Overview and Maintenance of Compressed Air Systems

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Compressed Air Systems

Topics

Objectives

Upon completion of this course, you will be able to:

1. Identify the classifications of compressed air systems.
2. Identify the air quality requirements.
3. Describe the components of air compressors and auxiliary equipment.
4. Describe the different types of distribution systems.
5. Describe the maintenance requirements associated with air compressor systems.

1.0.0 SYSTEM CLASSIFICATIONS

Compressed air is a form of power that has many important uses in industrial activities. An air compressor plant (*Figure 7-1*) is required to supply air of adequate volume, quality, and pressure at the various points of application. Compressed air is stated as pounds per square inch gauge (psig). These plants or systems are classified as low-pressure (0 to 125 psig), medium-pressure (126 to 399 psig), or high-pressure (400 to 6,000 psig) systems.

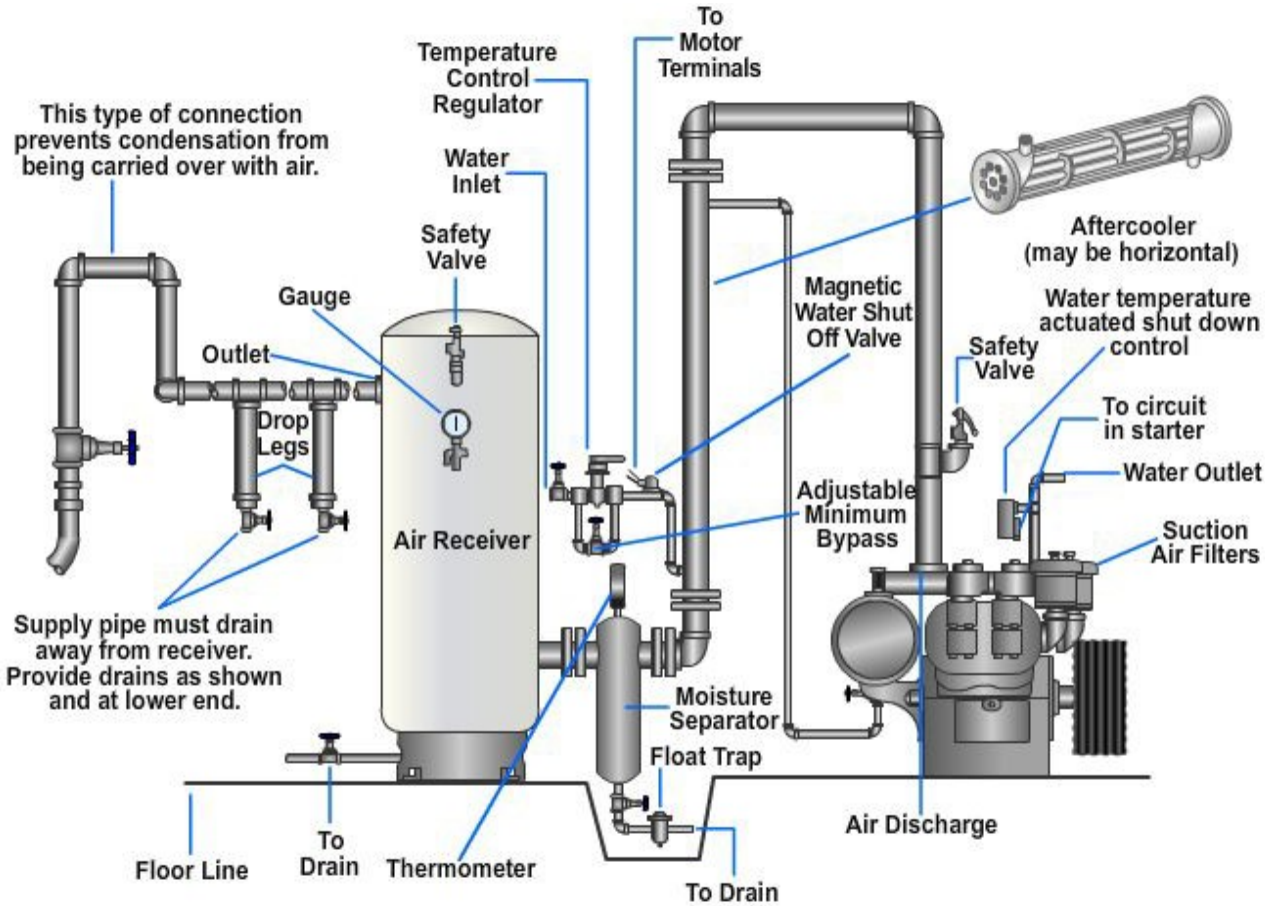

Figure 7-1 — Air compressor plant.

1.1.0 Low-Pressure Systems

Low-pressure systems provide compressed air up to 125 psig pressure. When you are installing a low-pressure system, pressure is usually reduced at reducing stations for branches requiring lower pressures. Several air pressure requirements for low-pressure air consumers are listed below:

- Laboratories - 5 to 50 psig
- Shops - 60 to 125 psig
- Laundries and dry cleaning plants - 70 to 100 psig
- Hospitals - 20 to 50 psig

- Ordinary service (tools, painting, and so forth) - 60 to 80 psig
- Soot blowing for boilers - 80 to 125 psig

1.2.0 Medium Pressure Systems

Medium-pressure systems provide compressed air within the range of 126 to 399 psig pressure. These systems are not extensive and are generally provided with individual compressors located near the loads. Medium-pressure systems are mainly used for the starting of diesel engines, soot blowing of boilers and high-temperature water (HTW) generators, and hydraulic lifts.

1.3.0 High-Pressure Systems

These systems provide compressed air within the range of 400 to 6,000 psig pressure. Hazards that increase with higher pressures and capacities can be minimized by the use of separate compressors for each required pressure. Systems operating at 3,000 psig may require small amounts of air at lower pressures, which is supplied through pressure-reducing stations. Caution must be used with high-pressure systems because when high-pressure air enters suddenly into pockets or dead ends, the air temperature in the confined space increases dramatically. If there is any combustible material in the space and the air temperature increases to the ignition point of the material, an explosion may occur. This is known as auto ignition or diesel action. Explosions of this type may set up shock waves that travel through the compressed air system. This travel may cause explosions at remote points. Even a small amount of oil residue or a small cotton thread may be sufficient enough to cause ignition. Some common pressure requirements for high-pressure systems may be as follows:

- Torpedo workshop - 600 to 3,000 psig
- Ammunition depot - 100, 750, 1,500, 2,000, and 4,500 psig
- Wind tunnels - Over 3,000 psig
- Testing laboratories - Up to 6,000 psig

2.0.0 AIR QUALITY REQUIREMENTS

The quality of air supplied from a compressed air system will vary with application. The installer and maintenance personnel should consider the class of air entrapment and specific air quality requirements for each application.

2.1.0 Classes of Air Entrapment

The classes of air entrapment may be subdivided into inert and chemical particulate, chemical gases, oil, and water. To prevent contamination of an air compression system by these types of entrapments, you should follow certain guidelines for each situation of possible contamination.

2.1.1 Particulate

Intake structures or openings should be free of shelves, pockets, or other surfaces that attract and accumulate particulate. Properly designed intakes are large enough to produce a low-velocity airflow. This limits the size of the particles that may be picked up by the intake suction.

Some particulate may contain active chemicals that may form acids or alkalines in the inevitable presence of water. These chemical particulate can accelerate damage to compressor surfaces. Particulate are sized in microns or micrometers. This measurement is size, not weight. One micron is a unit of length equal to one millionth of a meter. Particles larger than 10 microns are visual to the naked eye. Filter systems are required for all air compressors. Generally, filters should be able to remove particles down to 1 to 3 microns in size.

2.1.2 Gases or Fumes

Gases or fumes are airborne and generally independent of air velocity. They can be strong acid, alkaline, or otherwise corrosive to the internal surfaces or lubricants of the compressor. In addition, gases or fumes may be prohibited by the end-use process, such as medical gases or breathing air and for environmental or odor reasons. Intakes near normal flow paths of engine exhausts should be avoided.

2.1.3 Oil

Oil fumes, vapor, or mist can be as difficult to handle as particulate or gases. Even though many types of compressors are oil lubricated, the oil ingested may not be compatible, and compressor load may be increased.

2.1.4 Water

Waste and water vapor are always present in air intakes. Installation of intakes should prevent the accumulation of free water. Free water ingested into the compressor causes damage to internal components.

Since water vapor with chemical content corrodes steel piping, precautions must be taken to protect materials from corrosion. Galvanizing, applying protective coatings, or using plastic or stainless-steel piping for air intakes are some suggested methods to retard or prevent corrosion. Also, be sure to install intakes in a manner that excludes rainfall, snow, or spray by applying a weather hood.

2.2.0 Specific Air Quality Requirements

The diverse uses of air are accompanied by specific air quality requirements. These vary from high purity requirements through the need to introduce materials into a system to be carried along with the air. This section will discuss these specific air quality requirements.

2.2.1 Commercial Air

Commercial compressed air is graded according to its purity. The purest is grade A, running alphabetically to grade J, the least pure. The Compressed Gas Association has set guidelines for the grading of commercial compressed gas. The application of commercial compressed air is varied and generally specified for each individual installation by engineers. The full extent of the quality requirements for commercial compressed air applications can be located in the Compressed Air Association publication *Commodity Specification for Air,* G-7.1 (ANSI 286.1-1973).

2.2.2 Breathing Air

Breathing air must be of high quality for obvious reasons. Federal Specification BB-A- 1034, shown in *Table 7-1,* outlines the specific requirements for breathing air.

Table 7-1 — Breathing air requirements.

	Source I (Pressurized Container Air)		Source II (Compressed Air)	
Component	Grade A	Grade B	Grade A	Grade B
Oxygen Percent *	20 to 22	19 to 23	20 to 22	19 to 23
Carbon dioxide	500	1,000	500	1,000
Carbon monoxide	10	10	10	10
Oil (mist and vapor) Particulate matter (weight/ volume)	0.005	0.005	0.005	0.005
Separated water	None	None	None	None
Total water (weight/volume)	0.02 mg/l	0.02 mg/l	0.02 mg/l	0.02 mg/l

Special attention must be given to eliminating carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons, odor, and water from breathing air. Carbon monoxide has first priority as its effects are cumulative and very small concentrations can cause problems. Whenever possible, carbon monoxide monitoring should be provided at the compressor intake. This monitoring equipment should sound an alarm or shut down the system when CO is detected.

Carbon dioxide is found in combustion flue gases, such as boiler stacks. Do not place compressor intakes near or downwind of the stacks.

Systems should be kept free of oil to limit the possible concentration of hydrocarbons or petroleum products. For breathing air, compressors should be oil free rather than using auxiliary petroleum removal equipment. The heat caused by compression may cause thermal breakdown of oil, or an explosion danger may exist as a result of drawing hydrocarbons into the air system. Water content is kept below saturation to prevent condensation at points that cannot be cleaned. It is recommended that refrigerant or desiccant dryers be used to remove moisture from a breathing air system. This will limit the vapor clouding (fogging) of glasses and visors.

2.2.3 Medical Air

Medical air quality must be the same or better than breathing air. Whatever quality is established must be strictly adhered to.

2.2.4 Instrument and Control Air

Air quality requirements for instrument and control air should place emphasis on cleanliness and low moisture content. The Instrument Society of America (ISA) has established the following requirements:

- Dew point, exterior: 18°F (–7.8°C) below minimum recorded ambient temperature
- Dew point, interior: 18°F (–7.8°C) below minimum interior temperature but not higher than 35°F (1.7°C)
- Particle size: 3 microns maximum
- Oil content: As close to zero as possible but not over 1 ppm
- Contaminates: No corrosives or hazardous gases

- Water content must be low enough to prevent condensate accumulations. Special attention should be given to ensure that intake air is filtered and oil or water removed. A refrigerant dryer with a dew point at least as low as 30°F (–1.1°C) is recommended for these services.

2.2.5 Air for Pneumatic Tools

When compressed air is intended for use with pneumatic tools, it should be filtered for particulate, and water should be separated out. Oil is usually required to be ingested into the air for tool lubrication. Mist injection is preferred for tools to ensure dispersion and maximum settlement. Note that pressures in excess of 400 psig may cause compression combustion when oil is present.

2.2.6 High-Pressure Air Systems

Air quality must be carefully analyzed to minimize not only the normal hazards of high pressure, but also the internal explosive hazards that exist with high-pressure systems. Of particular danger is the introduction of oil and hydrocarbons during compression and their remaining and accumulating throughout the system. A high-pressure system of 500 psig or higher is subject to rapid local heat buildup whenever there is a rapid filling of a component or vessel. The heat buildup (combined with oil and foreign material) that permits the oil to wick or vaporize can readily cause an explosion or fire. Any explosion in the system may produce several shock waves to travel the system, compounding the damage. Because of this problem, special attention is required to clean the intake air, limit the introduction of lubrication oil, and remove oil after completion of the compression process.

