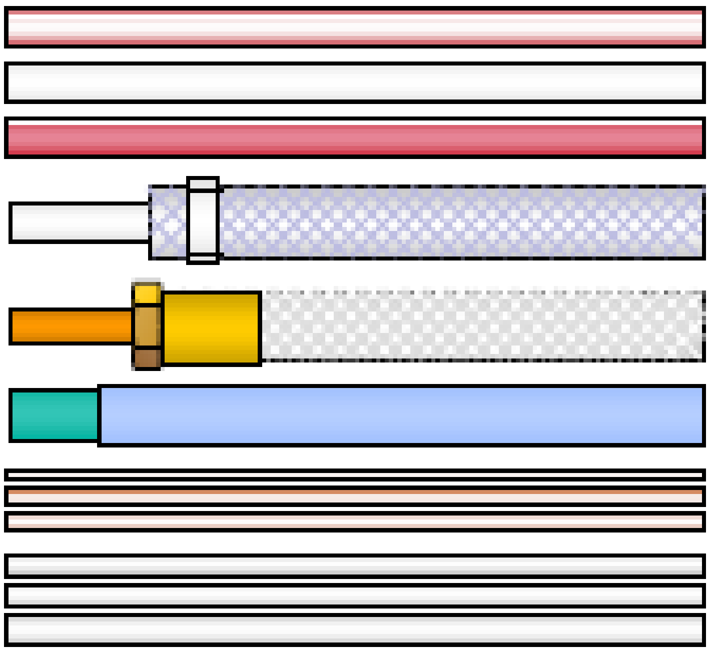
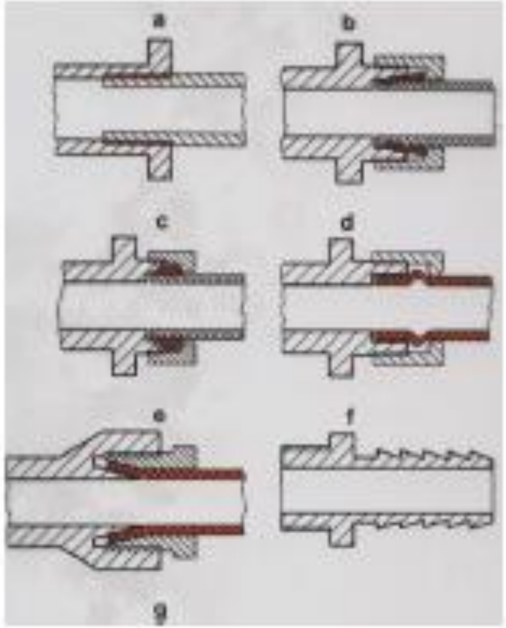


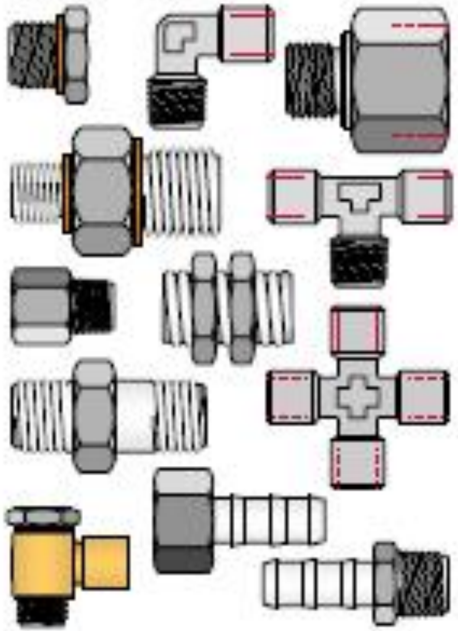
Figure 13-39. Flow control valve. *(Courtesy of Automatic Switch Co., Florham Park, New Jersey.)*

Conductor



Conector





Air Filters

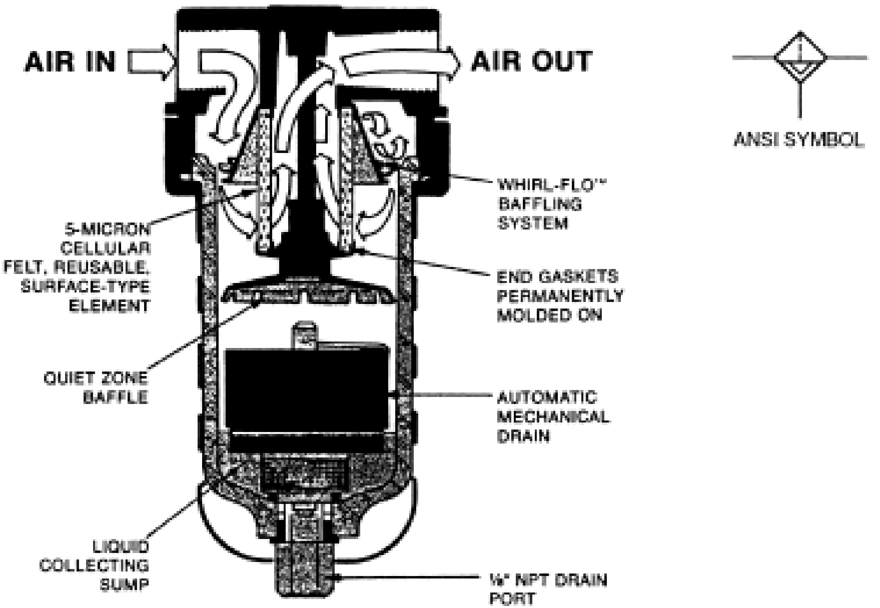


Figure 13-20. Operation of air filter. *(Courtesy of Wilkerson Corp., Englewood, Colorado.)*

Air Pressure Regulators

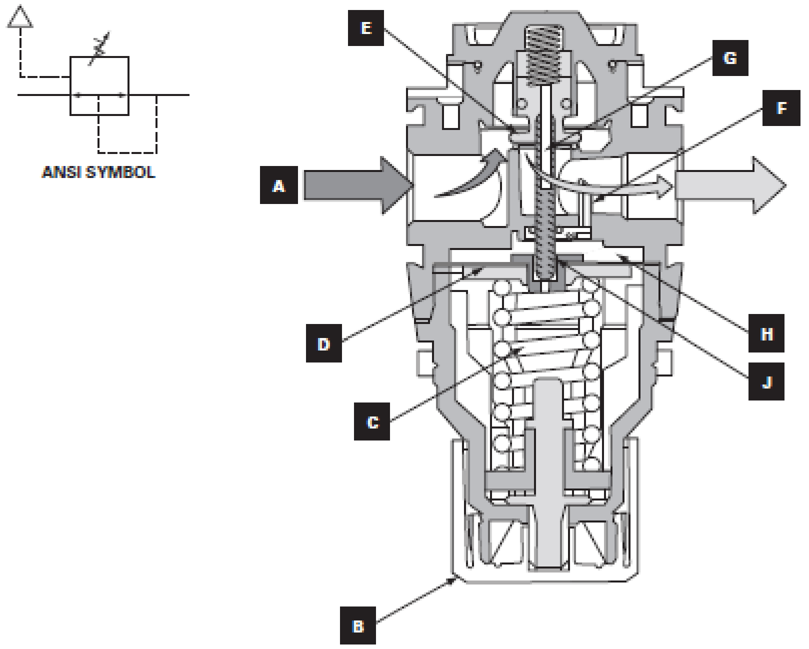


Figure 13-21. Air pressure regulator. *(Courtesy of Wilkerson Corp., Englewood, Colorado.)*

Air Lubricators

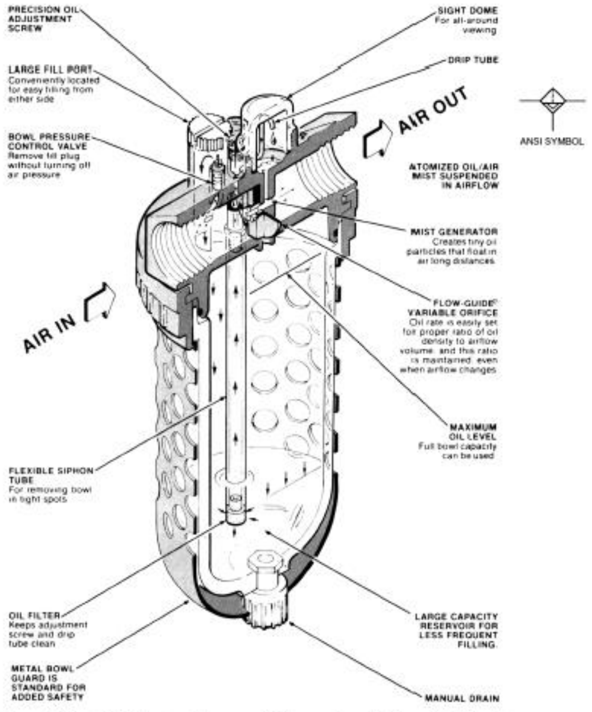


Figure 13-22. Air lubricator. *(Courtesy of Wilkerson Corp., Englewood, Colorado.)*

Figure 13-23. Individual filter, regulator, lubricator units. *(Courtesy of C. A. Norgren Co., Littleton, Colorado.)*

Pneumatic Pressure Indicators

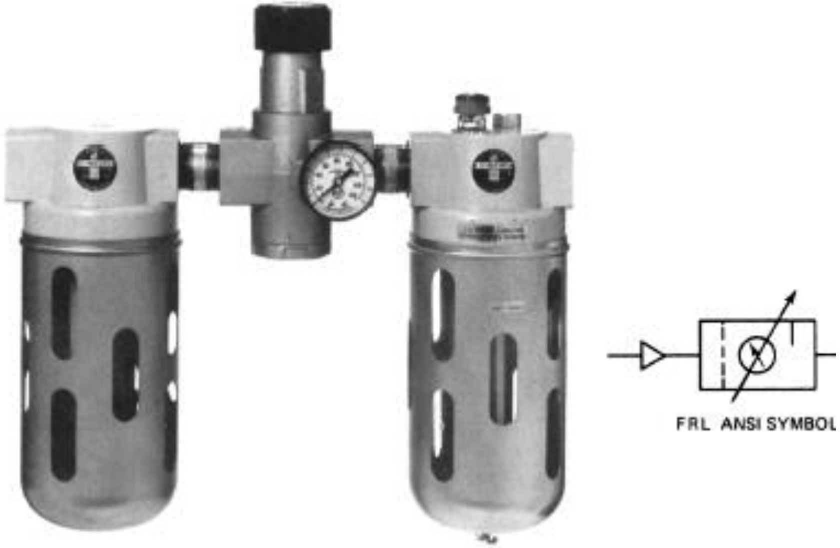
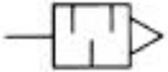


Figure 13-24. Combination filter, regulator, lubricator unit. *(Courtesy of C. A. Norgren Co., Littleton, Colorado.)*

Figure 13-25. Pneumatic pressure indicator. (a) Front view. (b) Rear view. *(Courtesy of Numatics Inc., Highland, Michigan.)*

Pneumatic Silencers



ANSI SYMBOL

Figure 13-26. Pneumatic silencers. *(Courtesy of C. A. Norgren Co., Littleton, Colorado.)*

Aftercoolers

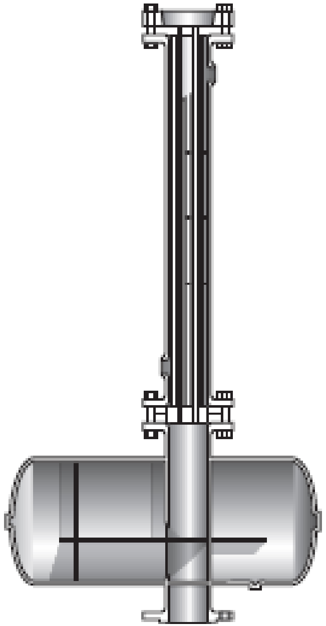


Figure 13-27. Aftercooler. *(Courtesy of Ingersoll-Rand Co., Washington, New Jersey.)*

Air Dryers

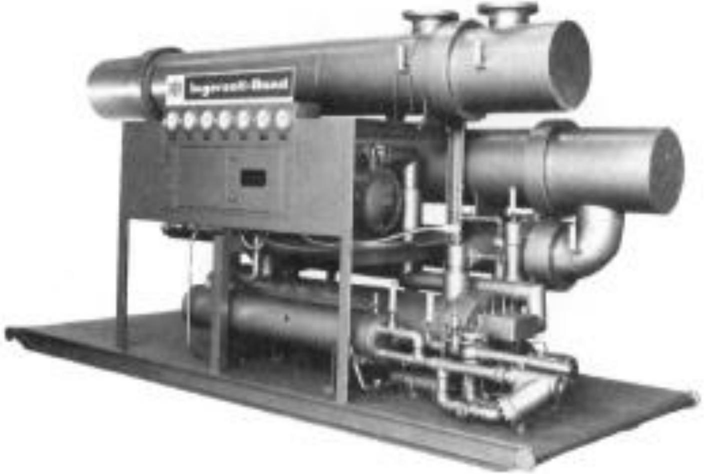


Figure 13-28. Chiller air dryer. *(Courtesy of Ingersoll-Rand Co., Washington, New Jersey.)*

Minggu 12

Air Capacity Rating of Compressors

Air compressors are generally rated in terms of cfm of free air, defined as air at actual atmospheric conditions. Cfm of free air is called scfm when the compressor inlet air is at the standard atmospheric conditions of 14.7 psia and 68°F. The abbreviation scfm means standard cubic feet per minute. Therefore, a calculation is necessary to determine the compressor capacity in terms of cfm of free air or scfm for a given application. In metric units a similar calculation is made using m³/min of free air or standard m³/min where standard atmospheric conditions are 101,000 Pa abs and 20°C.

