Pneumatic circuit components

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. It is particularly safe in environments where an electrical spark could ignite leaks from system components.

There are several reasons for considering the use of pneumatic systems instead of hydraulic systems:-

1. Liquids exhibit greater inertia than do gases. Therefore, in hydraulic systems the weight of oil is a potential problem when accelerating and decelerating actuators and when suddenly opening and closing valves.
2. Due to Newton's Jaw of motion (force equals mass multiplied by acceleration), the force required to accelerate oil is many times greater than that required to accelerate an equal volume of air.
3. Liquids also exhibit greater viscosity than do gases. This results in larger frictional pressure and power losses.
4. Also, since hydraulic systems use a fluid foreign to the atmosphere, they require special reservoirs and no-leak system designs. Pneumatic systems use air that is exhausted directly back into the surrounding environment.
5. Generally speaking, pneumatic systems arc less expensive than hydraulic systems.

However pneumatic systems has those disadvantages:-

1. Because of the compressibility of air, it is impossible to obtain precise, controlled actuator velocities with pneumatic systems.
2. Also, precise positioning control is not obtainable. In applications where actuator travel is to be smooth and steady against a variable load, the air exhaust from the actuator is normally metered.
3. Whereas pneumatic pressures are quite low due to compressor design limitations (less than 250 psi), hydraulic pressures can be as high as 10,000 psi.
4. Thus, hydraulics can be high-power systems, whereas pneumatics arc confined to low-power applications. Principal applications for pneumatics include circuits where end conditions are of prime importance (piston rod fully extended or fully retracted).
5. Pneumatic systems can be readily applied to drive rotary actuators as well as linear cylinders.

In pneumatic systems, compressors are used to compress and supply the necessary quantities of air. Compressors are typically of the piston, vane, or screw type. Basically a compressor increases the pressure of a gas by reducing its volume as described by the perfect gas laws. Pneumatic systems normally use a large centralized air compressor, which is considered to be an infinite air source similar to an electrical system where you merely plug into an electrical outlet for electricity. In this way, pressurized air can be piped from one source to various locations throughout an entire industrial plant. The compressed air is piped to each circuit through an air filter to remove contaminants, which might harm the closely fitting parts of pneumatic components such as valves and cylinders. The air then flows through a pressure regulator, which reduces the pressure to the desired level for the particular circuit application. Because air is not a good lubricant (contains about 20% oxygen), pneumatic systems require a lubricator to inject a very fine mist of oil into the air discharging from the pressure regulator. This prevents wear of the closely fitting moving parts of pneumatic components.

Free air from the atmosphere contains varying amounts of moisture. This moisture can be harmful in that it can wash away lubricants and thus cause excessive wear and corrosion. Hence, in some applications, air dryers are needed to remove this undesirable moisture. Since pneumatic systems exhaust directly into the atmosphere, they are capable of generating excessive noise. Therefore, mufflers are mounted on exhaust ports of air valves and actuators to reduce noise and prevent operating personnel from possible injury resulting not only from exposure to noise but also from high-speed airborne particles.

The Perfect Gas Laws

Single general gas law, as defined by

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

The general gas law contains all three gas parameters (pressure, temperature, and volume), since none are held constant during a process from state I to state 2.

EXAMPLE

Gas at 70 bars gage pressure and 37.8°C is contained in the 12,900-cm^3 cylinder of Fig. 10.9. A piston compresses the volume to 9,680 cm^3 while the gas is heated to 93.3°C. What is the final pressure in the cylinder?

Solution Solve Eq. (10-6) for P_2 and substitute known values.

$$P_2 = \frac{P_1 V_1 T_2}{V_2 T_1} = \frac{(70 \times 10^5 + 1 \times 10^5)(12{,}900)(93.3 + 273)}{(9680)(37.8 + 273)}$$

$$P_2 = 111.5 \times 10^5 \text{ Pa absolute} = 111.5 \text{ bars absolute}$$

Compressors

A compressor is a machine that compresses air or another type of gas from a low inlet pressure (usually atmospheric) to a higher desired pressure level. This is accomplished by reducing the volume of the gas. Air compressors are generally positive displacement units and are either of the reciprocating piston type or the rotary screw or rotary vane types.