Test your Knowledge (Select the Correct Response)

1. Low-pressure systems provide compressed air at a maximum of how many pounds per square inch gauge (psig)?

   A. 25
   B. 75
   C. 100
   D. 125

3.0.0 AIR COMPRESSORS and AUXILIARY EQUIPMENT

There are basically two types of compressors: positive displacement and dynamic. This section will discuss the reciprocating air compressors, the rotary air compressors, the helical screw compressors classed as positive displacement compressors, and the dynamic centrifugal compressors. General auxiliary equipment will also be discussed. Auxiliary equipment consists of any device(s) that may be added to the system to improve its efficiency or provide a specific function. It provides a safe condition under which the compressor system will be operating.

3.1.0 Reciprocating Air Compressors

The most commonly used stationary air compressors are the reciprocating, positive displacement design. They may be single acting or double acting, single stage or multistage, and horizontal, angle, or vertical in design. In a single-stage unit there is but one compressing element; it compresses air from the initial intake pressure to the final discharge pressure in one step. A multistage machine has more than one compressing element. The first stage compresses air to an intermediate pressure, and then one or more additional stages compress it to the final discharge pressure.

In the reciprocating compressor, the compression cycle is composed of three phases: intake, compression, and discharge.

During the intake stroke, the downward movement of the piston creates a partial vacuum inside the cylinder. The spring-operated intake valve is forced open by the differential pressure between free air on one side and the partial vacuum inside the cylinder. As the valve opens, air fills the cylinder. The piston now moves into the compression stroke, forcing the intake valve closed and raising the pressure of the air trapped in the cylinder. When the pressure of this air is great enough to overcome the force of the spring-operated discharge valve, the valve opens and the compressed air is discharged from the cylinder.

Compressors are classified as low pressure, medium pressure, or high pressure. Low-pressure compressors provide a discharge pressure of 150 psi or less. Medium-pressure compressors provide a discharge pressure of 151 psi to 1,000 psi.
Compressors that provide a discharge pressure above 1,000 psi are classified as high pressure. Note that compressors are classified at pressures different from those for classifying total compressed air systems discussed earlier.

Most low-pressure air compressors are of the two-stage type with either a vertical or a vertical W arrangement of cylinders. Two-stage, V-type, low-pressure compressors usually have one cylinder that provides the first (low-pressure) stage of compression and one cylinder that provides the second (high-pressure) stage, as shown in *Figure 7-2.* W-type compressors have two cylinders for the first stage of compression and one cylinder for the second stage. This arrangement is illustrated in *Figure 7-3*.

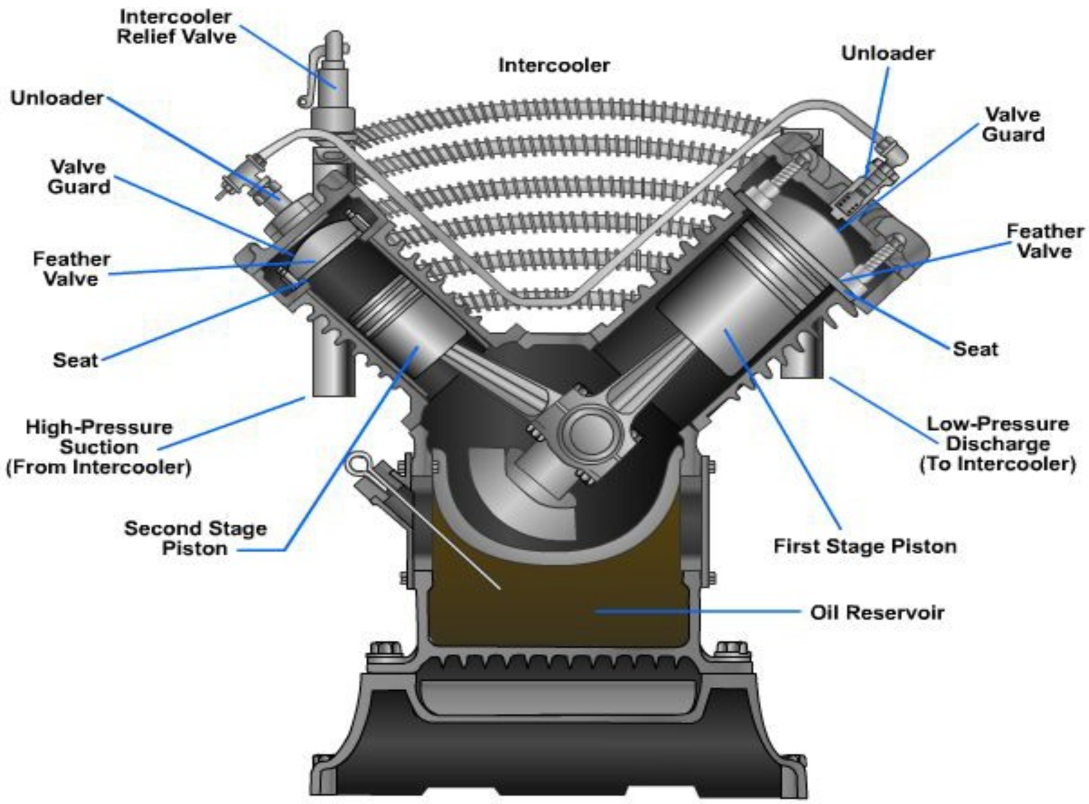

Figure 7-2 — Two-stage, two-cylinder compressor.

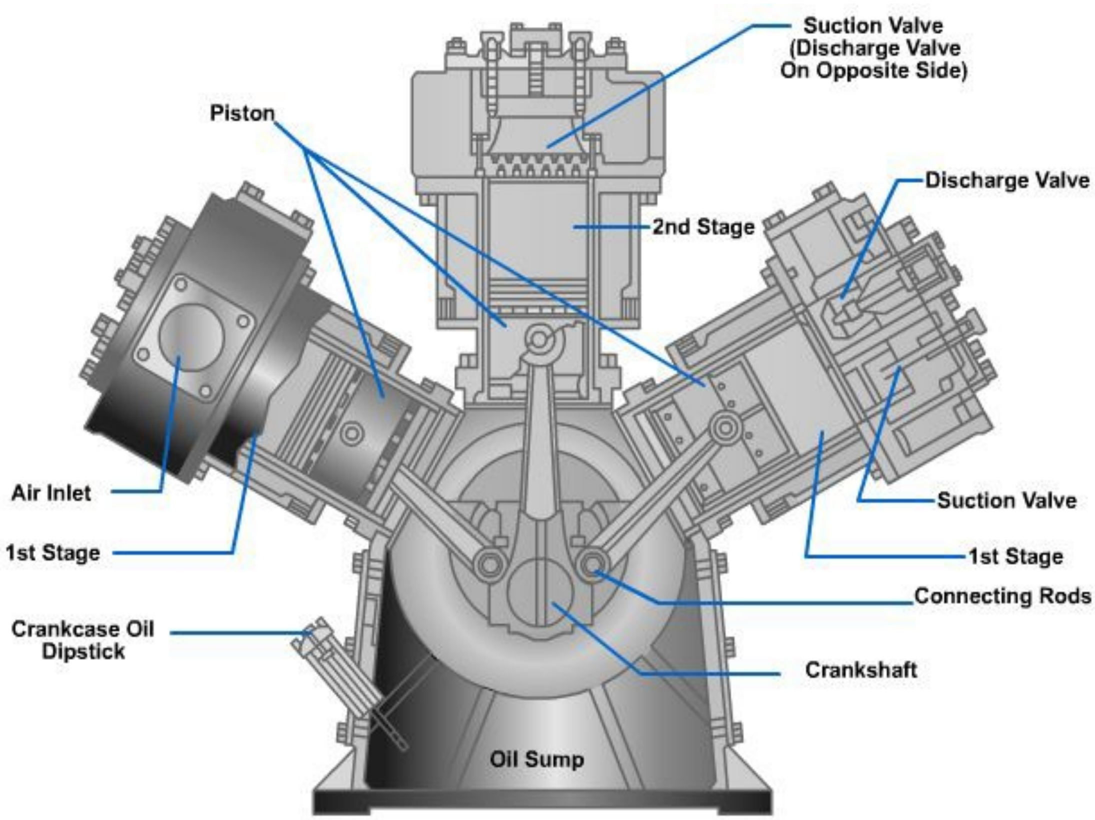

Figure 7-3 — Two-stage, three-cylinder compressor.

Compressors may be classified according to a number of other design features or operating characteristics.

Medium-pressure air compressors are of the two-stage, vertical, duplex, single-acting type. Many medium-pressure compressors have differential pistons, as shown in *Figure 7-4.* This type of piston provides more than one stage of compression on each piston.

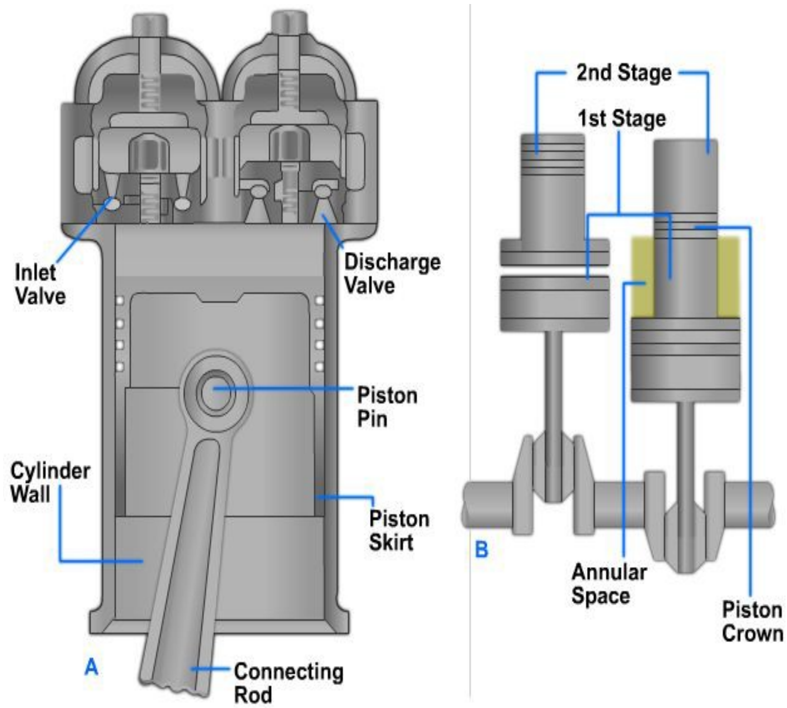

Figure 7-4 — Differential piston with a two-stage vertical arrangement.

3.2.0 Rotary Air Compressors

Rotary sliding vane compressors are a machine in which longitudinal vanes slide radially in a slotted rotor that is mounted eccentrically in a cylinder. The rotor is fitted with blades or vanes that are free to slide in and out of longitudinal slots and maintain contact with the cylinder walls by centrifugal force. In operation, as the blades are forced outward by centrifugal force, compartments are formed in which air is compressed (*Figure 7-5*). Each compartment varies from a maximum volume on the suction side of the revolution to a minimum volume on the compression half of the revolution. This gives a positive displacement type suction and pressure effect.

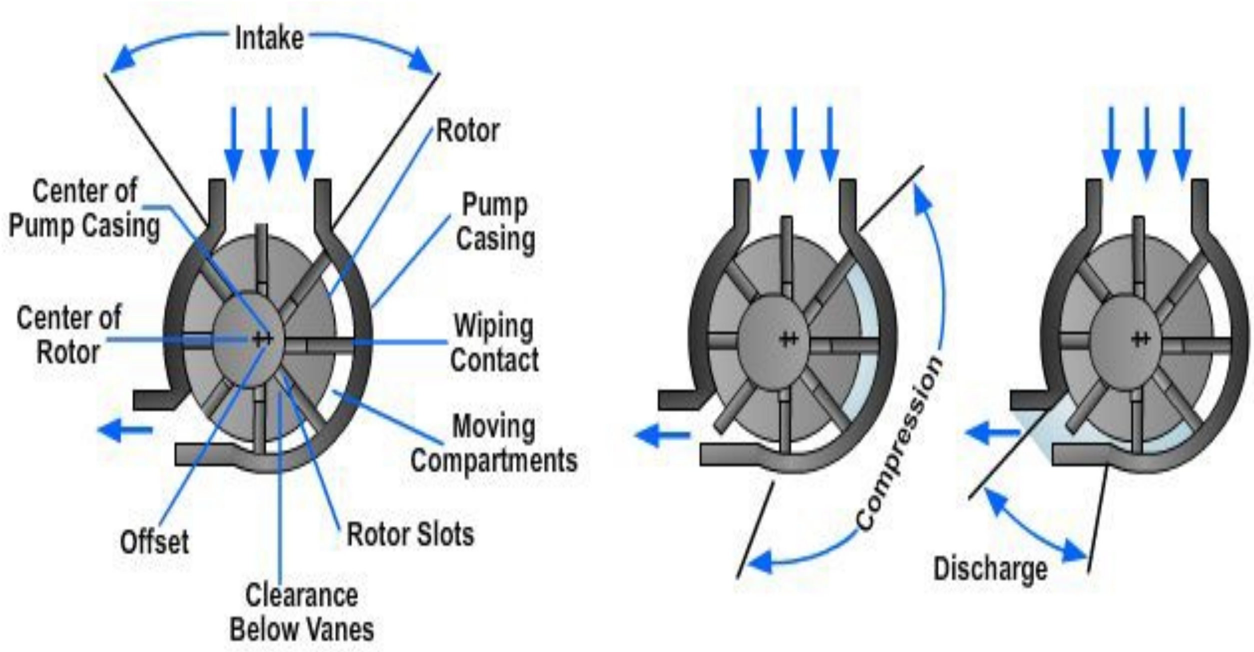

Figure 7-5 — Compression cycle of rotary compressor.