The equation that allows for this calculation is derived by solving the general gas law Eq. (13-6) for V_1 as follows:

$$V_1 = V_2\left(\frac{p_2}{p_1}\right)\left(\frac{T_1}{T_2}\right)$$

In the above equation, subscript 1 represents compressor inlet atmospheric conditions (standard or actual) and subscript 2 represents compressor discharge conditions. Dividing both sides of this equation by time (t) converts volumes V_1 and V_2 into volume flow rates Q_1 and Q_2, respectively. Thus, we have the desired equation:

$$Q_1 = Q_2\left(\frac{p_2}{p_1}\right)\left(\frac{T_1}{T_2}\right) \quad \textbf{(13-7)}$$

Note that absolute pressure and temperature values must be used in Eq. (13-7).

EXAMPLE 13-6

Air is used at a rate of 30 cfm from a receiver at 90°F and 125 psi. If the atmospheric pressure is 14.7 psia and the atmospheric temperature is 70°F, how many cfm of free air must the compressor provide?

Solution Substituting known values into Eq. (13-7) yields

$$Q_1 = Q_2\left(\frac{p_2}{p_1}\right)\left(\frac{T_1}{T_2}\right) = 30 \times \frac{125 + 14.7}{14.7} \times \frac{70 + 460}{90 + 460}$$

$$= 275 \text{ cfm of free air}$$

In other words, the compressor must receive atmospheric air (14.7 psia and 70°F) at a rate of 275 cfm in order to deliver air (125 psi and 90°F) at 30 cfm.

Sizing of Air Receivers

The sizing of air receivers requires taking into account parameters such as system pressure and flow-rate requirements, compressor output capability, and the type of duty of operation. Basically, a receiver is an air reservoir. Its function is to supply air at essentially constant pressure. It also serves to dampen pressure pulses either coming from the compressor or the pneumatic system during valve shifting and component operation. Frequently a pneumatic system demands air at a flow rate that exceeds the compressor capability. The receiver must be capable of handling this transient demand.

Equations (13-8) and (13-8M) can be used to determine the proper size of the receiver in English units and metric units, respectively.

$$V_r = \frac{14.7t(Q_r - Q_c)}{p_{max} - p_{min}} \quad \textbf{(13-8)}$$

$$V_r = \frac{101t(Q_r - Q_c)}{p_{max} - p_{min}} \quad \textbf{(13-8M)}$$

where t = time that receiver can supply required amount of air (min),
Q_r = consumption rate of pneumatic system (scfm, standard m^3/min),
Q_c = output flow rate of compressor (scfm, standard m^3/min),
p_{max} = maximum pressure level in receiver (psi, kPa),
p_{min} = minimum pressure level in receiver (psi, kPa),
V_r = receiver size (ft^3, m^3).

EXAMPLE 13-7

a. Calculate the required size of a receiver that must supply air to a pneumatic system consuming 20 scfm for 6 min between 100 and 80 psi before the compressor resumes operation.

b. What size is required if the compressor is running and delivering air at 5 scfm?

Solution

a. $$V_r = \frac{14.7 \times 6 \times (20 - 0)}{100 - 80} = 88.2 \text{ ft}^3 = 660 \text{ gal}$$

b. $$V_r = \frac{14.7 \times 6 \times (20 - 5)}{100 - 80} = 66.2 \text{ ft}^3 = 495 \text{ gal}$$

It is common practice to increase the calculated size of the receiver by 25% for unexpected overloads and by another 25% for possible future expansion needs.

Power Required to Drive Compressors

Another important design consideration is to determine the power required to drive an air compressor to meet system pressure and flow-rate requirements. Equations (13-9) and (13-9M) can be used to determine the theoretical power required to drive an air compressor.

$$\text{theoretical horsepower (HP)} = \frac{p_{in}Q}{65.4}\left[\left(\frac{p_{out}}{p_{in}}\right)^{0.286} - 1\right] \quad \textbf{(13-9)}$$

$$\text{theoretical power (kW)} = \frac{p_{in}Q}{17.1}\left[\left(\frac{p_{out}}{p_{in}}\right)^{0.286} - 1\right] \quad \textbf{(13-9M)}$$

where p_{in} = inlet atmospheric pressure (psia, kPa abs),
p_{out} = outlet pressure (psia, kPa abs),
Q = flow rate (scfm, standard m^3/min).

To determine the actual power, the theoretical power from Eq. (13-9) is divided by the overall compressor efficiency η_o.

Example 13-8

Determine the actual power required to drive a compressor that delivers 100 scfm of air at 100 psig. The overall efficiency of the compressor is 75%.

Solution Since absolute pressures must be used in Eq. (13-9), we have p_{in} = 14.7 psia and p_{out} = 114.7 psia. Substituting directly into Eq. (13-9) yields the theoretical horsepower required.

$$HP_{theor} = \frac{14.7 \times 100}{65.4}\left[\left(\frac{114.7}{14.7}\right)^{0.286} - 1\right] = 18.0 \text{ hp}$$

The actual horsepower required is

$$HP_{act} = \frac{HP_{theor}}{\eta_o} = \frac{18.0}{0.75} = 24.0 \text{ hp}$$

ANALYSIS OF MOISTURE REMOVAL FROM AIR

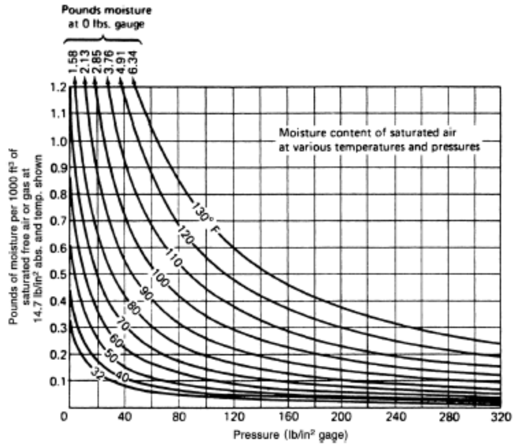


Figure 13-29. Moisture content of saturated air at various temperatures and pressures. *(Courtesy of the Compressed Air and Gas Institute,* Compressed Air and Gas Handbook, *5e.)*

EXAMPLE 13-9

A compressor delivers 100 scfm of air at 100 psig to a pneumatic system. Saturated atmospheric air enters the compressor at 80°F.

a. If the compressor operates 8 hours per day, determine the number of gallons of moisture delivered to the pneumatic system by the compressor per day.

b. How much moisture per day would be received by the pneumatic system if an aftercooler is installed to cool the compressed air temperature back to 80°F?

c. How much moisture per day would be received by the pneumatic system if an air dryer is installed to cool the compressed air temperature to 40°F?

Solution

a. Per Figure 13-29, the atmospheric air entering the compressor contains 1.58 lb of moisture per 1000 ft³. Thus, the rate at which moisture enters the compressor can be found.

$$\text{moisture rate (lb/min)} = \text{entering moisture content (lb/ft}^3) \times \text{entering scfm flow rate ft}^3\text{/min)}$$

$$= \frac{1.58}{1000}\ \text{lb/ft}^3 \times 100\ \text{ft}^3\text{/min} = 0.158\ \text{lb/min}$$

The number of gallons per day received by the pneumatic system can be found knowing that water weighs 8.34 lb/gal.

$$\text{gal/day} = 0.158\ \frac{\text{lb}}{\text{min}} \times \frac{60\ \text{min}}{1\ \text{hr}} \times \frac{8\ \text{hr}}{\text{day}} \times \frac{1\ \text{gal}}{8.34\ \text{lb}} = 9.09\ \text{gal/day}$$

b. Per Figure 13-29, if the compressed air is cooled back to 80°F, the maximum amount of moisture the air (leaving the aftercooler) can hold per 1000 ft³ of free air is 0.20 lb. Since (1.58 − 0.20)/1.58 = 0.873, this means that 87.3% of the moisture would condense out of the air and be drained away by the aftercooler. The gallons of moisture per day received by the pneumatic system are

$$\text{gal/day} = (1 - 0.873)(9.09\ \text{gal/day}) = 1.15\ \text{gal/day}$$

c. Per Figure 13-29, the maximum amount of moisture the air (leaving the air dryer) can hold per 1000 ft³ of free air is 0.05 lb. This represents a 96.8% moisture removal rate. Thus, the moisture received per day by the pneumatic system is

$$\text{gal/day} = (1 - 0.968)(9.09\ \text{gal/day}) = 0.29\ \text{gal/day}$$

Air leaves the dryer and enters the pneumatic system at 40°F. As long as the air temperature in the pneumatic system stays above the 40°F value reached in the air dryer (which is typically the case for indoor systems), none of the moisture will condense into water. Thus, the 0.29 gal/day of moisture entering the pneumatic system would remain in the form of water vapor. Moisture in the air in the form of water vapor does not cause harm to components because water vapor is a gas whereas water is a liquid. Refrigeration dryers are capable of lowering the temperature of the compressed air to as low as 35°F.

Flow Rate Through an Orifice

Flow Rate Through an Orifice

Since a valve is a variable orifice, it is important to evaluate the flow rate of air through an orifice. Such a relationship is discussed for liquid flow in Chapter 8. However, because of the compressibility of air, the relationship describing the flow rate of air is more complex.

Equations (13-10) and (13-10M) provide for the calculation of air volume flow rates through orifices using English and metric units, respectively.

$$Q = 22.7C_v\sqrt{\frac{(p_1 - p_2)(p_2)}{T_1}} \quad \textbf{(13-10)}$$

$$Q = 0.0698C_v\sqrt{\frac{(p_1 - p_2)(p_2)}{T_1}} \quad \textbf{(13-10M)}$$

where Q = volume flow rate (scfm, std m^3/min),
C_v = flow capacity constant,
p_1 = upstream pressure (psia, kPa abs),
p_2 = downstream pressure (psia, kPa abs),
T_1 = upstream temperature (°R, K).

The preceding equations are valid when p_2 is more than $0.53p_1$ or when p_2 is more than 53% of p_1. Beyond this region, the flow through the orifice is said to be choked. Thus, the volume flow rate through the orifice increases as the pressure drop $p_1 - p_2$ increases until p_2 becomes equal to $0.53p_1$. Any lowering of p_2 to values below $0.53p_1$ does not produce any increase in volume flow rate, as would be predicted by Eqs. (13-10) or (13-10M), because the downstream fluid velocity reaches the speed of sound. Thus, the pressure ratio p_2/p_1 must be calculated to determine if the flow is choked before using Eqs. (13-10) and (13-10M).

From a practical point of view, this means that a downstream pressure of 53% of the upstream pressure is the limiting factor for passing air through a valve to an actuator. Thus, for example, with 100-psia line pressure, if the pressure at the inlet of an actuator drops to 53 psia, the fluid velocity is at its maximum. No higher fluid velocity can be attained even if the pressure at the inlet of the actuator drops below 53 psia. Assuming an upstream pressure of 100 psia, the volume flow rate must be calculated for a downstream pressure of 53 psia using Eqs. (13-10) or (13-10M) even though the downstream pressure may be less than 53 psia.

By the same token, if p_2 is less than $0.53p_1$, increasing the value of p_1 will result in a greater pressure drop across the valve but will not produce an increase in fluid velocity, because the orifice is already choked. Thus, increasing the ratio of p_1/p_2 beyond 1/0.53 (or 1.89) does not produce any increase in volume flow rate. However, it should be noted that raising the value of p_1 beyond 1.89 p_2 will increase the mass flow rate because the density of air increases as the pressure rises. Thus raising the value of p_1 beyond 1.89 p_2 increases the mass flow rate even though the volume flow rate remains at the choked value.

Sizing of Valves Based on Flow Rates

Example 13-10

Air at 80°F passes through a ½-in-diameter orifice having a flow capacity constant of 7.4. If the upstream pressure is 80 psi, what is the maximum flow rate in units of scfm of air?

Solution

$$T_1 = 80 + 460 = 540°\text{R}$$

$$p_1 = 80 + 14.7 = 94.7 \text{ psia}$$

The maximum flow rate occurs when the orifice is choked ($p_2 = 0.53p_1$). Thus,

$$p_2 = 0.53 \times 94.7 = 50.2 \text{ psia}$$

Substituting directly into Eq. (13-10) yields

$$Q = 22.7 \times 7.4\sqrt{\frac{(94.7 - 50.2)(50.2)}{540}} = 22.7 \times 7.4 \times 2.03$$

$$= 341 \text{ scfm of air}$$

Sizing of Valves

Example 13-11

A pneumatically powered impact tool requires 50 scfm of air at 100 psig. What size valve (C_v) should be selected for this application if the valve pressure drop should not exceed 12 psi, and the upstream air temperature is 80°F?

Solution Convert the upstream temperature and downstream pressure into absolute units.

$$T_1 = 80 + 460 = 540°\text{R}$$

$$p_2 = 100 + 14.7 = 114.7 \text{ psia}$$

Air Requirements of Pneumatic Actuators

Pneumatic actuators are used to drive a variety of power tools for performing useful work. The air requirements of these tools in terms of flow rate and pressure depend on the application involved. Figure 13-47 gives the airflow requirements in scfm and standard m^3/min for a number of average-size pneumatic tools designed to operate at a nominal pressure of 100 psig (687 kPa gage).

Example 13-12

A single-acting pneumatic cylinder with a 1.75-in piston diameter and 6-in stroke drives a power tool using 100-psig air at 80°F. If the cylinder reciprocates at 30 cycles/min, determine the air-consumption rate in scfm (cfm of air at standard atmospheric conditions of 14.7 psia and 68°F).