Piston compressor

Next figure illustrates many of the design features of a piston-type compressor. Such a design contains pistons scaled with piston rings operating in precision-bored close-fitting cylinders. Notice that the cylinders have air fins to help dissipate heat. Cooling is necessary with compressors to dissipate the heat generated during compression. When air is compressed, it picks up heat as the molecules of air come closer together and bounce off each other at faster and faster rates. Excessive temperature can damage the metal components as well as increase input power requirements. Portable and small industrial compressors are normally air-cooled, whereas larger units must be water-cooled.

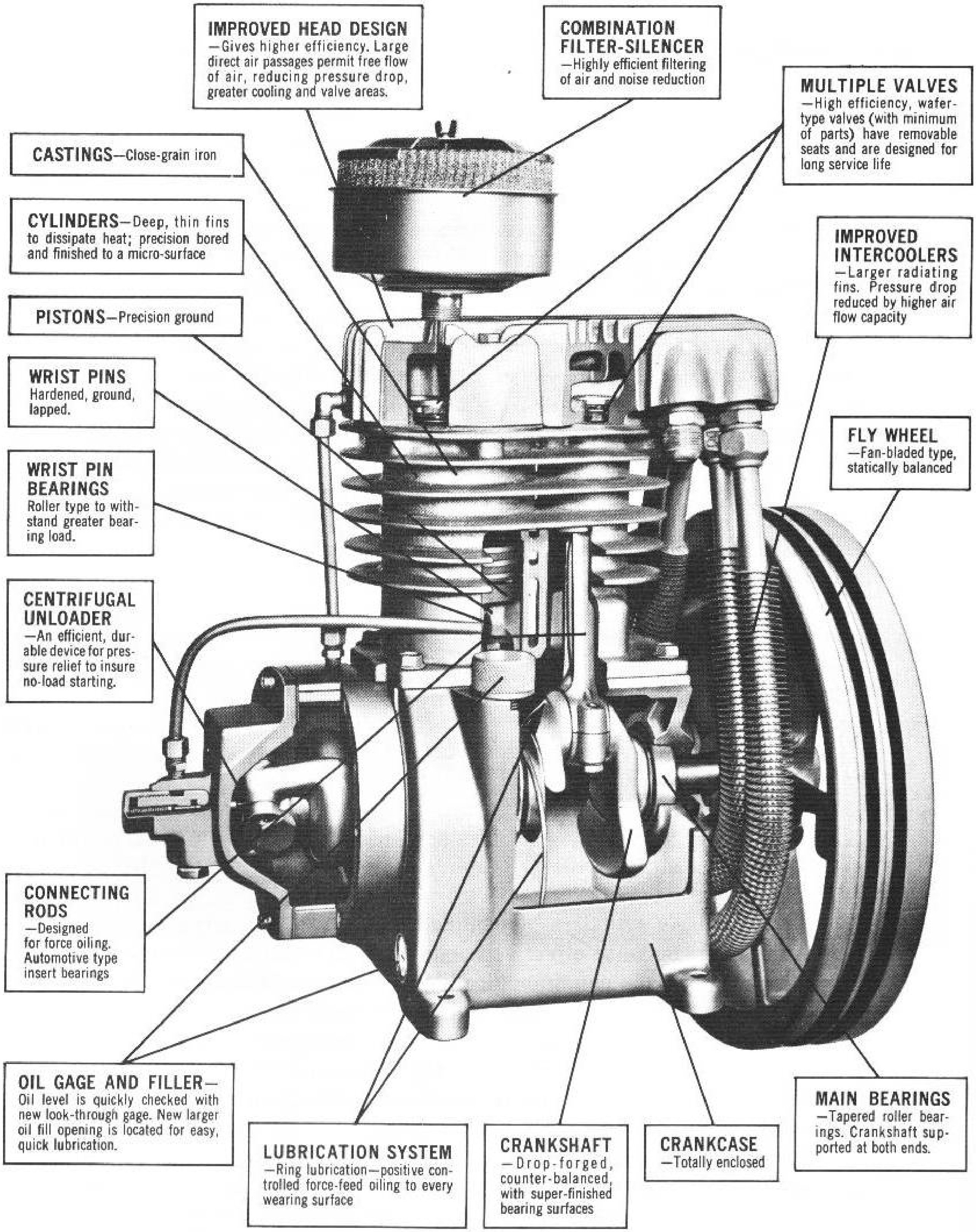
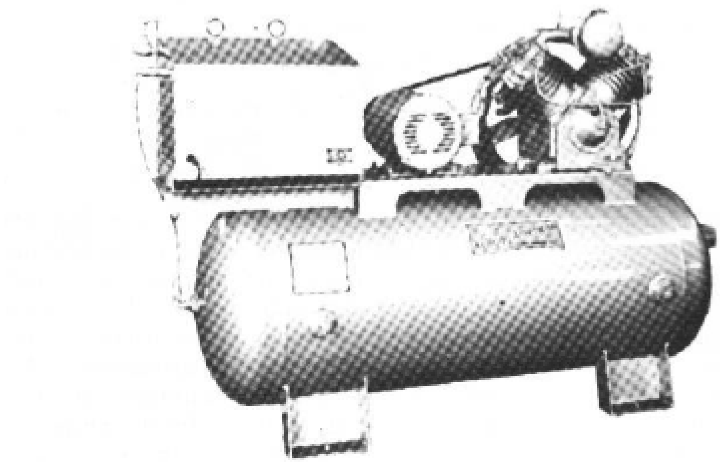