Another type of rotary compressor is the twin lobe unit, sometimes referred to as a blower (*Figure 7-6*). This unit consists of two impellers mounted on parallel shafts that rotate in opposite directions within a housing. As the impellers rotate, they trap a quantity of air themselves in the blower housing and move the air around the casing to the discharge port. This action takes place twice each revolution of an impeller and four times per revolution of both impellers. The impellers are positioned in relation to each other by timing gears, located at the end of each shaft and external to the blower housing.

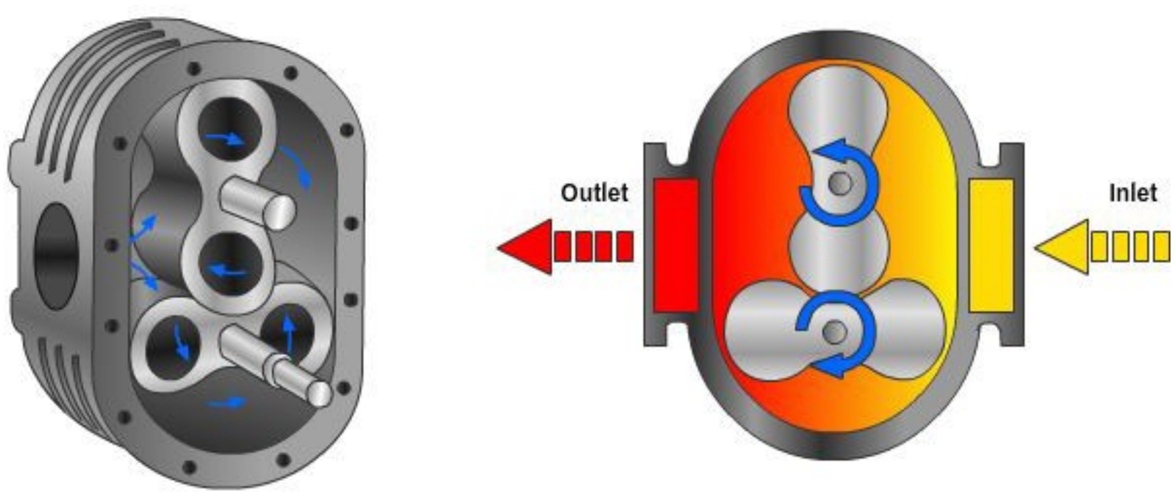

Figure 7-6 — Twin-lobe rotary compressor.

You should always use maintenance and service literature provided by manufacturers when you are working with rotary compressors.

3.3.0 Helical Screw Compressors

Helical screw compressors contain two mating rotating screws, one locked and one grooved, which provide the driving force. The unit's screws take in air, decreasing its volume as it progresses in a forward-moving cavity toward the discharge end of the compressor. *Figure 7-7* shows a typical single-stage helical screw compressor. These compressors are best used in booster or near constant-load conditions at low-pressure, oil-free application.

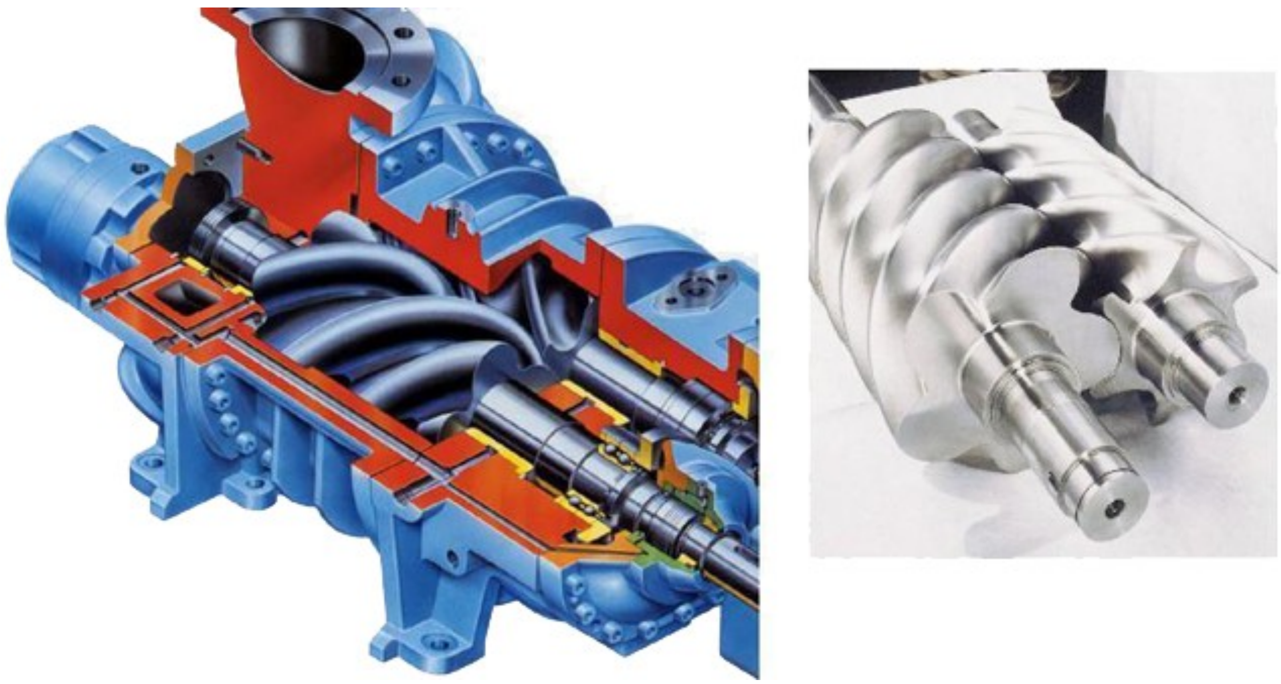

Figure 7-7 — Rotary helical screw compressor.

3.4.0 Dynamic Centrifugal Compressors

Dynamic compressors are high-speed rotating machines in which air is compressed by the action of rotating impellers or blades that impart velocity and pressure to the air through centrifugal force. *Figure 7-8* shows the internal parts of a multistage centrifugal compressor. This type will deliver air at an essentially constant pressure over a wide range of capacities. The direction of airflow is radial with respect to the axis of rotation.

Centrifugal compressors have a lower limit of stable operation called the surge point. Operation below this point results in pumping or surging of the airflow. Prime movers are normally electric motors or combustion engines.

Centrifugal compressors are intended for near continuous industrial air service when the load is reasonably constant. These compressors also work well when oil-free air is required and can be used for breathing air.

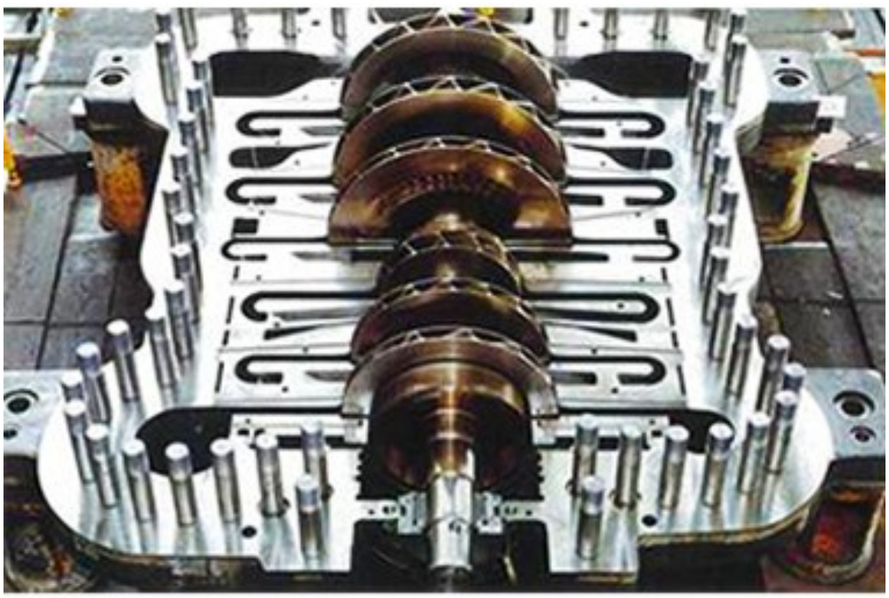

Figure 7-8 — Internal view of a multistage centrifugal compressor.

Table 7-2 shows typical application recommendations for both positive displacement and dynamic class compressors.

Table 7-2 — Summary application recommendations, types of compressors.

Type	Air Deliver Quality	Pressure Range scfm Range Horsepower Range	Remarks
Reciprocating, single stage, air cooled	L	100-125 psig, to 50 scfm, up to10 hp	Intermittent light duty
Reciprocating, two stage, air cooled	L	100-125 psig, to 200 scfm, up to 50 hp	Low volume requirements
Reciprocating, two stage air cooled	N	100-125 psig, to 50 scfm, up to 15 hp	Low volume requirements
Reciprocating, two stage water cooled	L	100-150 psig, 400-1,000 scfm, 75-200 hp	Wide application range
Reciprocating, two stage water cooled	N	100-125 psig, 400-1,000 scfm, 75-200 hp	Wide application where required
Reciprocating, two stage, water cooled, duplex and/or double acting	L	100-150 psig, 1,000-5,000 scfm, 200-1,200 hp	High volume requirements
Reciprocating, multi stage, water cooled	L, N	150-6,000 psig, 10-100 scfm, 3-1,000 hp	Medium and high pressure
Rotary, sliding vane, single-stage	L, N	5-50 psig, 50-3,000 scfm, 0.5-300 hp	Match to load only pressure booster
Rotary, sliding vane, two stage	L, N	60-100 psig, 100-3,000 scfm, 15-500 hp	Match to load only pressure booster
Rotary, sliding vane, single, or two stage oil injected	L	80-125 psig, 120-600 scfm, 15-200 hp	Wide application range
Helical screw, single stage, lubricated	L	To 35 psig, 30-12,000 scfm, up to 1,200 hp	Match to load only, single rating point
Helical screw, two stage, lubricated	L	60-100 psig, 30-12,000 scfm, up to 2,000 hp	Match load only, single rating point, aircraft air start, aircraft cooling
Helical screw, single stage, oil injected	L	To 125 psig, 40-1,500 scfm, 10-400 hp	Wide application range
Dynamic, centrifugal, single stage	N	To 35 psig, 1,500-15,000 scfm, 100-1,000 hp	Match load
Dynamic, centrifugal, two stage	N	35-70 psig, 1,500-15,000 scfm 100-2,000 hp	Match load, breathing air
Dynamic, centrifugal, three stage	N	70-125 psig, 1,500-15,000 scfm, 200-3,500 hp	High volume requirements, breathing air
Dynamic, centrifugal, four or more stage	N	125 psig or more, 1,500-15,000 scfm, up to 3,000 hp	Medium pressure high volume
Dynamic, axial or radial barrel, multistage	N	200 psig or more, 1,500 scfm or more, high horsepower	Medium and high pressure, high volume
* L=Lubricated N=Non-lubricated (1 psig = 6.90 kPa gauge, 1 scfm = 0.0268 mm^3/min, 1 hp = 0.746 kW)			

3.5.0 Auxiliary Equipment

A system that functions to provide a continuous supply of usable compressed air requires certain auxiliary devices in addition to the air compressor. Most compressed air systems require a minimum of auxiliary equipment that should include air intakes, intake filters, silencers, intercoolers, after coolers, air discharge systems, separators, dryers, receivers, and so forth. These types of auxiliary equipment will be discussed in this section in addition to less common auxiliary equipment.

3.5.1 Air Intakes

Air intakes should be located high enough to eliminate intake of particles of dust, smoke, dirt, water, and snow. Carbon monoxide sources should not be able to discharge into compressor intakes. Special attention should be given to the elimination of flammable fumes into the compressed air system.