Solution The volume per minute (Q_2) of 100-psig, 80°F air consumed by the cylinder is found first.

$$Q_2(\text{ft}^3/\text{min}) = \text{displacement volume (ft)}^3 \times \text{reciprocation rate (cycles/min)}$$

$$= \text{piston area (ft)}^2 \times \text{piston stroke (ft)} \times \text{recip. rate (cycles/min)}$$

$$= \frac{\pi}{4}\left(\frac{1.75}{12}\right)^2 \times \frac{6}{12} \times 30 = 0.251 \text{ ft}^3/\text{min}$$

To obtain the volume per minute (Q_1) of air (scfm) consumed by the cylinder, we use Eq. (13-7):

$$Q_1 = Q_2\left(\frac{p_2}{p_1}\right)\left(\frac{T_1}{T_2}\right)$$

PNEUMATIC TOOL	scfm	STANDARD m^3/min
HOISTS	5	0.14
PAINT SPRAYERS	10	0.28
IMPACT WRENCHES	10	0.28
HAMMERS	20	0.57
GRINDERS	30	0.85
SANDERS	40	1.13
ROTARY DRILLS	60	1.70
PISTON DRILLS	80	2.36

Figure 13-47. Air requirements of various average-sized pneumatic tools designed for operations at 100 psig (687 kPa gage).

Example 13-13

For the pneumatic cylinder-driven power tool of Exercise 13-12, at what rate can reciprocation take place? The following metric data apply:

a. Piston diameter = 44.5 mm

b. Piston stroke = 152 mm

c. Air pressure and temperature (at the pnuematic cylinder) = 687 kPa gage and 27°C

d. Available flow rate = 0.0555 standard m³/min (cfm of air at standard atmospheric conditions of 101 kPa abs and 20°C)

Solution First, solve for Q_2, which equals the volume per minute of air at 687 kPa gage and 27°C consumed by the cylinder. Using Eq. (13-7) yields

$$Q_2 = Q_1\left(\frac{p_1}{p_2}\right)\left(\frac{T_2}{T_1}\right)$$

where $p_2 = 687 + 101 = 788$ kPa abs,
$p_1 = p_{atm} = 101$ kPa abs,
$T_2 = 27 + 273 = 300$ K,
$T_1 = 20 + 273 = 293$ K,
$Q_1 = 0.0555$ standard m³/min of air.

Substituting values yields an answer for Q_2:

$$Q_2 = 0.0555\left(\frac{101}{788}\right)\left(\frac{300}{293}\right) = 0.00728\ \text{m}^3/\text{min}$$

Next, solve for the corresponding reciprocation rate:

$$Q_2(\text{m}^3/\text{min}) = \text{area}(\text{m}^2) \times \text{stroke}(\text{m}) \times \text{recip. rate (cycles/min)}$$

$$0.00728 = \frac{\pi}{4}(0.0445)^2 \times 0.152 \times \text{recip. rate (cycles/min)}$$

$$\text{recip. rate} = 30\ \text{cycles/min}$$

where $p_2 = 100 + 14.7 = 114.7$ psia,
$p_1 = p_{atm} = 14.7$ psia,
$T_2 = 80 + 460 = 540$°R,
$T_1 = 68 + 460 = 528$°R.

Substituting values yields

$$Q_1 = 0.251\left(\frac{114.7}{14.7}\right)\left(\frac{528}{540}\right) = 1.91\ \text{scfm}$$

If we ignore the temperature increase from standard atmospheric temperature (68°F) to the air temperature at the cylinder (80°F), the value of Q_1 becomes

$$Q_1 = 0.251\left(\frac{114.7}{14.7}\right)\left(\frac{528}{528}\right) = 1.96\ \text{scfm}$$

Thus, ignoring the increase in air temperature results in only a 2% error $\left(\frac{1.96 - 1.91}{1.91} \times 100\%\right)$. However, if the air temperature had increased to a value of 180°F, for instance, the percent error would equal 21%.

Minggu 13

Intro

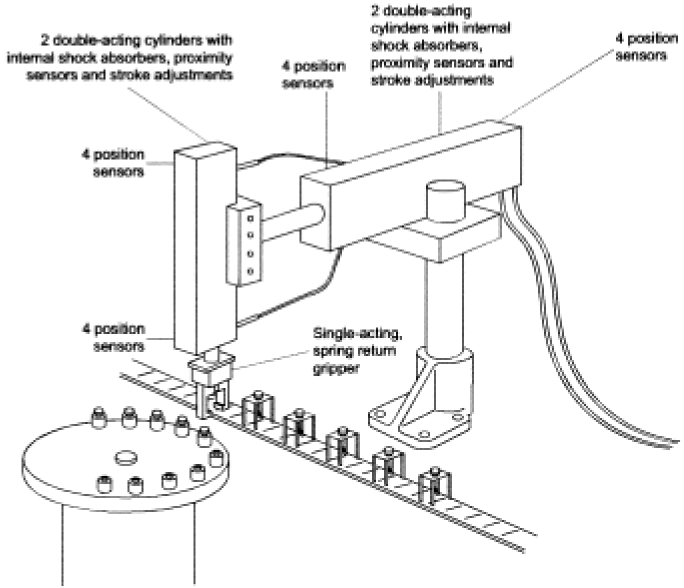


Figure 14-2. Pneumatic system for inserting a brush into nail polish bottles. *(Courtesy of National Fluid Power Association, Milwaukee, Wisconsin.)*

PNEUMATIC CIRCUIT DESIGN CONSIDERATIONS

When analyzing or designing a pneumatic circuit, the following four important considerations must be taken into account:

1. Safety of operation

2. Performance of desired function

3. Efficiency of operation

4. Costs

AIR PRESSURE LOSSES IN PIPELINES

As in the case for liquids, when air flows through a pipe, it loses energy due to friction. The energy loss shows up as a pressure loss, which can be calculated using the Harris formula:

$$p_f = \frac{cLQ^2}{3600\,(\mathrm{CR}) \times d^5} \qquad \textbf{(14-1)}$$

where p_f = pressure loss (psi),
c = experimentally determined coefficient,
L = length of pipe (ft),
Q = flow rate (scfm),
CR = compression ratio = pressure in pipe/atmospheric pressure,
d = inside diameter of pipe (in).

For schedule 40 commercial pipe, the experimentally determined coefficient can be represented as a function of the pipe inside diameter:

$$c = \frac{0.1025}{d^{0.31}} \qquad \textbf{(14-2)}$$

Substituting Eq. (14-2) into the Harris formula yields a single usable equation for calculating pressure drops in air pipelines:

$$p_f = \frac{0.1025LQ^2}{3600\,(\mathrm{CR}) \times d^{5.31}} \qquad \textbf{(14-3)}$$

Tabulated values of d and $d^{5.31}$ are given in Figure 14-3 for schedule 40 common pipe sizes.

Nominal Pipe Size (in)	Inside Diameter d (in)	$d^{5.31}$	Nominal Pipe Size (in)	Inside Diameter d (in)	$d^{5.31}$
$\frac{3}{8}$	0.493	0.0234	$1\frac{1}{2}$	1.610	12.538
$\frac{1}{2}$	0.622	0.0804	2	2.067	47.256
$\frac{3}{4}$	0.824	0.3577	$2\frac{1}{2}$	2.469	121.419
1	1.049	1.2892	3	3.068	384.771
$1\frac{1}{4}$	1.380	5.5304	$3\frac{1}{2}$	3.548	832.550

Figure 14-3. Tabulated values of d and $d^{5.31}$ for schedule 40 common pipe sizes.

AIR PRESSURE LOSSES IN PIPELINES

EXAMPLE 14-1

A compressor delivers 100 scfm of air through a 1-in schedule 40 pipe at a receiver pressure of 150 psi. Find the pressure loss for a 250-ft length of pipe.

Solution First, solve for the compression ratio:

$$\mathrm{CR} = \frac{150 + 14.7}{14.7} = 11.2$$

Next, find the value of $d^{5.31}$ from Figure 14-3:

$$d^{5.31} = 1.2892$$

Finally, using the Harris formula, the pressure loss is found:

$$p_f = \frac{0.1025 \times 250 \times (100)^2}{3600 \times 11.2 \times 1.2892} = 4.93 \text{ psi}$$

EXAMPLE 14-2

A compressor delivers 150 scfm of air through a pipe at a receiver pressure of 120 psig. What minimum size schedule 40 pipe should be used if the pressure loss is to be limited to 0.05 psi per foot of pipe length?

Solution First, solve for the compression ratio:

$$\mathrm{CR} = \frac{120 + 14.7}{14.7} = 9.16$$

Next, solve for $d^{5.31}$ from Eq. 14-3:

$$d^{5.31} = \frac{0.0125\, Q^2}{3600 \times (\mathrm{CR}) \times P_f/L} = \frac{0.1025 \times 150^2}{3600 \times 9.16 \times 0.05} = 1.398$$

Thus, the minimum required inside diameter can now be found:

$$d = (1.398)^{1/5.31} = (1.398)^{0.188} = 1.065 \text{ in}$$

From Figure 14-3 the minimum size pipe that can be used is 1-1/4 in schedule 40 which has a 1.380 inside diameter. The next smaller size is a 1 in schedule 40 which has only a 1.049-in inside diameter.

AIR PRESSURE LOSSES IN PIPELINES

FITTING	NOMINAL PIPE SIZE (in)						
	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2
GATE VALVE (FULLY OPEN)	0.30	0.35	0.44	0.56	0.74	0.86	1.10
GLOBE VALVE (FULLY OPEN)	14.0	18.6	23.1	29.4	38.6	45.2	58.0
TEE (THROUGH RUN)	0.50	0.70	1.10	1.50	1.80	2.20	3.30
TEE (THROUGH BRANCH)	2.50	3.30	4.20	5.30	7.00	8.10	10.44
90° ELBOW	1.40	1.70	2.10	2.60	3.50	4.10	5.20
45° ELBOW	0.50	0.78	0.97	1.23	1.60	1.90	2.40

Figure 14-4. Equivalent length of various fittings (ft).

The frictional losses in pneumatic fittings can be computed using the Harris formula if the equivalent lengths of the fittings are known. The term L in the Harris formula would then represent the total equivalent length of the pipeline including its fittings. Figure 14-4 gives equivalent length values in feet for various types of fittings.

Example 14-3

If the pipe in Example 14-1 has two gate valves, three globe valves, five tees (through run), four 90° elbows, and six 45° elbows, find the total pressure loss.

Solution The total equivalent length of the pipe is

$$L = 250 + 2(0.56) + 3(29.4) + 5(1.50) + 4(2.60) + 6(1.23)$$

$$= 250 + 1.12 + 88.2 + 7.5 + 10.4 + 7.38 = 364.6 \text{ ft}$$

Substituting into the Harris formula yields the answer:

$$p_f = \frac{0.1025 \times 364.6 \times (100)^2}{3600 \times 11.2 \times 1.2892} = 7.19 \text{ psi}$$

Thus, the total pressure loss in the pipes, valves, and fittings is 46% greater than the pressure loss in only the pipes. This shows that valves and fittings must also be adequately sized to avoid excessive pressure losses.

ECONOMIC COST OF ENERGY LOSSES IN PNEUMATIC SYSTEMS

EXAMPLE 14-4

A compressor delivers air at 100 psig and 270 scfm.

a. Determine the actual hp required to drive the compressor if the overall efficiency of the compressor is 75%.
b. Repeat part a assuming the compressor is required to provide air at 115 psig to offset a 15-psi pressure loss in the pipeline due to friction.
c. Calculate the cost of electricity per year for parts a and b. Assume the efficiency of the electric motor driving the compressor is 92% and that the compressor operates 3000 hr per year. The cost of electricity is \$0.11/kWh.

Solution

a. Using Eq. (13-9) and dividing by η_o, the actual horsepower (hp) required to drive the compressor at 100 psig is

$$\text{actual hp (at 100 psig)} = \frac{p_{in}Q}{65.4\eta_o}\left[\left(\frac{p_{out}}{p_{in}}\right)^{0.286} - 1\right]$$

$$= \frac{14.7 \times 270}{65.4 \times 0.75}\left[\left(\frac{114.7}{14.7}\right)^{0.286} - 1\right]$$

$$= 64.7 \text{ hp}$$

b. The actual hp required to drive the compressor at 115 psig is

$$\text{actual hp (at 115 psig)} = \frac{14.7 \times 270}{65.4 \times 0.75}\left[\left(\frac{129.7}{14.7}\right)^{0.286} - 1\right]$$

$$= 69.9 \text{ hp}$$

c. Since 0.746 kW = 1 hp, the actual power required to drive the compressor at 100 psig equals

$$64.7 \text{ hp} \times \frac{0.746 \text{ kW}}{1 \text{ hp}} = 48.3 \text{ kW}$$

Thus, the electric power required to drive the electric motor at 100-psig air delivery is

$$\frac{48.3 \text{ kW}}{0.92} = 52.5 \text{ kW}$$

The cost of electricity per year at a pressure of 100 psig is now found as follows:

$$\text{yearly cost} = \text{power rate} \times \text{time per year} \times \text{unit cost of elec.}$$

$$= 52.5 \text{ kW} \times 3000 \text{ hr/yr} \times \$0.11/\text{kWh} = \$17{,}300/\text{yr}$$

The electric power required to drive the electric motor at 115-psig air delivery is

$$\frac{69.9}{0.92} \times 0.746 = 56.7 \text{ kW}$$

The cost of electricity per year at a pressure of 115 psig is now found as follows:

$$\text{yearly cost} = 56.7 \text{ kW} \times 3000 \text{ hr/yr} \times \$0.11/\text{kWh} = \$18{,}700/\text{yr}$$

Hence, the cost of the compressor having to provide the additional 15 psi to offset the pressure loss in the pipeline is \$1400/yr.