Figure shows a typical small-sized, two-stage compressor unit. Observe that it is a complete system containing not only a compressor but also the compressed air tank (receiver), electric motor and pulley drive, pressure controls, and instrumentation for quick hookup and use. This particular compressor unit also contains an air dryer, which provides a constant supply of high-quality dry air for applications where moisture would be a problem. lt is driven by a 10-hp motor, has a 120·gal receiver, and is designed to operate in the 145-175-psi range with a capacity of 46.3 cfm (cubic ft per min).



NUMBER OF STAGES	PRESSURE CAPACITY (PSI)
1	150
2	500
3	2500
4	5000

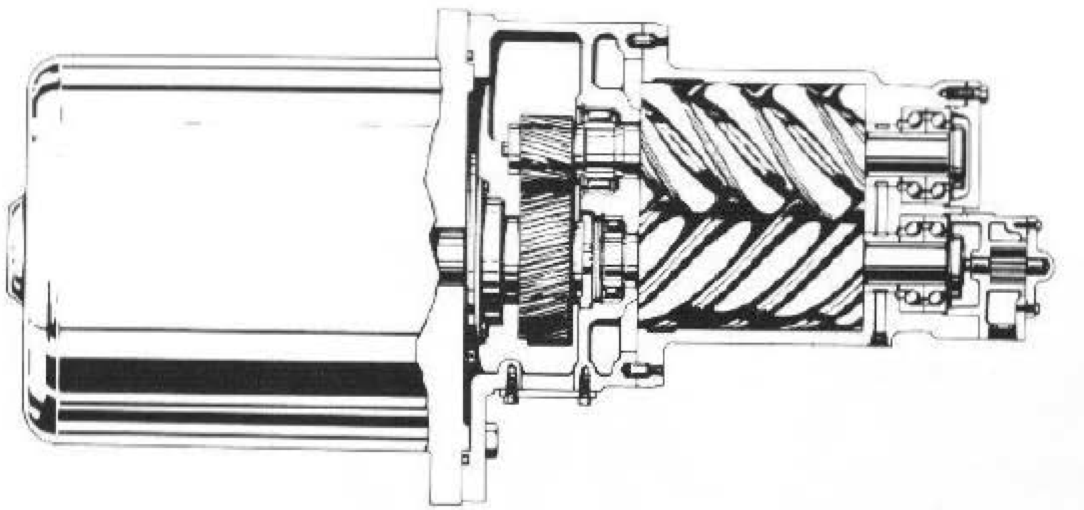
In multistage piston compressors, successive cylinder sizes decrease, and the inter-cooling removes a significant portion of the heat of compression. This increases air density and the volumetric efficiency of the compressor. This is shown in the previous table by the given pressure capacities for the various number of stages of a piston-type compressor.

Compressor starting unloader control

An air compressor must start, run, deliver air to the system as needed, stop, and be ready to start again without the attention of an operator. Since these functions usually take place after a compressed air system has been brought up to pressure, automatic controls are required to work against the air pressure already established by the compressor. If an air compressor is started for the very first time, there is no need for a starting unloader control since there is not yet an established pressure against which the compressor must start. However, once a pressure has been established in the compressed air piping, a starting unloader is needed to prevent the established air pressure from pushing back against the compressor, preventing it from coming up to speed.