Whenever air intakes must be placed through a roof that is surrounded by parapets, they should be 8 to 10 feet above the roof.

Noise may be generated by air intakes and must be considered during installation. Reciprocating compressors are most likely to develop resonance through intake piping. If this possibility exists, the use of intake dampeners or surge chambers will help. High velocities present noise level problems. Intake pipe velocities should be limited to 1,000 fpm in open areas or 350 fpm across filters. Acoustical silencers combined with filters and/or pulse dampeners are available and should be used whenever potential noise level difficulties are anticipated.

Intake resistance to airflow should be no more than necessary to maintain air quality. The resistance created by the air intake system will reduce compressor performance and efficiency. Refer to the compressor manufacturer’s manual for maximum resistance requirements.

3.5.2 Intake Filters

Air filters are provided on compressor intakes to prevent atmospheric dust from entering the cylinders and causing scoring and excessive wear. The two most common types of elements in use are the viscous impingement and the oil bath. Both types are illustrated in *Figure 7-9*.

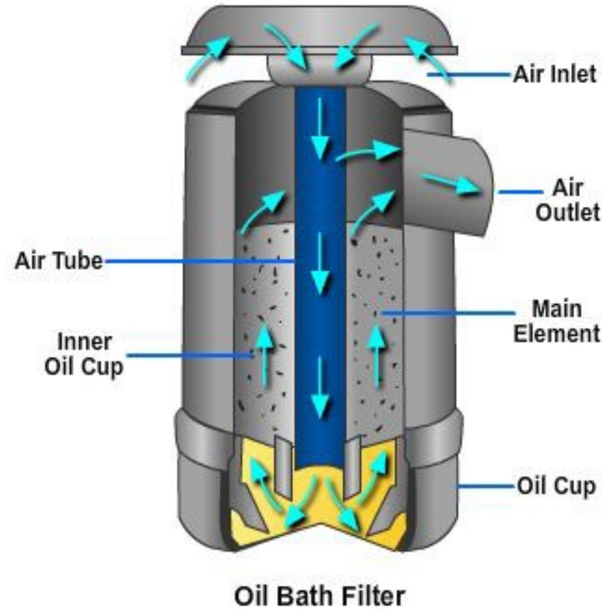

Figure 7-9 — Compressor intake filters.

In the oil bath type, air must pass through an oil seal that removes dirt particles, and then pass on through a wire mesh element, which is saturated by oil carry-over. Any remaining particles of dirt are removed by the wire mesh element. Captured dust particles settle to a sump at the bottom of the filter housing. Oil bath filters are recommended where dust concentrations are present in the atmosphere.

The viscous impingement filter consists of a wire mesh filter element, which is coated with oil. Air passing through the filter element must change directions many times, causing any dust to adhere to the oil film.

3.5.3 Silencers

Silencers are similar to mufflers and function simply to eliminate objectionable compressor suction noise. *Figure 7-10* illustrates a standard intake silencer. Some compressors are equipped with combination filter-silencer units that have the filter elements contained within the silencer housing.

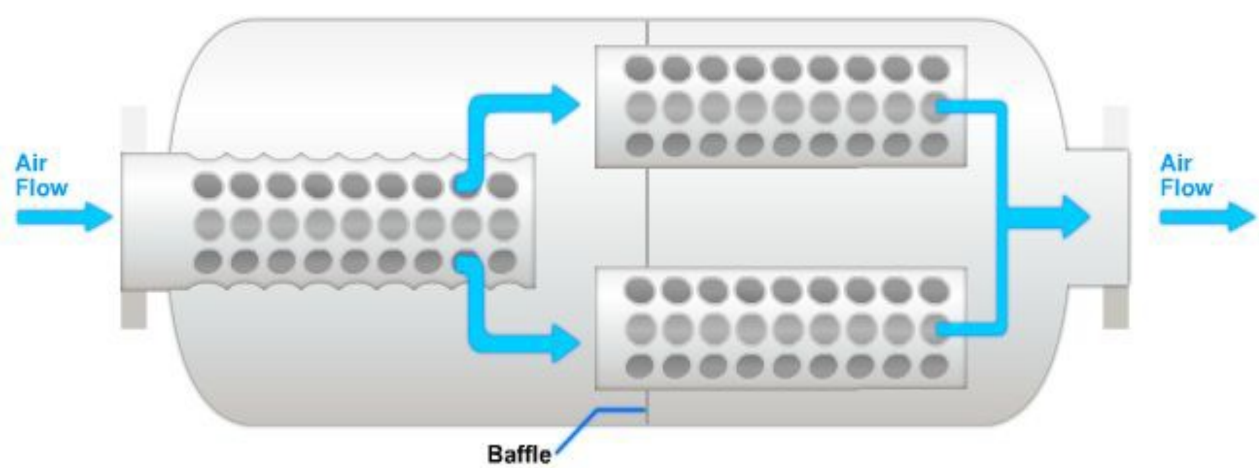

Figure 7-10 — Intake silencer.

3.5.4 Intercoolers

When air is compressed to 100 psi without heat loss, the final temperature is about 485°F. The increase in temperature raises the pressure of the air under compression, thus necessitating an increase in work to compress the air. After the air is discharged into the receiver tank and lines, the temperature falls rapidly to near that of the surrounding atmosphere, thereby losing part of the energy generated during compression. The ideal compressor would compress the air at a constant temperature, but this is not possible. In multistage compressors, the work of compressing is divided between two or more stages, depending on the final discharge pressure required. An intercooler is used between the stages to reduce the temperature of compression from each stage. Theoretically, the intercooler should be of sufficient capacity to reduce the temperature between stages to that of the low-pressure cylinder intake. Actually, intercooling has three purposes: to increase compressor efficiency, to prevent excessive temperatures within the compressor cylinders, and to condense moisture from the air.

Most intercoolers are either the shell and tube, air-to-water heat exchangers or the air-cooled, radiator-type heat exchangers. *Figure 7-11* illustrates a typical water-cooled intercooler.

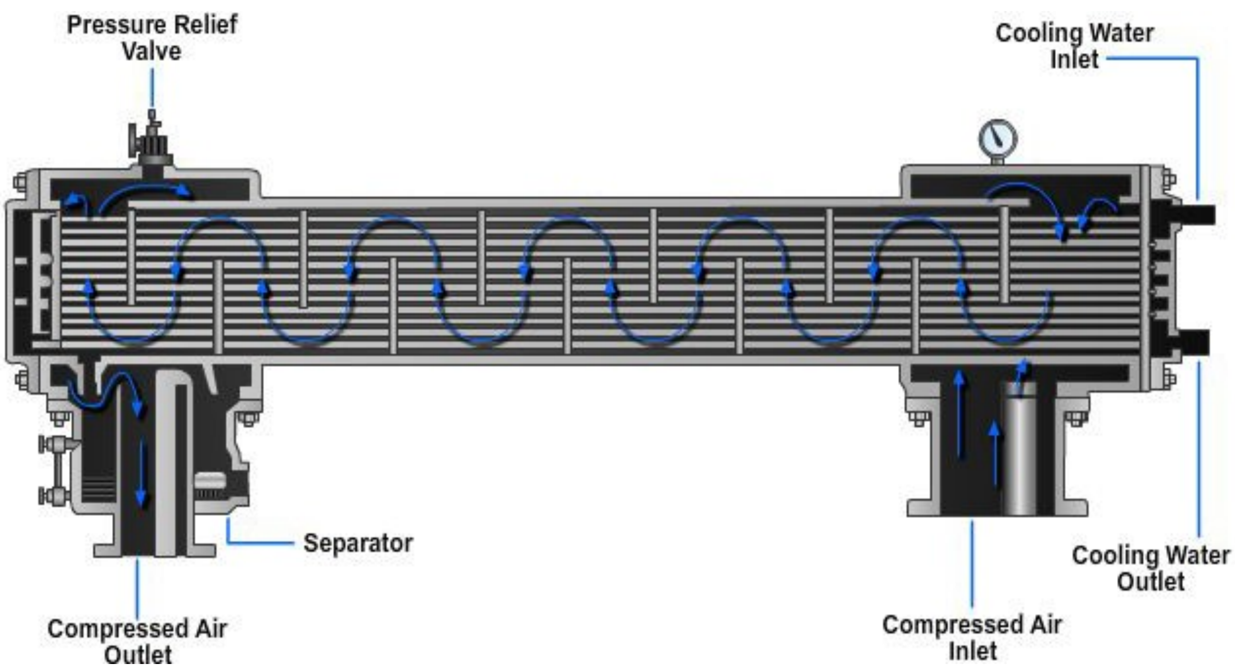

Figure 7-11 — Typical water-cooled intercooler.

3.5.5 Aftercoolers

Moisture carried in air transmission lines is undesirable because it causes damage to air-operated tools and devices. Aftercoolers are installed in compressor discharge lines to lower the air discharge temperature, thus condensing the moisture and allowing it to be removed. In addition, the cooling effect allows the use of smaller discharge piping. A water-cooled aftercooler is illustrated in *Figure 7-12*.

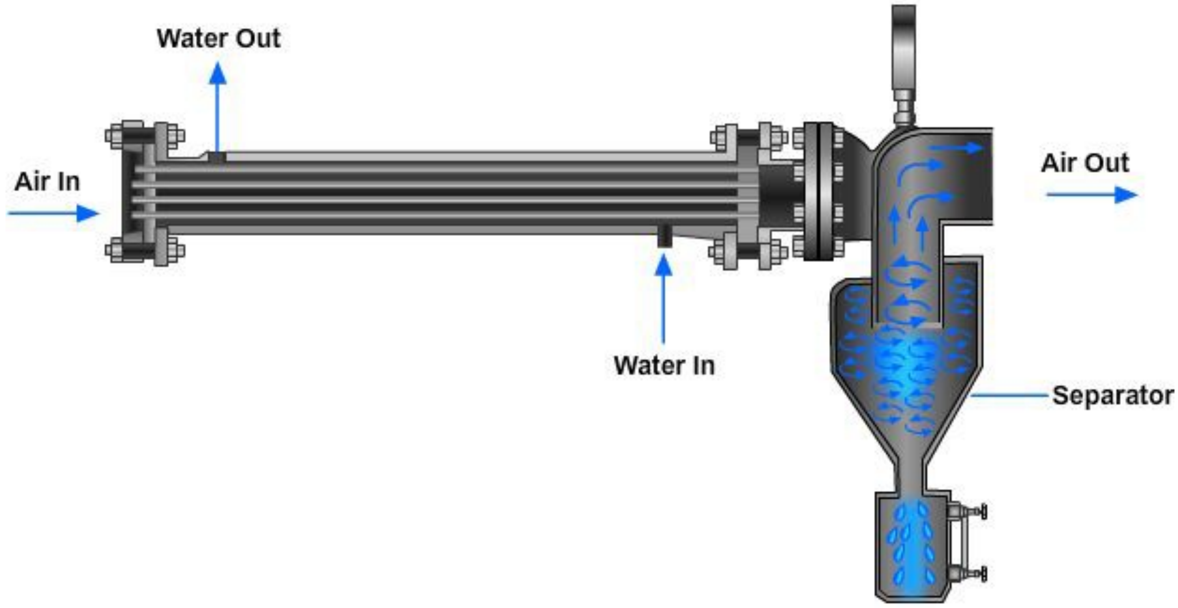

Figure 7-12 — Typical water-cooled aftercooler.

3.5.6 Air Discharge Systems

Some discharge systems require special consideration for the placement of auxiliary equipment. All positive displacement compressors require a relief valve on their discharge side to protect the equipment and piping upstream of the first shutoff valve. Relief valves should be sized for at least 125 percent of the maximum unit flow capacity and should carry the American Society of Mechanical Engineers (ASME) stamp, listing the capacity and pressure setting of the valve.