EXAMPLE 14-5

The compressor in Example 14-4 delivers air at 100 psig. If the compressor is required to provide an additional 70 scfm to compensate for air leakage from the pneumatic circuit into the atmosphere, what is the yearly cost of the leakage?

Solution From Example 14-4 the actual power required to drive the compressor at 100 psig and 270 scfm is 64.7 hp. The corresponding electric power required to drive the electric motor is 52.5 kW. Thus, the additional electric power required to drive the electric motor of the compressor to compensate for the air leakage of 70 scfm is

$$\frac{70}{270} \times 52.3 \text{ kW} = 13.6 \text{ kW}$$

As a result, if the pneumatic system operates with no downtime, the yearly cost of the 70-scfm leakage is

$$\text{yearly cost} = \text{power rate} \times \text{time per year} \times \text{unit cost of elec.}$$

$$= 13.6 \text{ kW} \times 24 \text{ hr/day} \times 365 \text{ days/yr} \times \$0.11/\text{kWh}$$

$$= \$13{,}100/\text{yr}$$

As stated in Section 14.2, 70 scfm is the amount of 100-psi air that would pass through the area of a 0.25-in-diameter hole. Thus, if all the various leakage areas of a pneumatic circuit (such as those existing in imperfectly sealed pipe fittings) add up to this hole area, the total leakage into the atmosphere would equal 70 scfm. The leakage area of a 0.25-in-diameter hole can easily occur even if only a few pipe fittings experience small leaks. The total cost of the air leakage plus the 15-psi pressure loss in the pipeline (from Example 14-4) equals the very significant amount of \$14,500/yr.

Operation of Single-Acting Cylinder

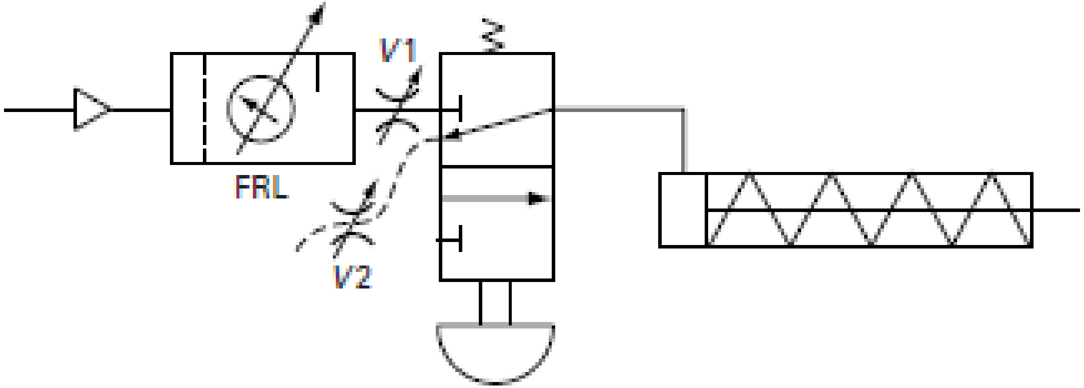


Figure 14-5. Operation of a single-acting cylinder.

Operation of Double-Acting Cylinder

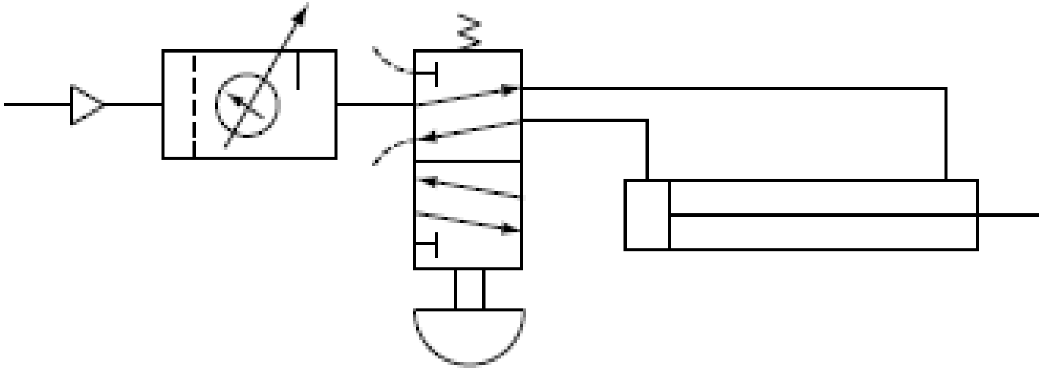


Figure 14-6. Operation of a double-acting cylinder.

Air Pilot Control of Double-Acting Cylinder

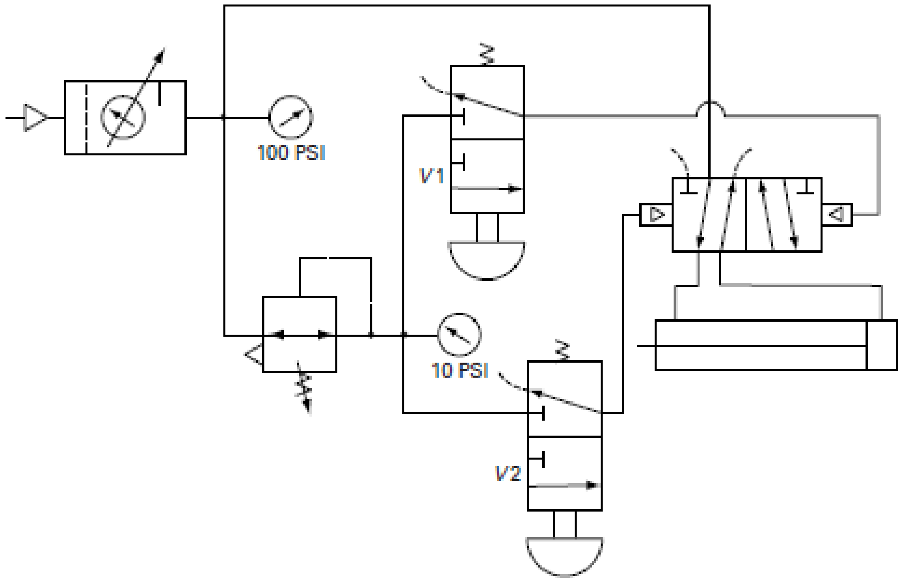


Figure 14-7. Air pilot control of a double-acting cylinder. *(This circuit is simulated on the CD included with this textbook.)*

Cylinder Cycle Timing System

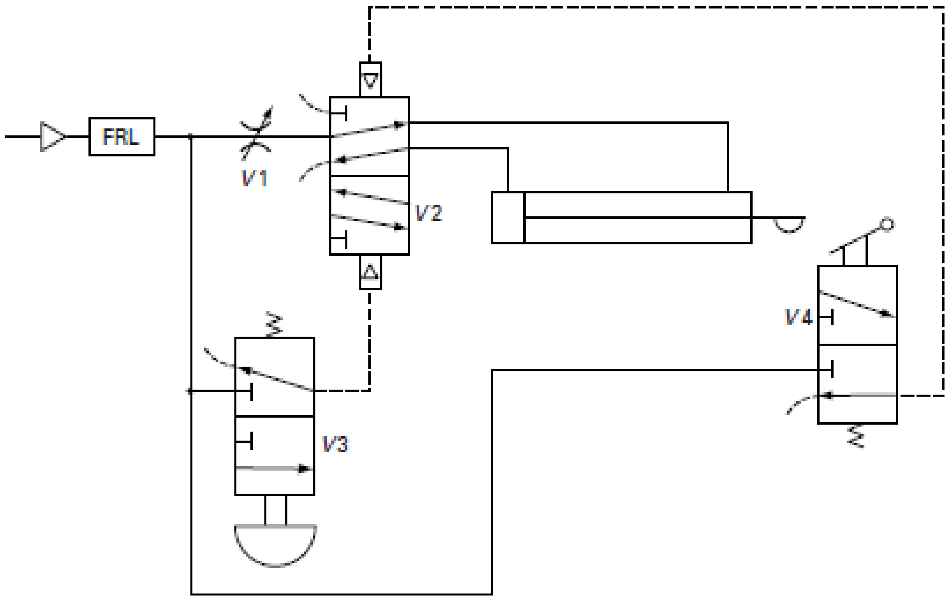


Figure 14-8. Cylinder cycle timing system.

Two-Step Speed Control System

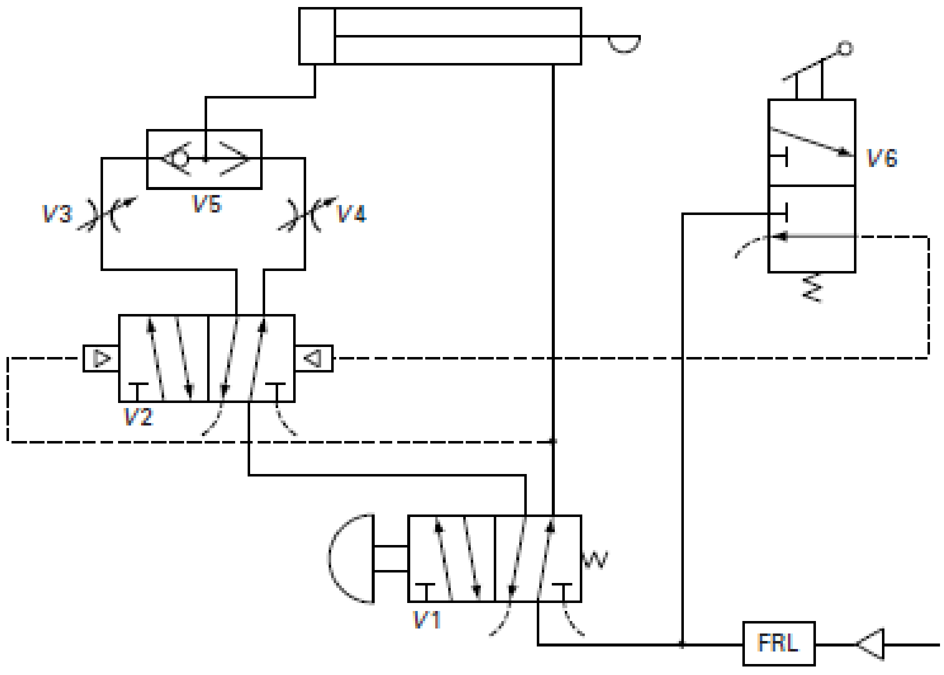


Figure 14-9. Two-step speed control system.

Two-Handed Safety Control System

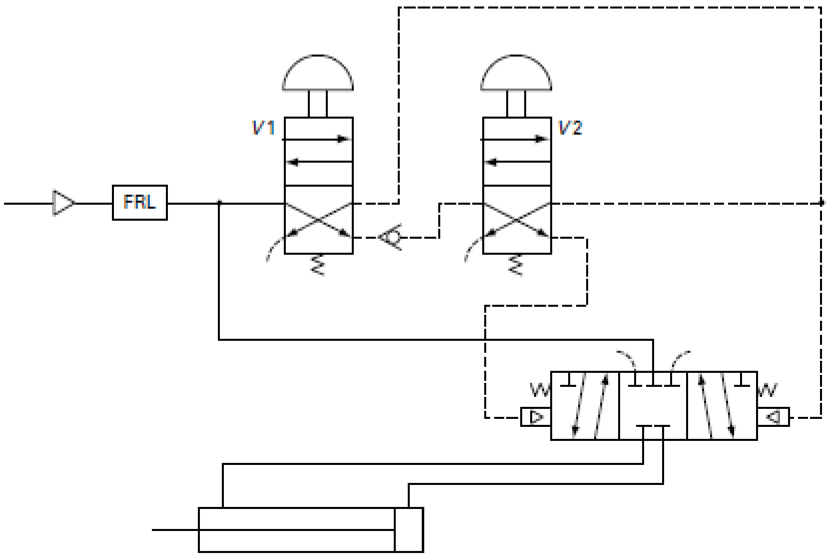


Figure 14-10. Two-handed safety control circuit.

Control of Air Motor

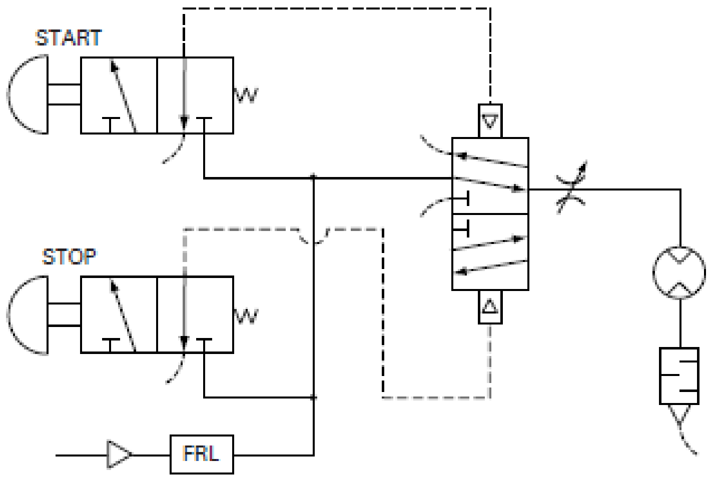


Figure 14-11. Control of an air motor. *(This circuit is simulated on the CD included with this textbook.)*

Deceleration Air Cushion of Cylinder

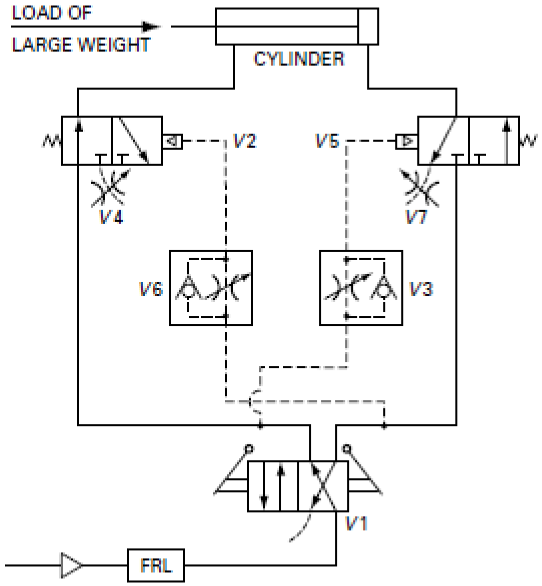


Figure 14-12. Deceleration air cushion of a pneumatic cylinder.