Screw compressor

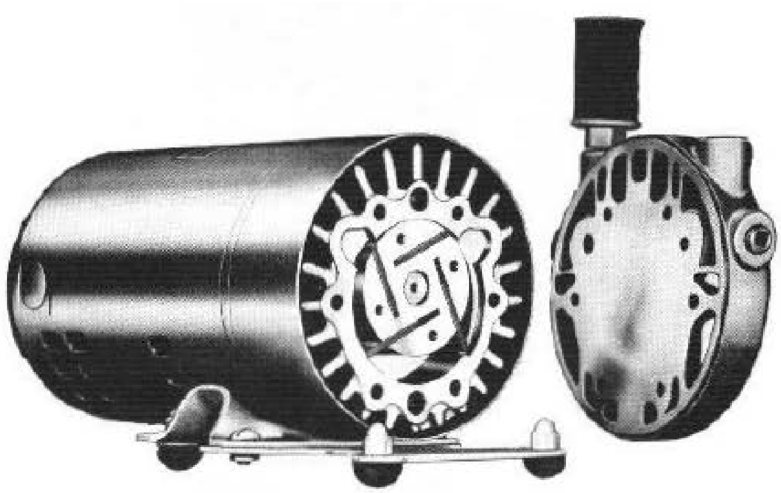
There is a present trend toward increased use of the rotary-type compressor due to technological advances, which have produced stronger materials and better manufacturing processes. Figure shows a cutaway view of a single-stage screw-type compressor, which is very similar to a screw pump that was previously discussed. Compression is accomplished by rolling the trapped air into a progressively smaller volume as the screws rotate. Rotor wear will not occur, since metal-to-metal contact is eliminated. A precisely measured amount of filtered and cooled air is injected into the compression chamber, mixing with the air as it is compressed. The oil lubricates the rotors, seals the rotor clearances for high-compression efficiency, and absorbs heat of compression, resulting in low discharge air temperatures. Single-stage screw compressors are available with capacities up to 1450 cfm and pressures of 120 psi.



Single-stage screw compressor.

Vane compressor

Figure shows a cutaway view of the sliding-vane-type rotary compressor. In this design, a cylindrical slotted rotor turns inside of a stationary outer casing. Each rotor slot contains a rectangular vane, which slides in and out of the slot due to centrifugal force. As the rotor turns, air is trapped and compressed between the vanes and then discharged through a port to the receiver. Rotary sliding vane compressors can operate up to approximately 50 psi in a single stage and up to 150 psi in a two-stage design. This low-pressure, low-volume type of compressor is normally used for instrument and other laboratory-type air needs.



Sliding-vane-type rotary compressor.

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 m^3/min of free air or standard m^3/min where standard atmospheric conditions are 101kPa abs and 20^oC.

The equation that allows for this calculation is derived by solving the general gas law 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) coverts volume to volume flow rate.

$$Q_1 = Q_2 \left(\frac{P_2}{P_1}\right)\left(\frac{T_1}{T_2}\right)$$

Note that: absolute pressure and temperature values must be used.

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 functions are:-

1. To supply air at essentially constant pressure.
2. It also serves to dampen pressure pulses either coming from the compressor or the pneumatic system during valve shifting and component operation.
3. 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.

These equations can be used to determine the proper size of the receiver in English units and metric units, respectively.

$$V_r = \frac{14.7t(Q_r - Q_c)}{P_{max} - P_{min}}$$

$$V_r = \frac{101t(Q_r - Q_c)}{P_{max} - P_{min}}$$

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, = receiver size volume (ft^3, m^3).

EXAMPLE

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. Next equations can be used to determine the theoretical power required to drive an air compressor.

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

$$theoretical\ horsepower\ (hp) = \frac{P_{in}Q}{17.1}\left[\left(\frac{P_{out}}{P_{in}}\right)^{0.286} - 1\right]$$

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

To determine the actual power. the theoretical power from Equation is divided by the overall compressor efficiency η_o·

EXAMPLE

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. (10-8), we have P_{in} = 14.7 psia and P_{out} = 114.7 psia. Substituting directly into Eq. (10-8) 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

$$HP_{act} = \frac{HP_{theor}}{\eta_0} = \frac{18.0}{0.75} = 24.0 \text{ hp}$$