3.5.7 Separators

Water and oil separators are required to separate and free excess water from the discharge air or gas. This is necessary to prevent corrosion, deposit buildup, and water or oil buildup in the piping or service. For example, water will cause rust in piping, wash away lubricants, and plug nozzles. Oil will contaminate many industrial processes and may present an explosion hazard. The need for water or oil separators will be determined by the end use of the compressed air. A centrifugal separator is illustrated in *Figure 7-13*. Air is directed into this unit in a manner that creates a swirling motion. Centrifugal force throws the

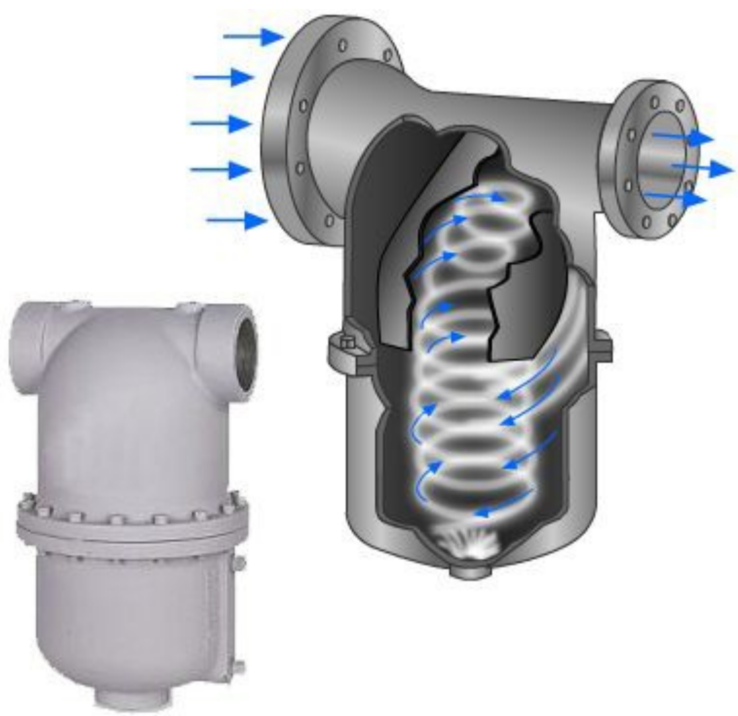

Figure 7-13 — Centrifugal-type moisture separator.

moisture particles against the wall, where they drain to the bottom.

A baffle-type separator is illustrated in *Figure 7-14*. In this unit, the air is subjected to a series of sudden changes in direction that result in the heavier moisture particles striking the baffles and walls, then draining to the bottom.

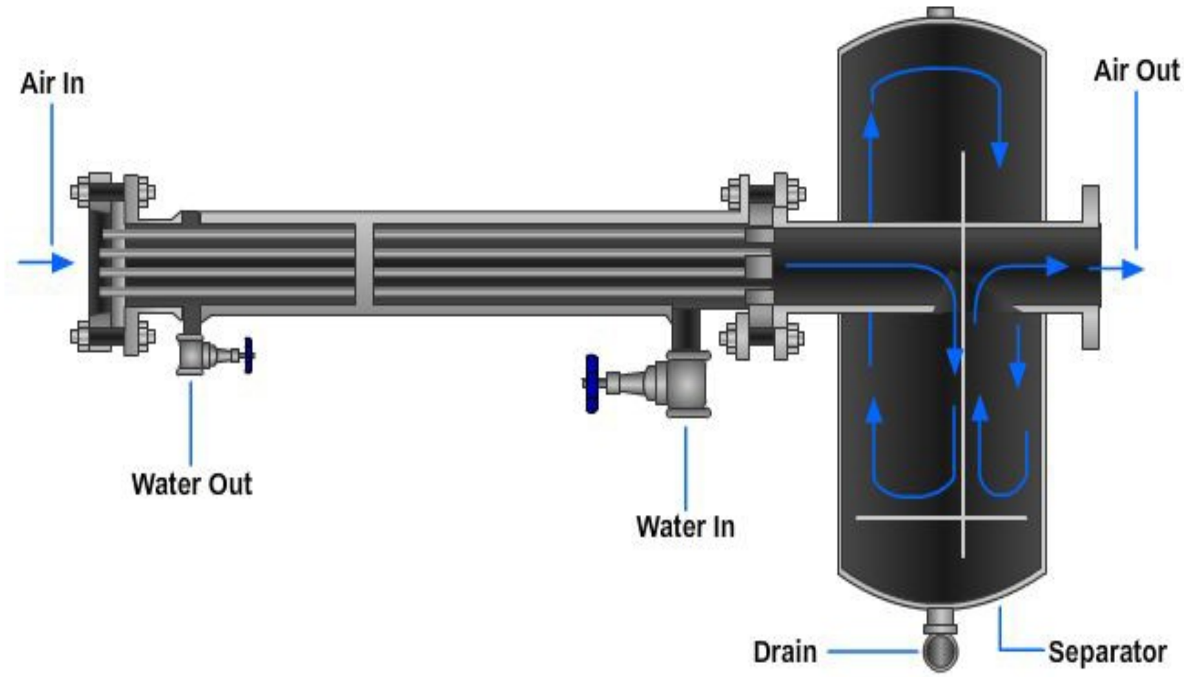

Figure 7-14 — Baffle-type moisture separator.

3.5.8 Dryers

Some compressed air supplies require dryers that ensure removal of all moisture that might otherwise condense in air lines, air-powered tools, or pneumatic instruments. Small amounts of moisture can cause damage to equipment from corrosion, freezing, and water hammer and can result in malfunctions of instruments and controls. The cost of dryers is often justified by the reduction in maintenance costs, production time lost in blowing down piping, and compressed air lost during blow down.

There are three basic designs of dryers: two absorption types and a condensation type. One type of absorption unit consists of two towers, each containing an absorbent material. Reactivation is accomplished by means of electric or steam heaters embedded in the absorbent material or by passing dried process air through it.

Another type of absorption unit consists of a single tank or tower containing a desiccant (drying agent) that dissolves as it absorbs moisture from the air and drains from the unit with the condensate. The drying agent must be replenished periodically.

The third type removes moisture from the air by condensation through the use of a mechanical refrigeration unit, or where available, cold water. Inlet air passes over cold coils, where moisture is condensed from the air and is drained from the unit by a trap. This process is illustrated in *Figure 7-15*.

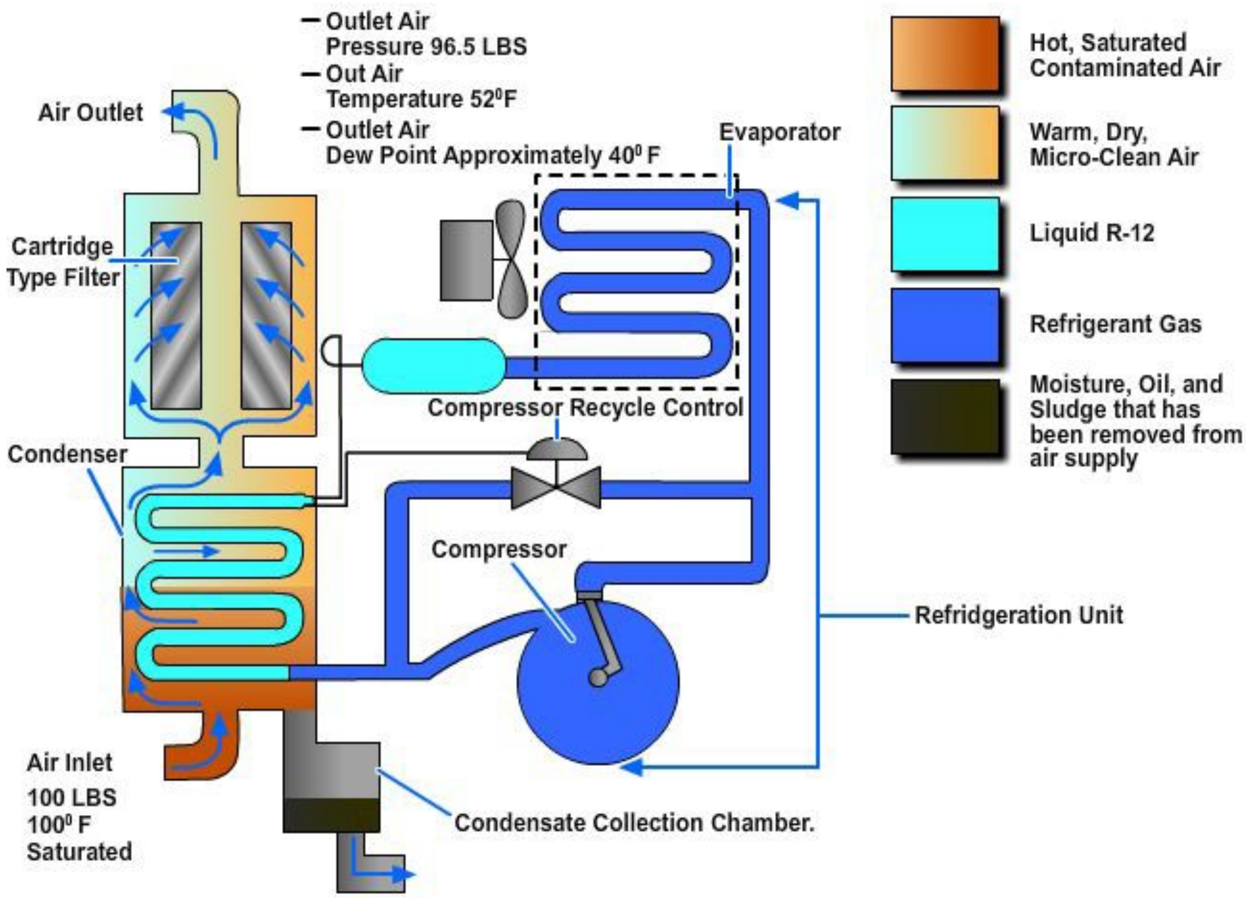

Figure 7-15 — Flow process of refrigeration-type air dryer.

3.5.9 Receivers

Air receiver tanks in compressed air plants act as surge tanks to smooth the flow of air from the action of the compressor to discharge. They collect excessive moisture that may condense from the cooled air and provide a volume of air necessary to operate the pressure control system. A typical air receiver is shown in *Figure 7-16*. Related components include a relief valve, pressure gauge, drain valve, service valve, and inspection opening.

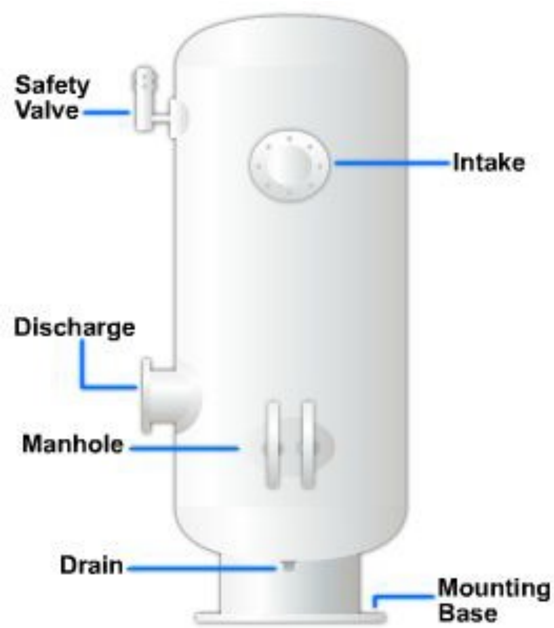

Figure 7-16 — Air receiver.

3.5.10 Lubrication

Compressors must receive adequate lubrication using clean oil of characteristics recommended by the compressor manufacturer. The manufacturer will usually specify oil requirements by characteristics, such as viscosity at one or more temperatures, pour point, flash point, and in some cases, by specific brands. Typical compressor cylinder oils will have the following characteristics:

- Flash point, 350°F minimum
- Viscosity at 210°F, 45 minimum to 90 maximum
- Pour point, +35°F maximum
- Neutralization number, 0.10 maximum
- Conradson carbon residue, 2.0% maximum

Where cylinder lubrication is separate from frame and bearing lubricants, a modified set of characteristics may be specified. Synthetic oils must conform to the manufacturer's requirements and must be used with care because many synthetic oils may cause swelling and softening of neoprene and certain rubbers, or may not be compatible or separable from water.

Some special considerations for lubricants include the provision of a lubrication oil heater to ensure adequate viscosity during cold weather start-up. High compressor discharge temperatures require lubrication flows and characteristics that still lubricate when subjected to 300°F or higher discharge air temperature conditions. Finally, oil injection or oil-flooded compressors need adequate oil flow and characteristics to maintain lubrication of temperatures within the cylinders or screws.

A typical lubrication arrangement is shown in *Figure 7-17*.