Minggu 14

Materials-Handling Application

Figure 14-14. Factory application of the lifting and transporting of large sheet metal panels using pneumatic vacuum system technology. *(Courtesy of Schmalz, Inc., Raleigh, North Carolina.)*

Figure 14-15. A variety of actual, different-sized vacuum cups. *(Courtesy of Schmalz, Inc., Raleigh, North Carolina.)*

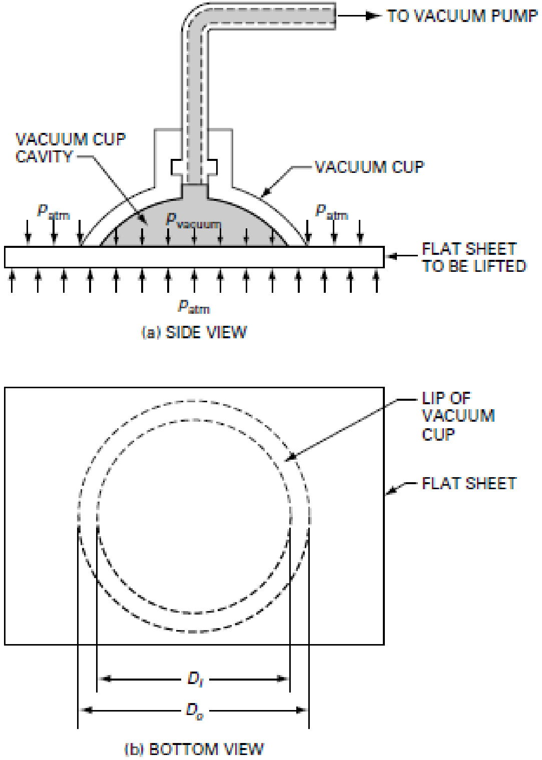


Figure 14-13. Vacuum cup used to lift a flat sheet.

Analysis of Suction Lift Force

The magnitude of this force can be determined by algebraically summing the pressure forces on the top and bottom surfaces of the flat sheet as follows:

$$F = p_{atm} A_o - p_{suction} A_i \quad \textbf{(14-4)}$$

where F = the upward force the suction cup exerts on the flat sheet (lb, N),
p_{atm} = the atmospheric pressure in absolute units (psia, Pa abs),
A_o = the area of the outer circle of the suction cup lip
$= \frac{\pi}{4} D_o^2 (\text{in}^2, \text{m}^2)$,
D_o = the diameter of the suction cup lip outer circle (in, m),
$p_{suction}$ = the suction pressure inside the cup cavity in absolute units (psia, Pa abs),
A_i = the area of the inner circle of the suction cup lip
$= \frac{\pi}{4} D_i^2 (\text{in}^2, \text{m}^2)$,
D_i = the diameter of the suction cup inner lip circle (in, m).

Note in Figure 14-13(a) that the atmospheric pressure on the top and bottom surfaces of the flat sheet cancel out away from the outer circle area of the cup lip. If all the air were removed from the cup cavity, we would have a perfect vacuum, and thus the suction pressure would be equal to zero in absolute pressure units. Thus, for a perfect vacuum, Eq. (14-4) becomes

$$F = p_{atm} A_o \quad \textbf{(14-5)}$$

Example 14-6

How heavy an object can be lifted with a suction cup having a 6-in lip outside diameter and a 5-in lip inside diameter for each suction pressure?

a. − 10 psig = 10-psi vacuum = 10-psi suction
b. Zero absolute (a perfect vacuum)

Solution

a. The suction pressure (which must be in absolute units) equals

$$p_{suction}\,(\text{abs}) = p_{suction}\,(\text{gage}) + p_{atm}$$
$$= -10 + 14.7 = 4.7 \text{ psia}$$

The maximum weight that can be lifted can now be found using Eq. (14-4):

$$F = \text{maximum weight } W = p_{atm}\, A_o - p_{suction}\, A_i$$
$$= 14.7 \times \frac{\pi}{4}(6)^2 - 4.7 \times \frac{\pi}{4}(5)^2 = 416 - 92 = 324 \text{ lb}$$

b. Substituting directly into Eq. (14-5), we have

$$F = W = 14.7 \times \frac{\pi}{4}(6)^2 = 416 \text{ lb}$$

If we use a factor of safety of 2, the answers to parts a and b become 162 lb and 208 lb, respectively.

- **Time to Achieve Desired Vacuum Pressure**

When a suction cup is placed on the top of a flat sheet and the vacuum pump is turned on, a certain amount of time must pass before the desired vacuum pressure is achieved. The time it takes to produce the desired vacuum pressure can be determined from Eq. (14-6):

$$t = \frac{V}{Q}\ln\left(\frac{p_{atm}}{p_{vaccum}}\right) \quad (14\text{-}6)$$

where t = the time required to achieve the desired suction pressure (min),
V = the total volume of the space in the suction cup cavity and connecting pipeline up to the location of the vacuum pump (ft^3, m^3),
ln = the natural logarithm to the base e, where e is approximately 2.718,
Q = the flow rate produced by the vacuum pump (scfm, standard m^3/min),
p_{atm} = atmospheric pressure in absolute units (psia, Pa abs),
p_{vacuum} = the desired vacuum pressure in absolute units (psia, Pa abs).

Because p_{atm}/p_{vacuum} is a ratio, it is dimensionless. Thus, any desired units can be used for p_{atm} and p_{vacuum} as long as the units are the same and are absolute. For

EXAMPLE 14-7

A pneumatic vacuum lift system has a total volume of 6 ft^3 inside the suction cup and associated pipeline leading to the vacuum pump. The vacuum pump produces a flow rate of 4 scfm when turned on. The desired suction pressure is 6 in Hg abs and atmospheric pressure is 30 in Hg abs. Determine the time required to achieve the desired vacuum pressure.

Solution Substituting into Eq. (14-6) yields the solution:

$$t = \frac{V}{Q}\ln\left(\frac{p_{atm}}{p_{vacuum}}\right) = \frac{6\ ft^3}{4\ ft^3/min}\ln\left(\frac{30\ in\ Hg\ abs}{6\ in\ Hg\ abs}\right) = 2.41\ min$$

Because division by zero cannot be done, a perfect suction pressure of zero absolute cannot be substituted into Eq. (14-6). To find the approximate time required to come close to obtaining a perfect vacuum, a very nearly perfect suction pressure of 0.50 in Hg abs (or the equivalent pressure of 0.245 psia) can be used. Substituting these values into Eq. (14-6) yields the time it takes to achieve an almost perfect vacuum:

$$t = \frac{6\ ft^3}{4\ ft^3/min}\ln\left(\frac{30\ in\ Hg\ abs}{0.5\ in\ Hg\ abs}\right) = \frac{6\ ft^3}{4\ ft^3/min}\ln\left(\frac{14.7\ psia}{0.245\ psia}\right) = 6.14\ min$$

Thus, it takes 2.55 times (6.14 min/2.41 min) as long to achieve a very nearly perfect vacuum as it does to achieve a vacuum of 1/5 atm (6 in Hg/30 in Hg).

SIZING OF GAS-LOADED ACCUMULATORS

EXAMPLE 14-8

The circuit of Figure 14-16 has been designed to crush a car body into bale size using a gas-loaded accumulator and 6-in-diameter hydraulic cylinder. The hydraulic cylinder is to extend 100 in during a period of 10 s. The time between crushing strokes is 5 min. The following accumulator gas absolute pressures are given:

p_1 = gas precharge pressure = 1200 psia

p_2 = gas charge pressure when pump is turned on

= 3000 psia = pressure relief valve setting

p_3 = minimum pressure required to actuate load = 1800 psia

a. Calculate the required size of the accumulator.

b. What are the pump hydraulic horsepower and flow requirements with and without an accumulator?

Solution Figure 14-17 shows the three significant accumulator operating conditions:

1. **Preload** [Figure 14-17(a)]. This is the condition just after the gas has been introduced into the top of the accumulator. Note that the piston (assuming a piston design) is all the way down to the bottom of the accumulator.
2. **Charge** [Figure 14-17(b)]. The pump has been turned on, and hydraulic oil is pumped into the accumulator since p_2 is greater than p_1. During this phase, the four-way valve is in its spring-offset position. Thus, system pressure builds up to the 3000-psia level of the pressure relief valve setting.
3. **Final position of accumulator piston at end of cylinder stroke** [Figure 14-17(c)]. The four-way valve is actuated to extend the cylinder against its load. When the system pressure drops below 3000 psia, the accumulator 3000-psia gas pressure forces oil out of the accumulator into the system to

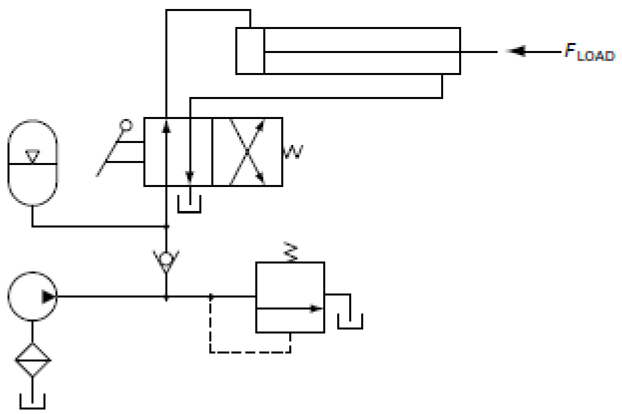


Figure 14-16. Use of gas-loaded accumulator in hydraulic system for crushing car bodies.

SIZING OF GAS-LOADED ACCUMULATORS

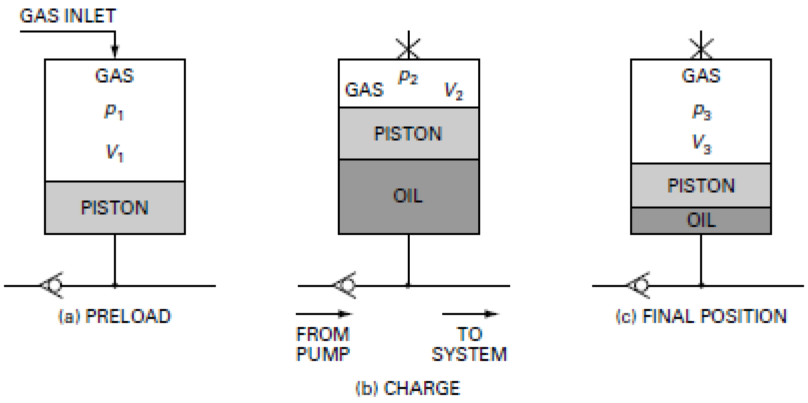


Figure 14-17. Operation of gas-loaded piston accumulator.

assist the pump during the rapid extension of the cylinder. The accumulator gas pressure reduces to a minimum value of p_3, which must not be less than the minimum value of 1800 psia required to drive the load.

a. Use Eq. (13-3):

$$p_1V_1 = p_2V_2 = p_3V_3$$

where V_1 = required accumulator size, and also use $V_{\text{hydraulic cylinder}} = V_3 - V_2$ (assuming negligible assistance from the pump).
Thus, we have

$$V_3 = \frac{p_2V_2}{p_3} = \frac{3000V_2}{1800} = 1.67\ V_2$$

$$V_{\text{hydraulic cylinder}} = \frac{\pi}{4}(6)^2 \times 100 = 2830\ \text{in}^3 = V_3 - V_2$$

Solving the preceding equations yields

$$V_2 = 4230\ \text{in}^3 \quad V_3 = 7060\ \text{in}^3$$

Therefore, we have a solution:

$$V_1 = \frac{p_2V_2}{p_1} = \frac{(3000)(4230)}{1200} = 10{,}550\ \text{in}^3 = 45.8\text{-gal accumulator}$$

SIZING OF GAS-LOADED ACCUMULATORS

Note that this is a very large accumulator because it is required to do a big job. For example, if the cylinder stroke were only 10 in, a 4.58-gal accumulator would suffice.

b. *With accumulator* (pump charges accumulator twice in 5 min):

Note that in 5 min the pump must recharge the accumulator only to the extent of the volume displaced in the cylinder during extension and retraction. Ignoring the diameter of the hydraulic cylinder rod, this volume equals $2(V_3 - V_2) = 2(2830/231)$ gal = 24.5 gal. Thus, we have

$$Q_{\text{pump}} = \frac{24.5 \text{ gal}}{5 \text{ min}} = 4.90 \text{ gpm (a small size pump)}$$

$$\text{hp}_{\text{pump}} = \frac{(3000)(4.90)}{1714} = 8.58 \text{ hp (a small horse power requirement)}$$

Without accumulator (pump extends cylinder in 10 s):

$$Q_{\text{pump}} = \frac{\left(\frac{2830}{231}\right) \text{ gal}}{\left(\frac{1}{6}\right) \text{ min}} = 73.4 \text{ gpm (a very large pump)}$$

$$\text{hp}_{\text{pump}} = \frac{(1800)(73.4)}{1714} = 76.6 \text{ hp (a very large horse power requirement)}$$

The results show that an accumulator, by handling large transient demands, can dramatically reduce the size and power requirements of the pump.

PNEUMATIC CIRCUIT ANALYSIS USING METRIC UNITS

Example 14-9

A 75% efficient compressor delivers air at 687 kPa gage and 7.65 standard m³/min. Calculate the cost of electricity per year if the efficiency of the electric motor driving the compressor is 92% and the compressor operates 3000 hr per year. The cost of electricity is $0.11/kWh.

Solution Using Eq. (13-8M) and dividing by η_o, the actual power needed to drive the compressor is

$$\text{actual power (kW)} = \frac{p_{in}Q}{17.1\eta_o}\left[\left(\frac{p_{out}}{p_{in}}\right)^{0.286} - 1\right]$$

$$= \frac{101 \times 7.65}{17.1 \times 0.75}\left[\left(\frac{788}{101}\right)^{0.286} - 1\right] = 48.2 \text{ kW}$$

Thus, the electric power required to drive the electric motor is 48.2/0.92 kW = 52.4 kW. The cost of electricity per year can now be found:

$$\text{yearly cost} = \text{power rate} \times \text{time per year} \times \text{unit cost of elec.}$$

$$= 52.4 \text{ kW} \times 3000 \text{ hr/yr} \times \frac{\$0.11}{\text{kWh}} = \$17{,}300/\text{yr}$$

Example 14-10

A pneumatic vacuum lift system uses four suction cups, each having a 100-mm lip outside diameter and a 80-mm lip inside diameter. The vacuum system is to lift large steel sheets weighing 1000 N. The total volume inside the cup cavities and associated pipelines up to the vacuum pump is 0.15 m³. If a factor of safety of 2 is used, what flow rate must the vacuum pump deliver if the time required to produce the desired vacuum pressure is 1.0 min?

Solution First, solve for the required vacuum pressure using Eq. (14-4):

$$F = p_{atm} A_o - p_{vacuum} A_i$$

$$\frac{1000 \times 2}{4} = 101{,}000 \times \frac{\pi}{4}(0.100)^2 - p_{vacuum} \times \frac{\pi}{4}(0.080)^2$$

$$500 = 793 - 0.00503 p_{vacuum}$$

$$p_{vacuum} = 58{,}300 \text{ Pa abs}$$

Now we can solve for the required vacuum pump flow rate using Eq. (14-6):

$$Q = \frac{V}{t}\ln\left(\frac{p_{atm}}{p_{vacuum}}\right) = \frac{0.15}{1.0}\ln\left(\frac{101{,}000}{58{,}300}\right)$$

$$= 0.0824 \text{ standard m}^3\text{/min of air}$$

PNEUMATIC CIRCUIT ANALYSIS USING METRIC UNITS

Example 14-11

The circuit of Figure 14-16 has been designed to crush a car body into bale size using a 152-mm-diameter hydraulic cylinder. The hydraulic cylinder is to extend 2.54 m during a period of 10 s. The time between crushing strokes is 5 min. The following accumulator gas absolute pressures are given:

p_1 = gas precharge pressure = 84 bars abs

p_2 = gas charge pressure when pump is turned on = 210 bars abs = pressure relief valve setting

p_3 = minimum pressure required to actuate load = 126 bars abs

a. Calculate the required size of the accumulator.

b. What are the pump hydraulic kW power and the flow requirements with and without an accumulator?

Solution Figure 14-17 shows the three significant accumulator operating conditions (preload, charge, and final position of accumulator piston at end of cylinder stroke).

a. Use Eq. (13-3).

$$p_1V_1 = p_2V_2 = p_3V_3$$

where V_1 = required accumulator size, and also use

$$V_{\text{hydraulic cylinder}} = V_3 - V_2$$

Thus, we have

$$V_3 = \frac{p_2V_2}{p_3} = \frac{210}{126}V_2 = 1.67\,V_2$$

$$V_{\text{hydraulic cylinder}} = \frac{\pi}{4}(0.152)^2 \times 2.54 = 0.0461\text{ m}^3 = V_3 - V_2$$

Solving the preceding equations yields

$$V_2 = 0.0688\text{ m}^3 \quad V_3 = 0.115\text{ m}^3$$

Therefore, we have a solution

$$V_1 = \frac{p_2V_2}{p_1} = \frac{(210)(0.0688)}{84} = 0.172\text{ m}^3 = 172\text{ L}$$

b. *With accumulator* (pump charges accumulator twice in 5 min):

Ignoring the diameter of the hydraulic cylinder rod yields (see solution to Example 14-8):

$$Q_{\text{pump}} = \frac{2(V_3 - V_2)}{300\text{ s}} = \frac{2(46.1\text{ L})}{300\text{ s}} = 0.307\text{ L/s (a small size pump)}$$

$$\text{kW}_{\text{pump}} = \frac{(210 \times 10^5)(30.7 \times 10^{-5})}{1000} = 6.45\text{ kW (a small power requirement)}$$

Without accumulator (pump extends cylinder in 10 s):

$$Q_{\text{pump}} = \frac{46.1\text{ L}}{10\text{ s}} = 4.61\text{ L/s (a very large pump)}$$

$$\text{kW}_{\text{pump}} = \frac{(126 \times 10^5)(461 \times 10^{-5})}{1000} = 58.1\text{ kW (a very large power requirement)}$$

Minggu 15

Maintenance

Maintenance requirements can be considered under three headings

- Tools and appliances.
- Systems.
- Compressors.

Air tools

A programme for air tool maintenance should cover the following points:

- Ensuring that the air supply is maintained at the required pressure with the required delivery.
- Regular checking and refilling of lubricators to ensure adequate lubrication. This may require attention more than once per shift, so the operator should be supplied with equipment and lubricant for this purpose.
- Checking tools for damage.
- Checking that the tools are handled in a proper manner, that they are cleaned and lubricated after use.
- Checking that the proper tool bit or attachment is kept sharp and in good condition.

TABLE 1 – Air tool maintenance points.

Check of fault	*Likely cause*	*Action*
Dirt of gummy deposits on motor	Insufficient or wrong oil; dirty air	Check lubricator Check line filter
High blade wear on motor	Insufficient oil; normal wear	Reduce periods between scheduled maintenance
Bearing play	Excessive load; normal wear	Check tool capacity for job; replace bearing
Bearing rough	Dirty air Lack of lubrication Normal wear	Check filter Check lubricator Replace bearing
Governor action sluggish	Air leakage	Check governor bushings for wear
Loss of power	Low air pressure Air leakage Governor fault	Check line pressure & filter Check and rectify Check governor condition; adjust action if necessary
Vibration	Breakage	Replace faulty part(s)
Loss of speed	Low air pressure Air leakage Governor fault	Check line pressure and filter Check and rectify Check

Appliance maintenance

Overhaul of air-operated appliances requires the following precautions:

- All air pressures to be completely released from the system.
- It should be impossible to start the appliance inadvertently.
- The correct tools must be available.
- Adequate lifting gear should be available and checked to be in good condition.

After maintenance and before clearing the machine for use, check:

- The operating pressures, speed and working temperature are correct.
- The controls and shut-down devices work correctly.
- That the sump or oil container is filled with the correct grade of oil, where appropriate.
- That there is a full flow of coolant, where appropriate.
- Condition of exhaust or discharge pipe and pulsation chamber. Clean off any deposits.
- Clean the outside of the appliance.
- Record the work done and replacement parts.

Air cylinder maintenance

Air cylinders require little in the way of maintenance if properly used, except for periodic replacement of expendable parts, such as seals, boots and gaiters. The items to be checked include piston seals, end cover seals, rod seals and bearings.

TABLE 2 – Trouble-shooting – air cylinders.

Fault	*Cause*	*Action*
Loss of thrust*	1. Leaking piston seals	Replace seals
	2. Corrosion on bore	Refinish bore as necessary to eliminate wear on seals
	3. Dirt trapped in seals	Replace seals. Clean cylinder. Check condition of rod wiper seal. Fit external gaiter if necessary for better protection.
	4. Excessive friction	Check condition of hose, seals, wear rings and rod bearing
	5. Low pressure	Check supply pressure at inlet
Leakage past rod	Rod seals faulty	Replace seals unless compression type seals are fitted in an adjustable gland. In that case, tighten gland.
Loss of cushioning	1. Cushion valve blocked	Remove and clean
	2. Cushion seals failed	Replace cushion seal(s)

* Loss of thrust can also result from substantially increasing the speed of working with no fault present in the cylinder or system.

System maintenance

TABLE 3 – Maintenance points – pipework.

Type of line	*Possible cause of trouble*	*Action*
Rigid line system	1. Dead weight of piping	Support with pipe clips, closer spaced on horizontal runs
	2. Expansion and contraction	(a) use clips which allow lateral movement of pipes (b) incorporate bends to accommodate movement where there is a large difference in ambient temperatures
	3. Internal pressure	Provide adequate support as necessary to prevent movement and flexing
	4. Leakage	(a) all pipe joints to be properly made (b) replace faulty valves or fittings (c) if caused by damage, check environmental conditions; resite or protect vulnerable fittings
	5. Water entrainment	Check that suitable water traps are provided and that their location is satisfactory. Establish suitable draining period and check period for manual traps. All loop bends should be upward facing, not downward
Flexible lines	1. Leakage	(a) check for wear or deterioration at end couplings (b) resite or protect hoses subjected to bad environmental conditions (c) lay down standard procedure for manipulation of flexible hoses (d) consider possible use of automatic close-coil flexible lines
	2. Excessive pressure drop	(a) check hose for bore condition (b) check that suitable size of hose is being used.

Pipe work should require minimum attention, usually only inspection for possible leaks. Installation faults needing correction are:

- Sagging or displaced pipes requiring proper support.
- Evidence of whipping at bends or vibration due to inadequate support during pressure surges.
- Distortion of runs caused by expansion or contraction movement, which can be cured by incorporating bends or expansion joints.

Compressor maintenance

While a general indication can be given of the principles of compressor maintenance (see Tables 4 to 8), it is better to rely on the manufacturer's schedules where available. Basic requirements include:

- cleanliness (regular cleaning of intake filters);
- attention to drain points on the compressor, intercooler and receiver;
- ensuring an adequate supply of lubricant;
- correct tensioning of intercooler and main driving belts;
- routine oil changes in accordance with the manufacturer's recommendations;
- cleaning or replacement of intake filters;
- inspection and cleaning of valves on a reciprocating compressor;
- inspection and replacement of vanes on a rotary vane compressor.

Compressors

TABLE 4 – Maintenance Points - reciprocating compressors

Component	*Interval†*	*Action*
Air filter (inlet)	Fortnightly	Clean as necessary
Cooling system	Continuous As necessary	Check water temperatures Clean water side on water-cooled systems
Lubrication	Periodically†	1. Check cylinder oil feed rate 2. Check oil levels 3. Change crankcase oil
Bearings	Periodically†	Check wear. Adjust for wear or replace as necessary
Drains	Hourly† Daily†	Intercooler drains Other drains or all automatic drains
Valves	Periodically†	Check for condition and replace plates or springs as necessary
Safety valves	Periodically†	Clean and inspect
Piston rings	Annually	Inspect for condition and replace as necessary
Packing glands	Periodically†	Adjust if applicable; otherwise inspect for condition and replace if necessary

†Suitable intervals can only be established by experience or on manufacturer's recommandations

TABLE 5 – Oil Changes - reciprocating compressors

Compressor type	*Working conditions*	*Change interval*
All stationary	Running in	After 100 hours
All portable	Running in	After 50 hours
Stationery	Clean atmosphere Dirty atmosphere	6 months or 2000 hours 3 months or 1000 hours†
Portable	Average Dirty atmosphere Very dirty atmosphere	1 month or 500 hours 2 weeks or 250 hours† 1 week or 100 hours†

†Suitable intervals can only be established by experience or on manufacturer's recommendations

TABLE 6 – Trouble-shooting - reciprocating compressors

Fault or symptom	*Possible causes*	*Action*
'Knocking' or heavy vibration	Drive or coupling elements loose Unstable oil-relief valve causing hydraulic hammer Excessive working clearances on crosshead or bearings Cylinder clearance volume too small	Check and rectify Check valve springs (a) Check for wear (b) Check for misalignment Check for accumulation or water, oil or other deposits
Abnormal air temperature	Faulty cooling system Defective air filter Excessive cylinder wear	Check and clean Replace Check and replace
Abnormal air pressure	Leakage Loss of compression efficiency Seal failure	Find and correct leakage Check cylinder and ring wear Replace if faulty Check compression seals
Rumbling noise	Air leakage past piston rings	Replace
Valve chatter	Defective valve springs	Replace