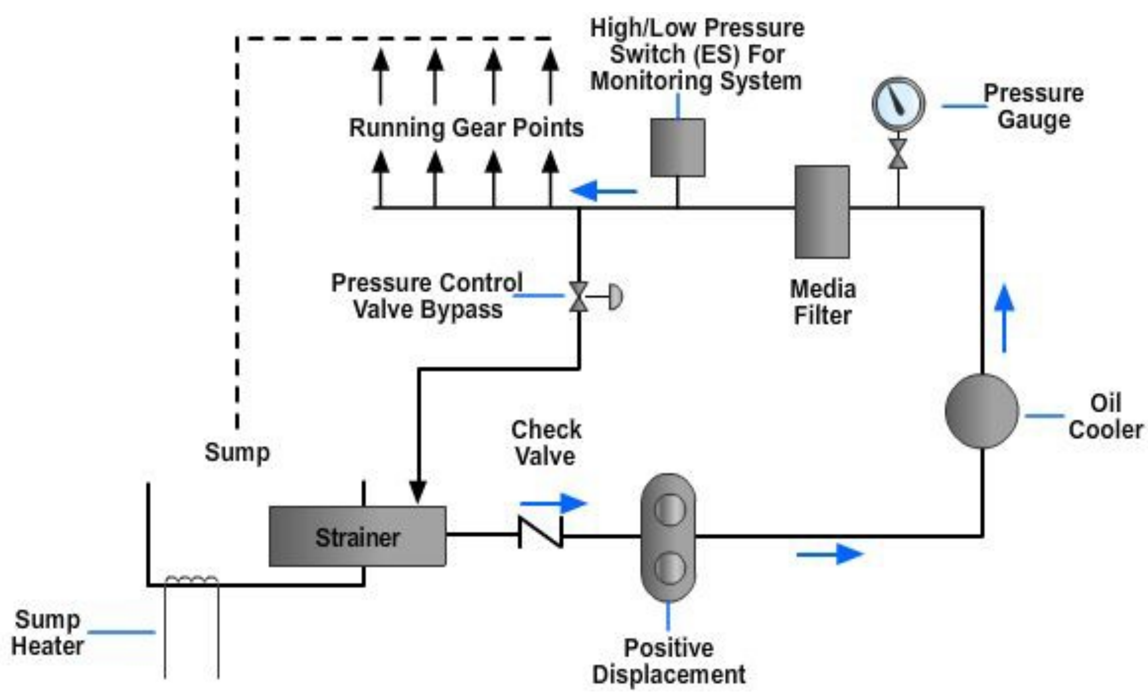

Figure 7-17 — Typical pressure lubrication system.

3.5.11 Discharge Pulsation

Reciprocating compressor discharge lines are subject to pulsations caused by the compressor-forcing frequency. The pulsations set up a resonant frequency in the discharge piping, and the resulting vibration amplification will cause noise, support damage, and piping damage. There is no single solution to this problem, but some specific guidelines will be discussed below.

Pulsation dampeners serve as pulsation and noise mufflers by providing acoustical chambers with the dampener. Manufacturers generally provide dampeners to a specified discharge pulsation peak of ± 2 percent of line pressure. *Figure 7-18* shows several typical pulsation dampeners. These units should be used whenever reciprocating and centrifugal compressors serve the same compressed air main because the pulsations of the reciprocating compressor can transmit to and disturb the operation of the centrifugal compressor. Pulsation dampeners may not completely solve downstream resonance, but they will reduce the vibration amplitudes.

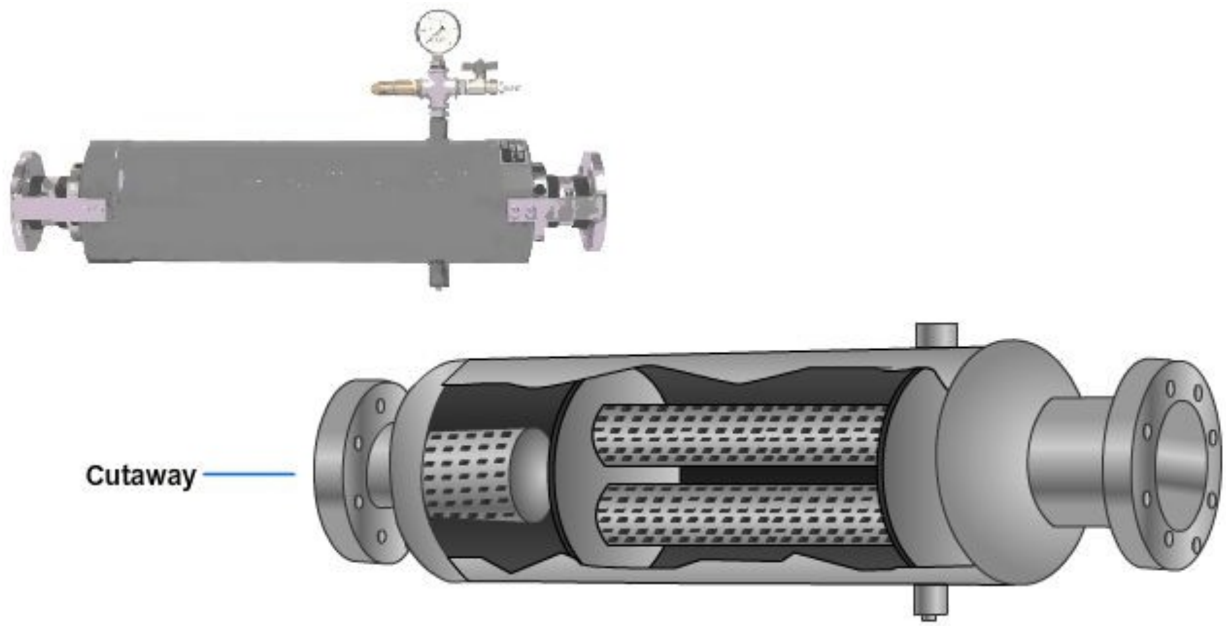

Figure 7-18 — Pulsation dampener.

Several other ways to decrease noise and amplification caused by discharge pulsation are available. Surge chambers can be used to change the equivalent length of the piping and increase the pulse-absorbing volume of the pipe. A surge chamber can be as simple as an increased diameter of discharge piping near the compressor discharge. An orifice plate or plates may be installed in conjunction with surge chambers to change the acoustical resonant frequency of the piping system. Piping support is also important at the compressor. The piping must not only be supported from top or bottom but also have lateral support. When piping is large, spring-loaded two-way lateral supports to absorb vibration are needed.

3.5.12 Controls

Compressor control systems generally include one or more controlling devices, such as safety controls, speed controls, and capacity controls. Such devices function in the system to regulate the output of the compressor as it meets the demand for compressed air.

On some small compressors, the simple Bourdon tube-type pressure switch serves as a controller by actuating the prime mover on and off over a predetermined pressure range. Compressors that are more complex require control systems that load and unload the compressor as air demands change. The constant speed type of controller is used with many compressors. It decreases or increases compressor capacity in one or more steps by the use of unloading devices, while allowing the prime mover speed to remain constant. Another type, referred to as the dual control, is a combination of the constant speed and an automatic start-stop control. It permits constant speeds when demands are continuous and an automatic stop or start when demands are light. There is still another system that enables the prime mover to idle and compressor suction valves to remain open when air pressure reaches a set maximum. As the pressure drops below a set minimum, the prime mover speed is increased, suction valves are closed, and air is compressed.

Generally, control systems include unloading devices that function to remove all but the friction loads on compressors; thus, starting is unaffected by compression loads.
Various types of unloading devices are discussed below.

The inlet-valve-type unloader holds the inlet valve open mechanically during both the suction and compression strokes, thereby preventing compression. *Figure 7-19* illustrates a common inlet valve unloader. The unloader is positioned above the inlet valve. When air pressure rises to the preset unloading pressure, a pressure switch operates a solenoid unloader valve, which opens and allows receiver pressure to the inlet valve unloader. The pressure from the receiver, acting on the diaphragm of the inlet valve unloader, forces the yoke fingers against the inlet valve, holding it open. The intake air is pushed back out the inlet valve on the compression stroke so no compression takes place.

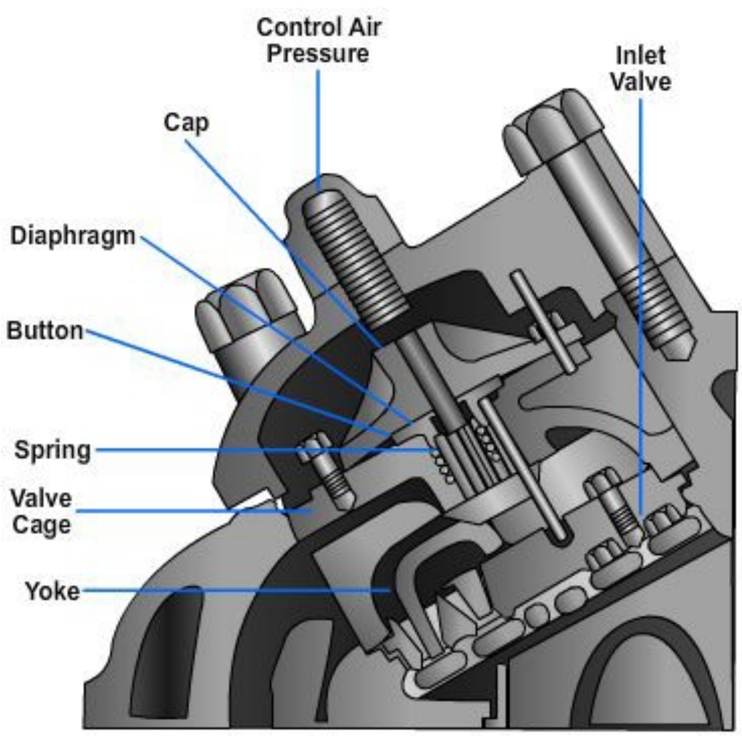

Figure 7-19 — Inlet valve unloader.

Figure 7-20 illustrates the thin plate, low-lift type of compressor valve. Most compressors use this type of valve.

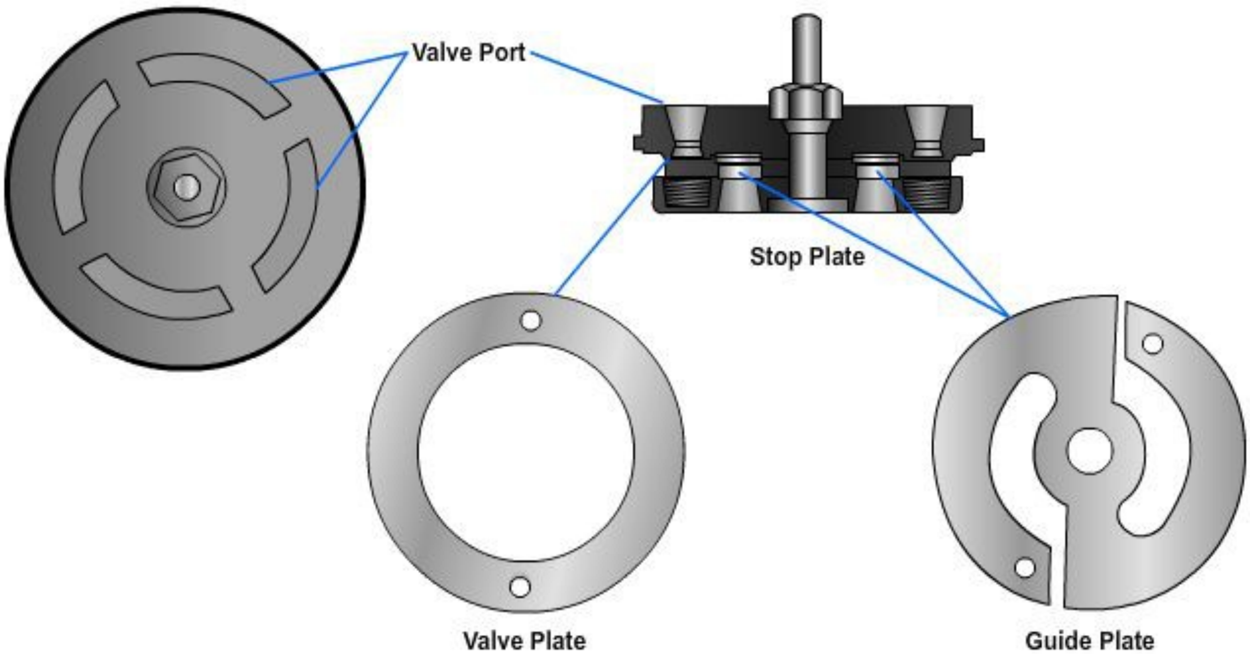

Figure 7-20 — Thin plate, low lift, compressor valve assembly.

The use of a pressure switch with a solenoid unloader valve on each cylinder provides a step or sequenced capacity control. *Figure 7-21* illustrates a flow diagram of a five-step capacity control system applied to a two-stage, four-cylinder, double-acting, reciprocating compressor. Assuming that the compressor in the figure is required to maintain a pressure of 92 to 100 psi, the pressure switches should be set to load and unload as follows: switch 1, load at 93 psi and unload at 97 psi; switch 2, load at 94 psi and unload at 98 psi; switch 3, load at 95 psi and unload at 99 psi; and switch 4, load at 96 psi and unload at 100 psi. As the receiver pressure reaches the high limit of each pressure switch, 25 percent of the compressor capacity will unload. As receiver pressure falls to the low setting of each switch, 25 percent of the compressor capacity will load. Pressure switch 1 will therefore unload 25 percent of the compressor capacity at 97 psi and will load 25 percent at 93 psi, and so forth. As receiver pressure fluctuates between 93 and 100 psi, the compressor capacity varies in five steps: full, 75 percent, 50 percent, 25 percent, and zero capacity.