Compressors

TABLE 7 – Trouble-shooting - rotary compressors

Fault	*Possible cause*	*Remedy*
Compressor fails to build up pressure	Regulator needs adjustment Unloader valve stuck Faulty blow down valve Choked intake cleaner (indicator shows red)	Adjust to give normal pressure Inspect and release Overhaul or renew Renew element
Compressor fails to offload (safety valve blows)	Unloader/compressor joint leak Unloader valve stuck open Unloader diaphragm punctured Faulty safety valve	Renew Inspect and release Renew Test and adjust
Plant operates at incorrect speed (portable compressors)	Plant operating at incorrect pressure Speed control linkage worn or needs adjustment	Adjust pressure regulator Renew or adjust
Air delivery temperature too high	Exterior of oil cooler clogged Insufficient oil in cooling system Incorrect grade oil Oil filter clogged Faulty thermal bypass valve	Clean Fill to correct level Drain and refill Renew Check temp. in cooler & adjust
Excessive oil consumption (oil carryover with air)	Incorrect oil grade Minimum air pressure too low Too much oil Air/oil separator faulty	Drain and refill Inspect and adjust minimum pressure valve Drain to correct level Clean or renew
Emission of oil from air inlet after machine has stopped	Oil control valve stuck open	Examine and clean. Check for lacquer around valve

TABLE 8 – Maintenance Points - rotary compressors

Component	*Inspection*	*Further action*
Electric motor	Clean motor; inspect for wear; check bearings; check clearances; check general condition	As necessary
Couplings (where appropriate)	Clean and examine	Replace if necessary
Casing	Open and examine for corrosion and wear	
Journal bearings	Examine for wear	Replace, reline, adjust with shims (as necessary)
Shaft seals	Check condition of clearances	Replace if necessary
Rotor	Examine for corrosion, pitting and wear; check clearances; check balance	As necessary
Gear case (where appropriate)	Examine for corrosion and wear; check damper	As necessary
Other parts	Examine for corrosion, erosion erosion and wear	As necessary
Governor/Regulator	Clean and inspect; check for wear; check adjustment	Replace worn parts; adjust for proper operation
Auxiliary drives	Check	Replace worn parts
Instrumentation	Check for operation and correct reading	Recalibrate or adjust as necessary

The End

Lampiran 3. RENCANA PELAKSANAAN PEMBELAJARAN (*Output* Kegiatan 3)

Program Studi : Teknik Mesin
Mata Kuliah : Sistem Hidraulik dan Pneumatik
Kode Mata Kuliah : TM201505
Semester/sks : VII (Pilihan)/ 3 sks
Pertemuan Ke/Waktu : **1-4** / 4 x 150 menit
Dosen Pengampu : Gad Gunawan, S.T., M.T.
CPMK : Mampu menerapkan prinsip dasar hidraulik dan pneumatik dalam pemanfaatannya di industri **(C3).**

Deskripsi Mata Kuliah : Memberikan dasar-dasar tentang pemanfaatan tenaga hidraulik & pneumatik. Prinsip pemindahan tenaga yang berkaitan dangan karakteristik fluida yang digunakan. Karakteristik komponen, operasi dan fungsinya. Pemahaman sirkuit hidraulik/pneumatik dan kontrol diskrit. Pemilihan komponen peralatan dari sirkuit yang ada. Pemanfaatan sistem hidraulik & pneumatik dalam industri, baik kekurangan maupun kelebihan dibanding sistem lainnya.

Indikator :

1. Mengetahui komponen sistem hidraulik

Tujuan Pembelajaran, Setelah menempuh perkuliahan ini :

1. Mahasiswa mampu mengetahui komponen sistem hidraulik

Materi Pokok (Bahan Kajian):

Komponen-komponen sistem hidraulik:

1. Pengenalan
2. Karakteristik Fluida Hidraulik
3. Pompa
4. Aktuator
5. Control Valve
6. Conduktor and fitting
7. Ancilary hidraulic devices

Minggu ke-1

No	Tahap	Kegiatan Pembelajaran	Metode	Alokasi waktu	Sumber Belajar/ Bahan Ajar/ Media	Penilaian
1	Awal	• Melakukan perkenalan • Membuat kontrak perkuliahan • Menyampaikan tujuan perkuliahan dan deskripsi singkat bahan kajian	Daring	5 menit 15 menit 10 menit	Google meeting	
2	Inti	• Memberikan pengenalan sistem hidraulik • Menjelaskan metode Pembelajaran Problem Based Learning • Membagi mahasiswa menjadi beberapa kelompok • Memberikan masalah yang perlu dipecahkan	Daring Daring Daring (*chat online)* Daring (*chat online)*	30 menit 30 menit 15 menit 5 menit 40 menit	Google meeting	

		• Kelompok mengidentifikasi isu dan bahan ajar yang sesuai dengan isu serta membagi tugas anggota mencari bahan ajar tersebut • Setiap kelompok mengisi Borang Pemantauan Pendefinisian Masalah secara daring	Daring (*chat online)*			
3	Akhir	• Menyimpulkan kegiatan perkuliahan	Daring (*chat online)*	10 menit		

Minggu ke-2

No	**Tahap**	**Kegiatan Pembelajaran**	**Metode**	**Alokasi waktu**	**Sumber Belajar/ Bahan Ajar/ Media**	**Penilaian**
1	Awal	• Memberikan arahan kegiatan perkuliahan	Daring	15 menit	Google meeting	

2	Inti	• Mahasiswa saling menjelaskan bahan ajar yang berkaitan dengan isu sesuai dengan tugasnya kepada anggota yang lain • Tanya jawab kelompok dan diskusi isu yang belum terselesaikan • Setiap kelompok mengisi Borang Pemantauan Diskusi Kelompok daring	Daring Daring (*Chat online*)	75 menit 50 menit	Google meeting	
3	Akhir	• Menutup kegiatan perkuliahan dan memberikan arahan pertemuan berikutnya	Daring (*chat online)*	10 menit		

Minggu ke-3

No	**Tahap**	**Kegiatan Pembelajaran**	**Metode**	**Alokasi waktu**	**Sumber Belajar/ Bahan Ajar/ Media**	**Penilaian**
1	Awal	• Memberikan arahan kegiatan perkuliahan	Daring (*Chat online*)	15 menit	Google meeting	

2	Inti	• Kelompok menyelesaikan solusi dari masalah • Menambahkan bahan kajian yang terlewatkan oleh semua kelompok	Daring (*Chat online*) Daring	65 menit 60 menit	Google meeting	
3	Akhir	• Menutup kegiatan perkuliahan dan memberikan arahan pertemuan berikutnya	Daring	10 menit		

Minggu ke-4

No	**Tahap**	**Kegiatan Pembelajaran**	**Metode**	**Alokasi waktu**	**Sumber Belajar/ Bahan Ajar/ Media**	**Penilaian**
1	Awal	• Memberikan arahan kegiatan perkuliahan	Daring	15 menit	Google meeting	

2	Inti	• Setiap kelompok mempresentasikan hasil yang didapatkan • Menambahkan dan memberikan saran kepada setiap kelompok	Daring Daring (*Chat online*)	90 menit 30 menit	Google meeting	
3	Akhir	• Menutup kegiatan perkuliahan dan memberikan arahan pertemuan berikutnya	Daring (*chat online)*	15 menit		

Referensi:

Buku [1] : Esposito, A., (2014). Fluid Power with Applications, New York : Prentice Hall

Lampiran

RENCANA PELAKSANAAN PEMBELAJARAN (RPP)

Program Studi : Teknik Mesin
Mata Kuliah : Sistem Hidraulik dan Pneumatik
Kode Mata Kuliah : TM201505
Semester/sks : VII (Pilihan)/ 3 sks
Pertemuan Ke/Waktu : **5-6**/ 2 x 150 menit
Dosen Pengampu : Gad Gunawan, S.T., M.T.
CPMK : Mampu menerapkan prinsip dasar hidraulik dan pneumatik dalam pemanfaatannya di industri **(C3).**

Deskripsi Mata Kuliah : Memberikan dasar-dasar tentang pemanfaatan tenaga hidraulik & pneumatik. Prinsip pemindahan tenaga yang berkaitan dangan karakteristik fluida yang digunakan. Karakteristik komponen, operasi dan fungsinya. Pemahaman sirkuit hidraulik/pneumatik dan kontrol diskrit. Pemilihan komponen peralatan dari sirkuit yang ada. Pemanfaatan sistem hidraulik & pneumatik dalam industri, baik kekurangan maupun kelebihan dibanding sistem lainnya.

Indikator :

1. Mendesain dan menganalisis Sistem Hidraulik

Tujuan Pembelajaran, Setelah menempuh perkuliahan ini :

1. Mahasiswa mampu mendesain dan menganalisis sistem hidraulik

Materi Pokok (Bahan Kajian):

1. Desain dan analisis Sistem Hidraulik

Minggu ke-5

No	Tahap	Kegiatan Pembelajaran	Metode	Alokasi waktu	Sumber Belajar/ Bahan Ajar/ Media	Penilaian
1	Awal	• Memberikan arahan kegiatan perkuliahan	Daring (*Chat online*)	15 menit	Google meeting	
2	Inti	• Mahasiswa membaca bahan ajar yang diberikan/ menonton video kuliah • Mendiskusikan bahan ajar/video yang telah ditonton	Daring (*download* materi) Daring	60 menit 60 menit	Google meeting	
3	Akhir	• Menutup kegiatan perkuliahan dan memberikan arahan pertemuan berikutnya	Daring (*chat online)*	15 menit	Google meeting	

Minggu ke-6

No	Tahap	Kegiatan Pembelajaran	Metode	Alokasi waktu	Sumber Belajar/ Bahan Ajar/ Media	Penilaian
1	Awal	• Memberikan arahan kegiatan perkuliahan	Daring (*Chat online*)	15 menit	Google meeting	
2	Inti	• Mahasiswa membaca bahan ajar yang diberikan/ menonton video kuliah • Mendiskusikan bahan ajar/video yang telah ditonton	Daring (*download* materi) Daring	60 menit 60 menit	Google meeting	
3	Akhir	• Menutup kegiatan perkuliahan dan memberikan arahan pertemuan berikutnya	Daring (*chat online)*	15 menit	Google meeting	

Referensi:

Buku [1] : Esposito, A., (2014). Fluid Power with Applications, New York : Prentice Hall

Lampiran

RENCANA PELAKSANAAN PEMBELAJARAN (RPP)

Program Studi : Teknik Mesin
Mata Kuliah : Sistem Hidraulik dan Pneumatik
Kode Mata Kuliah : TM201505
Semester/sks : VII (Pilihan)/ 3 sks
Pertemuan Ke/Waktu : **7** / 1 x 150 menit
Dosen Pengampu : Gad Gunawan, S.T., M.T.
CPMK : Mampu menerapkan prinsip dasar hidraulik dan pneumatik dalam pemanfaatannya di industri **(C3).**

Deskripsi Mata Kuliah : Memberikan dasar-dasar tentang pemanfaatan tenaga hidraulik & pneumatik. Prinsip pemindahan tenaga yang berkaitan dangan karakteristik fluida yang digunakan. Karakteristik komponen, operasi dan fungsinya. Pemahaman sirkuit hidraulik/pneumatik dan kontrol diskrit. Pemilihan komponen peralatan dari sirkuit yang ada. Pemanfaatan sistem hidraulik & pneumatik dalam industri, baik kekurangan maupun kelebihan dibanding sistem lainnya.

Indikator :

1. Mengetahui perawatan Sistem Hidraulik

Tujuan Pembelajaran, Setelah menempuh perkuliahan ini :

1. Mahasiswa mampu mengetahui perawatan sistem hidraulik

Materi Pokok (Bahan Kajian):

1. Perawatan Sistem Hidraulik

Minggu ke-7

No	Tahap	Kegiatan Pembelajaran	Metode	Alokasi waktu	Sumber Belajar/ Bahan Ajar/ Media	Penilaian
1	Awal	• Memberikan arahan kegiatan perkuliahan	Daring (*Chat online*)	15 menit	Google meeting	
2	Inti	• Mahasiswa membaca bahan ajar yang diberikan/ menonton video kuliah • Mendiskusikan bahan ajar/video yang telah ditonton	Daring (*download* materi) Daring	60 menit 60 menit	Google meeting	
3	Akhir	• Menutup kegiatan perkuliahan dan memberikan arahan pertemuan berikutnya	Daring (*chat online)*	15 menit	Google meeting	

Referensi:

Buku [1] : Esposito, A., (2014). Fluid Power with Applications, New York : Prentice Hall

Tugas :

-

Lampiran:

Video	Link
Simple Hydraulic System Working and simulation	**https://www.youtube.com/watch?v=kzqkPx8F3D8**
Animation How basic hydraulic circuit works	**https://www.youtube.com/watch?v=KgphO-u7MlQ**
How Hydraulic Ram Works	https://www.youtube.com/watch?v=svdsbL4PLL4
Directional Control Valve Basics - Part 1 Directional Control Valve Basics - Part 2	https://www.youtube.com/watch?v=CQPwvWXbV3w https://www.youtube.com/watch?v=o-A_9nFpzek

RENCANA PELAKSANAAN PEMBELAJARAN (RPP)

Program Studi : Teknik Mesin
Mata Kuliah : Sistem Hidraulik dan Pneumatik
Kode Mata Kuliah : TM201505
Semester/sks : VII (Pilihan)/ 3 sks
Pertemuan Ke/Waktu : **9-12** / 4 x 150 menit
Dosen Pengampu : Gad Gunawan, S.T., M.T.
CPMK : Mampu menerapkan prinsip dasar hidraulik dan pneumatik dalam pemanfaatannya di industri **(C3).**

Deskripsi Mata Kuliah : Memberikan dasar-dasar tentang pemanfaatan tenaga hidraulik & pneumatik. Prinsip pemindahan tenaga yang berkaitan dangan karakteristik fluida yang digunakan. Karakteristik komponen, operasi dan fungsinya. Pemahaman sirkuit hidraulik/pneumatik dan kontrol diskrit. Pemilihan komponen peralatan dari sirkuit yang ada. Pemanfaatan sistem hidraulik & pneumatik dalam industri, baik kekurangan maupun kelebihan dibanding sistem lainnya.

Indikator :

1. Mengetahui komponen sistem pneumatik

Tujuan Pembelajaran, Setelah menempuh perkuliahan ini :

1. Mahasiswa mampu mengetahui komponen sistem pneumatik

Materi Pokok (Bahan Kajian):

Komponen-komponen sistem pneumatik:

1. Pengenalan
2. Karakteristik Fluida Pneumatik
3. Kompresor
4. Aktuator
5. Control Valve
6. Conduktor and fitting
7. Fluid Conditioners

Minggu ke-9

No	Tahap	Kegiatan Pembelajaran	Metode	Alokasi waktu	Sumber Belajar/ Bahan Ajar/ Media	Penilaian
1	Awal	• Melakukan perkenalan • Membuat kontrak perkuliahan • Menyampaikan tujuan perkuliahan dan deskripsi singkat bahan kajian	Daring	5 menit 15 menit 10 menit	Google meeting	
2	Inti	• Memberikan pengenalan sistem pneumatik • Menjelaskan metode Pembelajaran Problem Based Learning • Membagi mahasiswa menjadi beberapa kelompok • Memberikan masalah yang perlu dipecahkan	Daring Daring Daring (*chat online)* Daring (*chat online)*	30 menit 30 menit 15 menit 5 menit 40 menit	Google meeting	

		• Kelompok mengidentifikasi isu dan bahan ajar yang sesuai dengan isu serta membagi tugas anggota mencari bahan ajar tersebut • Setiap kelompok mengisi Borang Pemantauan Pendefinisian Masalah secara daring	Daring (*chat online)*			
3	Akhir	• Menyimpulkan kegiatan perkuliahan	Daring (*chat online)*	10 menit		

Minggu ke-10

No	**Tahap**	**Kegiatan Pembelajaran**	**Metode**	**Alokasi waktu**	**Sumber Belajar/ Bahan Ajar/ Media**	**Penilaian**
1	Awal	• Memberikan arahan kegiatan perkuliahan	Daring	15 menit	Google meeting	

2	Inti	• Mahasiswa saling menjelaskan bahan ajar yang berkaitan dengan isu sesuai dengan tugasnya kepada anggota yang lain • Tanya jawab kelompok dan diskusi isu yang belum terselesaikan • Setiap kelompok mengisi Borang Pemantauan Diskusi Kelompok daring	Daring Daring (*Chat online*)	75 menit 50 menit	Google meeting	
3	Akhir	• Menutup kegiatan perkuliahan dan memberikan arahan pertemuan berikutnya	Daring (*chat online)*	10 menit		

Minggu ke-11

No	**Tahap**	**Kegiatan Pembelajaran**	**Metode**	**Alokasi waktu**	**Sumber Belajar/ Bahan Ajar/ Media**	**Penilaian**
1	Awal	• Memberikan arahan kegiatan perkuliahan	Daring (*Chat online*)	15 menit	Google meeting	

2	Inti	• Kelompok menyelesaikan solusi dari masalah • Menambahkan bahan kajian yang terlewatkan oleh semua kelompok	Daring (*Chat online*) Daring	65 menit 60 menit	Google meeting	
3	Akhir	• Menutup kegiatan perkuliahan dan memberikan arahan pertemuan berikutnya	Daring	10 menit		

Minggu ke-12

No	Tahap	Kegiatan Pembelajaran	Metode	Alokasi waktu	Sumber Belajar/ Bahan Ajar/ Media	Penilaian
1	Awal	• Memberikan arahan kegiatan perkuliahan	Daring	15 menit	Google meeting	

2	Inti	• Setiap kelompok mempresentasikan hasil yang didapatkan • Menambahkan dan memberikan saran kepada setiap kelompok	Daring Daring (*Chat online*)	90 menit 30 menit	Google meeting	
3	Akhir	• Menutup kegiatan perkuliahan dan memberikan arahan pertemuan berikutnya	Daring (*chat online)*	15 menit		

Referensi:

Buku [1] : Esposito, A., (2014). Fluid Power with Applications, New York : Prentice Hall

Lampiran

-

RENCANA PELAKSANAAN PEMBELAJARAN (RPP)

Program Studi : Teknik Mesin
Mata Kuliah : Sistem Hidraulik dan Pneumatik
Kode Mata Kuliah : TM201505
Semester/sks : VII (Pilihan)/ 3 sks
Pertemuan Ke/Waktu : **13-14**/ 2 x 150 menit
Dosen Pengampu : Gad Gunawan, S.T., M.T.
CPMK : Mampu menerapkan prinsip dasar hidraulik dan pneumatik dalam pemanfaatannya di industri **(C3).**

Deskripsi Mata Kuliah : Memberikan dasar-dasar tentang pemanfaatan tenaga hidraulik & pneumatik. Prinsip pemindahan tenaga yang berkaitan dangan karakteristik fluida yang digunakan. Karakteristik komponen, operasi dan fungsinya. Pemahaman sirkuit hidraulik/pneumatik dan kontrol diskrit. Pemilihan komponen peralatan dari sirkuit yang ada. Pemanfaatan sistem hidraulik & pneumatik dalam industri, baik kekurangan maupun kelebihan dibanding sistem lainnya.

Indikator :

1. Mendesain dan menganalisis Sistem pneumatik

Tujuan Pembelajaran, Setelah menempuh perkuliahan ini :

1. Mahasiswa mampu mendesain dan menganalisis sistem pneumaatik

Materi Pokok (Bahan Kajian):

1. Desain dan analisis Sistem Pneumatik

Minggu ke-13

No	Tahap	Kegiatan Pembelajaran	Metode	Alokasi waktu	Sumber Belajar/ Bahan Ajar/ Media	Penilaian
1	Awal	• Memberikan arahan kegiatan perkuliahan	Daring (*Chat online*)	15 menit	Google meeting	
2	Inti	• Mahasiswa membaca bahan ajar yang diberikan/ menonton video kuliah • Mendiskusikan bahan ajar/video yang telah ditonton	Daring (*download* materi) Daring	60 menit 60 menit	Google meeting	
3	Akhir	• Menutup kegiatan perkuliahan dan memberikan arahan pertemuan berikutnya	Daring (*chat online)*	15 menit	Google meeting	

Minggu ke-14

No	Tahap	Kegiatan Pembelajaran	Metode	Alokasi waktu	Sumber Belajar/ Bahan Ajar/ Media	Penilaian
1	Awal	• Memberikan arahan kegiatan perkuliahan	Daring (*Chat online*)	15 menit	Google meeting	
2	Inti	• Mahasiswa membaca bahan ajar yang diberikan/ menonton video kuliah • Mendiskusikan bahan ajar/video yang telah ditonton	Daring (*download* materi) Daring	60 menit 60 menit	Google meeting	
3	Akhir	• Menutup kegiatan perkuliahan dan memberikan arahan pertemuan berikutnya	Daring (*chat online)*	15 menit	Google meeting	

Referensi:

Buku [1] : Esposito, A., (2014). Fluid Power with Applications, New York : Prentice Hall

Lampiran

RENCANA PELAKSANAAN PEMBELAJARAN (RPP)

Program Studi : Teknik Mesin
Mata Kuliah : Sistem Hidraulik dan Pneumatik
Kode Mata Kuliah : TM201505
Semester/sks : VII (Pilihan)/ 3 sks
Pertemuan Ke/Waktu : **15** / 1 x 150 menit
Dosen Pengampu : Gad Gunawan, S.T., M.T.
CPMK : Mampu menerapkan prinsip dasar hidraulik dan pneumatik dalam pemanfaatannya di industri **(C3).**

Deskripsi Mata Kuliah : Memberikan dasar-dasar tentang pemanfaatan tenaga hidraulik & pneumatik. Prinsip pemindahan tenaga yang berkaitan dangan karakteristik fluida yang digunakan. Karakteristik komponen, operasi dan fungsinya. Pemahaman sirkuit hidraulik/pneumatik dan kontrol diskrit. Pemilihan komponen peralatan dari sirkuit yang ada. Pemanfaatan sistem hidraulik & pneumatik dalam industri, baik kekurangan maupun kelebihan dibanding sistem lainnya.

Indikator :

1. Mengetahui perawatan Sistem pneumatik

Tujuan Pembelajaran, Setelah menempuh perkuliahan ini :

1. Mahasiswa mampu mengetahui perawatan sistem pneumatik

Materi Pokok (Bahan Kajian):

1. Perawatan Sistem Pneumatik

Minggu ke-15

No	Tahap	Kegiatan Pembelajaran	Metode	Alokasi waktu	Sumber Belajar/ Bahan Ajar/ Media	Penilaian
1	Awal	• Memberikan arahan kegiatan perkuliahan	Daring (*Chat online*)	15 menit	Google meeting	
2	Inti	• Mahasiswa membaca bahan ajar yang diberikan/ /menonton video kuliah • Mendiskusikan bahan ajar/video yang telah ditonton	Daring (*download* materi) Daring	60 menit 60 menit	Google meeting	
3	Akhir	• Menutup kegiatan perkuliahan dan memberikan arahan pertemuan berikutnya	Daring (*chat online)*	15 menit	Google meeting	

Referensi:

Barber, A. (1997). Pneumatic Handbook 8th Edition. Elsevier Science & Technology Books

Lampiran

Video	Link
How a Industrial Pneumatic Systems Works And The Five Most Common Elements Used	https://www.youtube.com/watch?v=lBARBZNLxQI
Pneumatic Cylinder Working explained - with Animation	https://www.youtube.com/watch?v=R-OBtVCPjMc

Lampiran 4. Masalah dan Tugas Besar mata kuliah (*Output* Kegiatan 4)

	***Problem*/Masalah**	**Tugas Besar**
Sistem Hidraulik	1. Anda akan membuka usaha pencucian mobil. Sebuah *supplyer* peralatan hidraulik menawarkan mesin pengangkat mobil kepada anda. Untuk mendapatkan mesin hidraulik yang lebih murah, anda dapat membeli dan merakit sendiri sistem hidraulik. Cobalah mendata kebutuhan komponen yang akan anda gunakan! 2. Anda bekerja pada divisi *heavy equipment maintenance* di sebuah pertambangan batubara. Salah satu tugas anda adalah memonitoring kesehatan *excavator*. Salah satu sistem yang ada pada *excavator* adalah sistem hidraulik. Komponen-komponen apa sajakah yang akan anda prioritaskan pada sistem tersebut ?	1. Desain sebuah sistem hidraulik untuk pengangkat mobil pada pencucian mobil ! 2. Desain sebuah sistem hidraulik untuk parkiran mobil bawah tanah !
Sistem Pneumatik	1. Anda akan membuka usaha bengkel motor dengan 3 *bay*. Untuk mempercepat proses pemasangan baut, anda akan melengkapi *air impact wrench* setiap *bay*-nya. Untuk mendapatkan mesin pneumatik yang lebih murah, anda dapat membeli dan merakit sendiri sistem pneumatik. Cobalah mendata kebutuhan komponen yang akan anda gunakan! 2. Anda bekerja pada divisi *heavy equipment maintenance* di sebuah pertambangan batubara. Salah satu tugas anda adalah memonitoring kesehatan offhighway dumptrack. Salah satu sistem yang ada pada offhighway dumptrack adalah sistem braking yang menggunakan mekanisme pneumatik. Komponen-komponen apa sajakah yang akan anda prioritaskan pada sistem tersebut ?	*1.* Desain sebuah instalasi sistem pneumatik untuk air impact wrench sebuah bengkel dengan 3 *bay service !* 2. Desain sebuah instalasi sistem pneumatik untuk sebuah bengkel yang menggunakan pompa oli dengan mekanisme penggerak pneumatik !

KARTU KONSULTASI COACH

Nama : Gad Gunawan, S.T., M.T.
NDH : 17
Jabatan : Dosen Asisten Ahli
Coach : Muhammad Abdi Rahman, S.Sos., M.Si.

NO	HARI / TANGGAL	URAIAN KONSULTASI	KETERANGAN	PARAF
1	23 Juli 2020	Asistensi isu-isu yang akan diangkat	Via Whatsapp	
2	26 Juli 2020	Asistensi isu yang terpilih, gagasan pemecahan dan kegiatan-kegiatan aktualisasi	Via Whatsapp	
3	28 Juli 2020	Asistensi Rancangan Aktualisasi	Via Whatsapp	
4	28 Juli 2020	Asistensi Rancangan Aktualisasi	Via Zoom	
5	30 Juli 2020	Konfirmasi perbaikan Rancangan Aktualisasi berdasarkan hasil seminar	Via Whatsapp	
6	11 Agustus 2020	Konfirmasi menambahkan tahapan kegiatan	Via Whatsapp	
7	03 September 2020	Penjelasan struktur Laporan Aktualisasi	Via Whatsapp	
8	07 September 2020	Asistensi laporan aktualisasi (penambahan biografi dan saran)	Via Whatsapp	

9	09 September 2020	Asistensi revisi1 laporan aktualisasi (perbaikan sampul, melampirkan dokumen *output*)	Via Whatsapp	
10	10 September 2020	Asistensi revisi2 laporan aktualisasi (melengkapi lampiran)	Via Whatsapp	
11	11 September 2020	Asistensi revisi3 laporan aktualisasi	Via Whatsapp	
12	16 September 2020	Persiapan seminar Laporan Aktualisasi	Via Zoom	