The compressor illustrated in *Figure 7-21* operates on the following principle: When it is started, air pressure switches are closed and the solenoids in the unloader valves become energized so that receiver pressure cannot enter the unloading lines, and compression is permitted. As the receiver pressure builds up and reaches 97 psi, pressure switch 1 breaks contact, de-energizing unloader 1, and allowing 97 psi receiver air to enter control line 1, actuating the inlet valve unloader. Twenty-five percent of the compressor has become unloaded and compression has reduced from full to 75-percent capacity. Control lines 2, 3, and 4 will operate in the same way as receiver pressure increases. At 100 psi, all cylinders will be unloaded. Air compression ceases, but the compressor continues to run under no load. As air is drawn off from the receiver, the pressure begins to drop. When the pressure falls to 96 psi, pressure switch 4 makes contact and energizes unloading valve 4, which cuts off receiver pressure from the inlet unloader and vents the unloader pressure to the atmosphere. The inlet valve unloader releases the inlet valve and normal compression takes place, loading the compressor to 25-percent capacity. If the demand for air increases and receiver pressure continues to decrease, control lines 3, 2, and 1 will load in sequence.

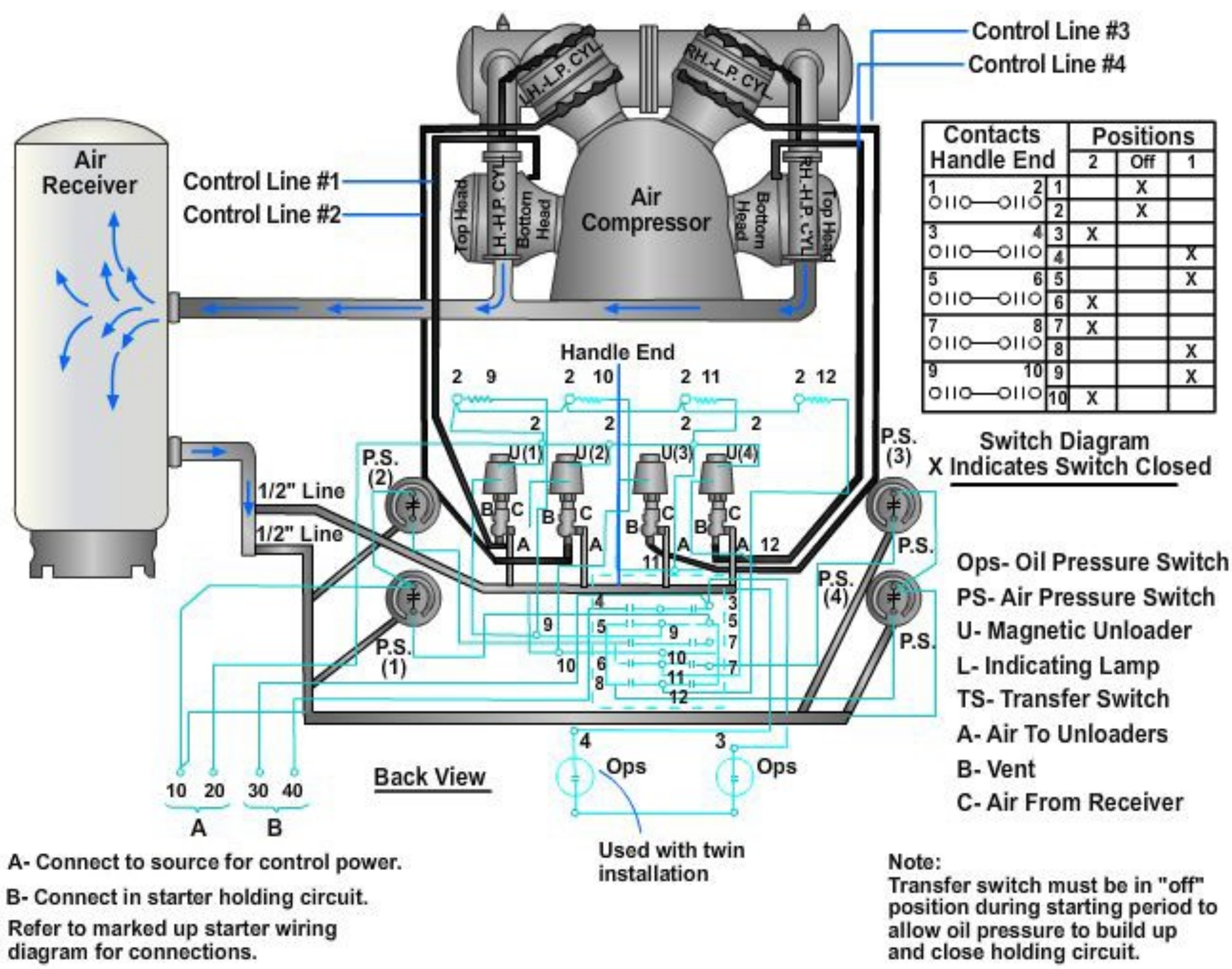

Figure 7-21 — Flow diagram of a five-step capacity control system applied to a two-stage, four-cylinder, double-acting, reciprocating compressor.

Another method of unloading a compressor is by the use of clearance pockets built into the cylinders. Normal clearance is the volume at the end of the piston and under the valves when the piston is at the end of the compression stroke. *Figure 7-22* shows an air cylinder with clearance pockets and clearance valves used with a five-step clearance control.

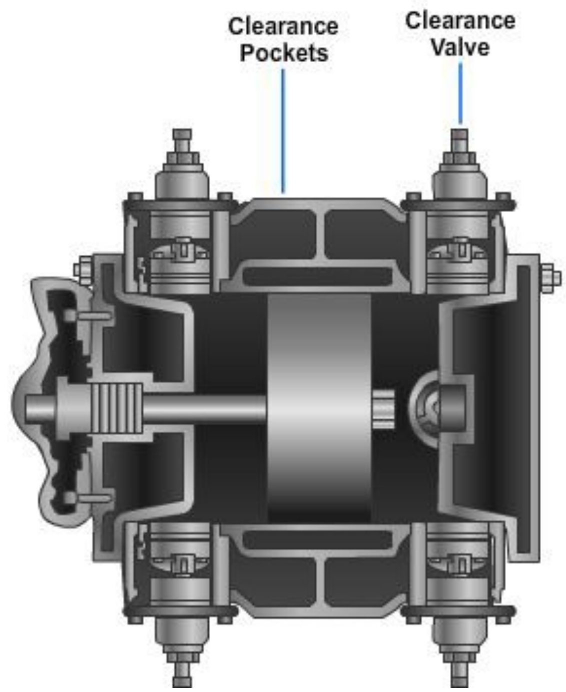

Figure 7-22 — Clearance pockets.

Each end of the cylinder is fitted with two clearance pockets that are connected with or cut off from the cylinder by air-operated clearance valves. A regulated device, not shown, which is operated by receiver pressure, uses pilot valves to open and close the clearance pocket valve in the proper sequence. Each clearance pocket can hold one-quarter of the air compressed by the cylinder in one stroke. When both pockets at the end of the cylinder are open, no air is taken into that end of the cylinder. *Figure 7-23* illustrates the operation of clearance pockets under five-step clearance control.

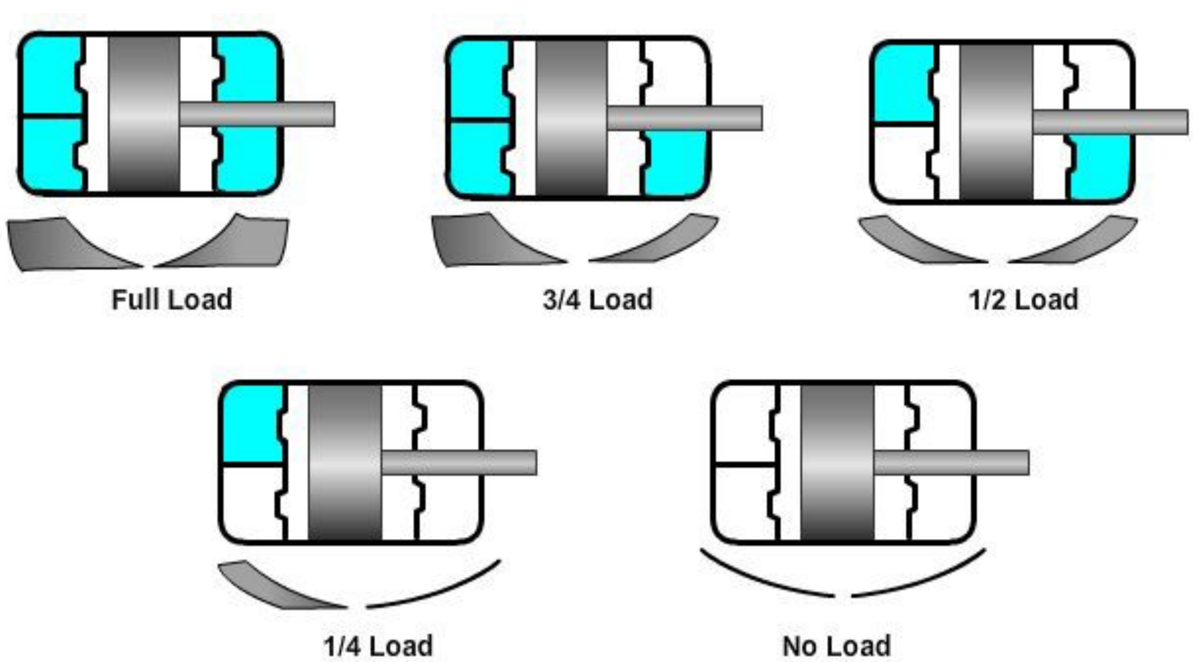

Figure 7-23 — Five-step clearance control.

3.6.0 Prime Movers

Prime movers for compressors can be electrical, gasoline, or diesel driven. This section will address electrical prime movers only. Gasoline and diesel-driven prime movers are normally the responsibility of the Construction Mechanic. Several types of electric motors can be used to drive compressors: induction, synchronous-wound motor, and direct current (dc) motors.

Although electric motor drive is available for compressors of almost any capacity, an induction motor best drives certain types of machines; others may be driven by a synchronous motor. Generally, cost will rule out synchronous motors except in unusual cases. Direct current motors are seldom used.

The type of connection that is used between the motor and compressor may further identify motor-driven compressors. Any one of the following types of drives may be used: belt, direct connected, or speed reduction gears.

Induction motors can be used to power single-acting, reciprocating compressors ranging from fractional horsepower up to approximately 300 horsepower at a speed of 1,800 rpm. Speeds of 1,200 and 900 rpm and lower are sometimes used in higher horsepower applications. When sizing a motor, you must allow for belt or drive losses of power.

Caution must be exercised when large belted motors are used; manufacturers' recommendations should be applied. Most motors that are belted to compressors are rated as normal starting torque, low-starting current motors. Belt selection should be based on a continuous operation rating of at least 125 percent of motor size with 150 percent preferred. Other compressors that start under load may require motors rated as high-start torque, low-starting current. Consideration should be given to compressor inertia and load to avoid lengthy acceleration time. Whenever possible, it is best to arrange the compressor to be unloaded during start-up.

An induction motor may drive a reciprocating compressor with a speed reduction gear placed between the motor and compressor. This permits the use of a higher speed with a less costly motor. Gear-driven compressors should have the flywheel or inertia effect carefully checked. Couplings should have enough elasticity and dampening to allow for torque and current pulsations. Without this consideration, changes in torque caused by load variations or loading and unloading of a compressor could result in drive and motor damage.

4.0.0 DISTRIBUTION SYSTEMS

The development of a distribution system is dependent upon a combination of factors, such as location and size of each service, time rate demand of larger services, and concurrence or demand factor of larger services.

4.1.0 Types of Air Distribution Systems

The more common types of distribution systems or patterns (*Figure 7-24*) and their prime advantages are as follows:

- Radial, one-way system—used for isolated or individual service or where special requirements dictate a single path.
- Loop system—used for a closed route, such as throughout a building. The two-directional flow capacity represents an economical way to provide constant pressure to all services and permits selective isolation when necessary.
- Parallel system—used to provide dual service source to ensure at least one source will be available at all times.

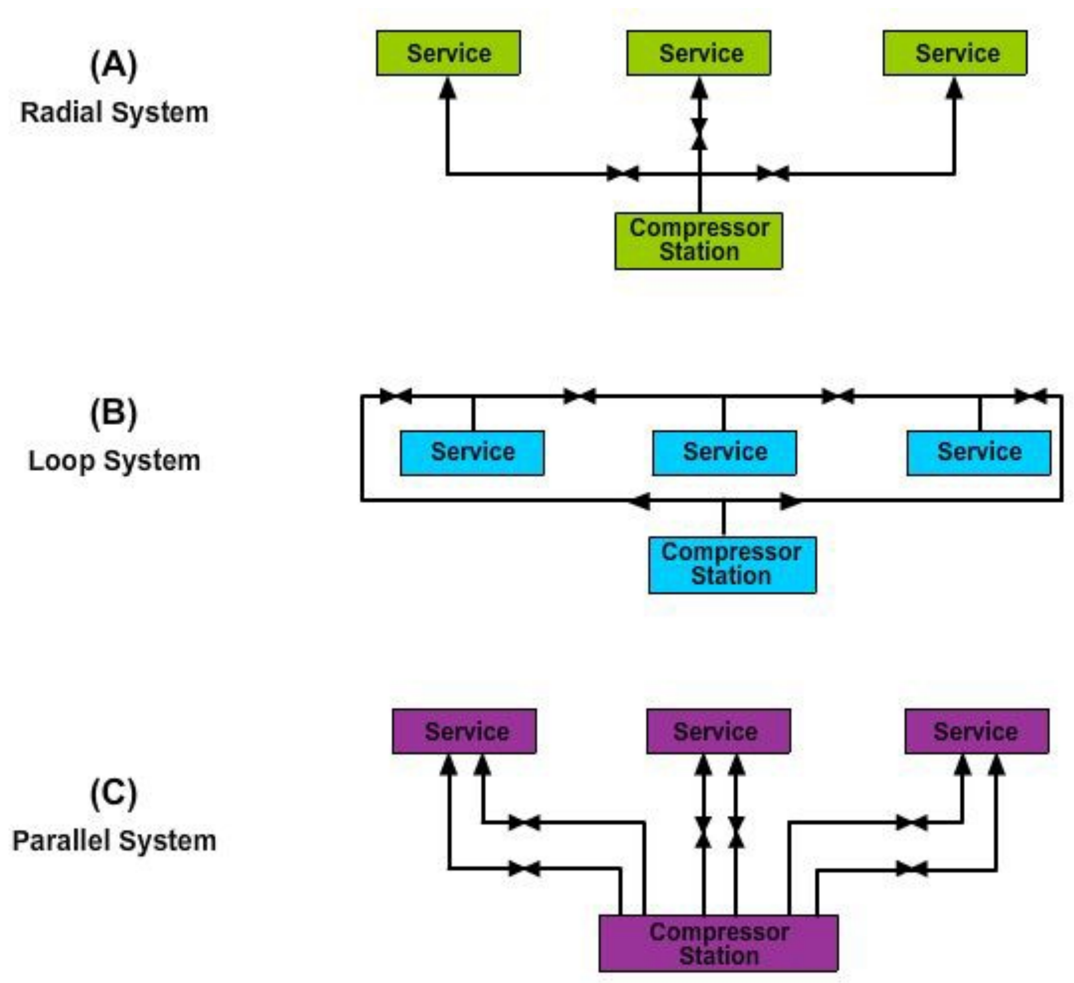

Figure 7-24 — Types of air distribution systems.

4.2.0 Sizing Distribution Systems

Compressed air distribution systems are sized mainly by calculating the friction loss to be expected from piping, fittings, and valves as well as various accessories you may install.

Pipe diameters are determined from commercially available products, such as copper, stainless steel tubing, or steel piping. As contained pressure increases, the pipe wall thickness must increase and interior diameters decrease. This affects friction pressure loss; it should not exceed 15-percent pressure loss.

When you are determining total friction loss for a distribution system, the total length of the system piping plus the equivalent length of each fitting, valve, or device is summed to produce an equivalent hydraulic length. The equivalent lengths of fittings, valves, and other devices can be determined from *Table 7-3*. Friction loss in air hoses may be taken from *Table 7-4*.

Table 7-3 — Representative Equivalent Length in Pipe Diameters (L/D) of Various Valves and Fittings.

Description of Product				Equivalent Length in Pipe Diameters (L/D)
Globe Valves	Stem Perpendicular to Run	With no obstruction in flat, bevel, or plug-type seat	Fully open	340
		With wing or pin-guided disk	Fully open	450
	Y-Pattern	(No obstruction in flat, bevel, or plug-type seat) —With stem 60 degrees from run of pipe line	Fully open	175
		—With stem 45 degrees from run of pipe line	Fully open	145
Angle Valves		With no obstruction in flat, bevel, or plug-type seat	Fully open	145
		With wing or pin guided disk	Fully open	200
Gate Valves	Wedge, Disk, Double Disk, or Plug Disk		Fully open	13
			Three-quarters open	35
			One-half open	160
			One-quarter open	900
	Pulp Stock		Fully open	17
			Three-quarters open	50
			One-half open	260
			One-quarter open	1200
Conduit Pipe Line Gate, Ball, and Plug Valves			Fully open	3**
Check Valves	Conventional Swing		0.5†. . .Fully open	135
	Clearway Swing		0.5†. . .Fully open	50
	Globe Lift or Stop; Stem Perpendicular to Run or Y-Pattern		2.0†. . .Fully open	Same as Globe
	Angle Lift or Stop		2.0†. . .Fully open	Same as Angle
	In-Line Ball		2.5 vertical and 0.25 horizontal†. . .Fully open	150
Foot Valves with Strainer		With poppet lift-type disk	0.3†. . .Fully open	420
		With leather-hinged disk	0.4†. . .Fully open	75
Butterfly Valves (8-inch and larger)			Fully open	40
Cocks	Straight-Through	Rectangular plug port are equal to 100% of pipe area	Fully open	18
	Three-Way	Rectangular plug port are equal to 80% of pipe area (fully open)	Flow straight through	44
			Flow through branch	140
Fittings	90-Degree Standard Elbow			30
	45-Degree Standard Elbow			16
	90-Degree Long Radius Elbow			20
	90-Degree Street Elbow			50
	45-Degree Street Elbow			26
	Square Corner Elbow			57
	Standard Tee	With flow through run		20
		With flow through branch		60
	Close Pattern Return Bend			50

**Exact equivalent length equal to the length between flange faces or welding ends

†Minimum calculated pressure drop (psi) across valve to provide sufficient flow to lift disk fully

Table 7-4 — Loss of Air Pressure in Hose Caused by Friction

Pulsating flow															
Size of hose, coupled at each end (in.)	Gage pressure at line (lb)	Free air (cfm)													
		20	30	40	50	60	70	80	90	100	110	120	130	140	150
		Loss of pressure (psi) in 50 ft. lengths of hose													
½	50	1.8	5.0	10.1	18.1										
	60	1.3	4.0	8.4	14.8	23.4									
	70	1.0	3.4	7.0	12.4	20.0	28.4								
	80	0.9	2.8	6.0	10.8	17.4	25.2	34.6							
	90	0.8	2.4	5.4	9.5	14.8	22.0	30.5	41.0						
	100	0.7	2.3	4.8	8.4	13.3	19.3	27.2	36.6						
	110	0.6	2.0	4.3	7.6	12.0	17.6	24.6	33.3	44.5					
¾	50	0.4	0.8	1.5	2.4	3.5	4.4	6.5	8.5	11.4	14.2				
	60	0.3	0.6	1.2	1.9	2.8	3.8	5.2	6.8	8.6	11.2				
	70	0.2	0.5	0.9	1.5	2.3	3.2	4.2	5.5	7.0	8.8	11.0			
	80	0.2	0.5	0.8	1.3	1.9	2.8	3.6	4.7	5.8	7.2	8.8	10.6		
	90	0.2	0.4	0.7	1.1	1.6	2.3	3.1	4.0	5.0	6.2	7.5	9.0		
	100	0.2	0.4	0.5	1.0	1.4	2.0	2.7	3.5	4.4	5.4	6.6	7.9	9.4	11.1
	110	0.1	0.3	0.4	0.9	1.3	1.8	2.4	3.1	3.9	4.9	5.9	7.1	8.4	9.9
1	50	0.1	0.2	0.3	0.5	0.8	1.1	1.5	2.0	2.6	3.5	4.9	7.0	…	…
	60	0.1	0.2	0.3	0.4	0.6	0.8	1.2	1.5	2.0	2.6	3.3	4.2	5.5	7.2
	70	…	0.1	0.2	0.4	0.5	0.7	1.0	1.3	1.6	2.0	2.5	3.1	3.8	4.7
	80	…	0.1	0.2	0.3	0.5	0.7	0.8	1.1	1.4	1.7	2.0	2.4	2.7	3.5
	90	…	0.1	0.2	0.3	0.4	0.6	0.7	0.9	1.2	1.4	1.7	2.0	2.4	2.8
	100	…	0.1	0.2.2	0.2	0.4	0.5	0.6	0.8	1.0	1.2	1.5	1.8	2.1	2.4
	110	…	0.1		0.2	0.3	0.4	0.6	0.7	0.9	1.1	1.3	1.5	1.8	2.1
1-1/4	50	…	…	0.1	0.2	0.2	0.3	0.4	0.5	0.7	1.1	…	…	…	…
	60	…	…	…	0.1	0.2	0.3	0.3	0.5	0.6	0.8	1.0	1.2	1.5	…
	70	…	…	…	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.7	0.8	1.0	1.3
	80	…	…	…	…	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0
	90	…	…	…	…	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.3	0.7	0.8
	100	…	…	…	…	…	0.1	0.2	0.2	0.3	0.4	0.4	0.2	0.6	0.7
	110	…	…	…	…	…	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6
1-1/2	50	…	…	…	…	…	0.1	0.2	0.2	0.2	0.	0.3	0.4	0.5	0.6
	60	…	…	…	…	…	…	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.5
	70	…	…	…	…	…	…	…	0.1	0.2	0.2	0.2	0.3	0.3	0.4
	80	…	…	…	…	…	…	…	…	0.1	0.2	0.2	0.2	0.3	0.4
	90	…	…	…	…	…	…	…	…	…	0.1	0.2	0.2	0.2	0.3
	100	…	…	…	…	…	…	…	…	…	…	0.1	0.2	0.2	0.2
	110	…	…	…	…	…	…	…	…	…	…	0.1	0.2	0.2	0.2
(1 inch = 25.4 mm, 1 CFM = 0.0283 mm^3 /min, 1 psi=6.90 kPA, 50 feet = 15.2 m)															

4.3.0 Layout Details

When installing compressed air systems, you must follow seven basic guidelines just as you must consider basic guidelines when installing any other type of piping or drainage system. Compressed air lines should be installed as level as practical with a slight pitch in the direction of airflow. This pitch is generally placed at 3 inches per 100 feet of piping. In cases when pipes must be pitched upward causing condensate to flow against the flow of air, the pitch upward must be 6 inches or greater per 100 feet, and the piping size should be increased one pipe diameter. The layout of the piping systems should always allow for the removal of dirt, water, oil, or other foreign material, which can accumulate over long periods of time. Because of this, pockets should be avoided and, where necessary, low points should be provided with drip legs. In addition to providing low points to drain foreign material from the system, the prevention of carryover of this material into branch lines is necessary. Carryover into branch lines can be prevented by making connections from the top of the distribution mains.

Piping must be placed with sufficient flexibility to prevent excessive strain or distortion caused by thermal expansion or sudden changes in pressure. By properly placing pipe supports, as shown in *Table 7-5*, movement of pipe can be accounted for. In addition, piping should be supported at all changes in direction and load concentrations, such as heavy valves. There are many other considerations in the layout of compressed air systems, which are beyond the scope of this manual. Refer to NAVFAC DM 3-5, *Compressed Air and Vacuum Systems,* for further information.

Table 7-5 — Maximum Span for Pipe.

Diameter (inches)	Standard Weight Steel Pipe 40S	Copper Tube Type K
1/2	5’-0”	3’-9”
3/4	5’-9”	4’-3”
1	6’-6”	5’-0”
1-1/2	7’-6”	5’-9”
2	8’-6”	6’-6”
2-1/2	9’-3”	7’-3”
3	10’-3”	7’-9”
3-1/2	11’-0”	8’-3”
4	11’-6”	9’-0”
5	12’-9”	10’-0”
6	13’-9”	10’-9”
8	15’-6”	
10	17’-0”	
12	18’-3”	
(1 inch = 25.4 mm, 1 foot = 0.3048 m)		

4.4.0 Test Procedures

After installation, the compressed air system must undergo testing. Generally, all piping and pressurized components should be tested at 150 percent of maximum working pressure. When testing, use clean, dry air or nitrogen. The system should be held at test pressure without loss for at least 4 hours.

5.0.0 MAINTENANCE REQUIREMENTS

As with any system, preventive maintenance conducted on a scheduled basis is an important factor in providing reliable service. Breakdown maintenance causes interruption in services that prove costly to the facility. It also requires more extensive repair to system components. An understanding of the maintenance required for each component will assist in carrying out this type of duty.

5.1.0 Prime Mover Maintenance

Diesel, gasoline, and electrical prime movers can drive air compressors. These power-producing items of equipment require the same maintenance as any prime mover used to drive other equipment.

Establish a definite lubrication schedule. Normal oil levels in engines must be maintained at all times, using lubricants recommended by the manufacturer. The frequency of oil changes depends on the severity of service, atmospheric dust, and dirt. These factors also affect the filter and in the case of electrical motors, the need for regular lubrication of bearings.

Daily operator maintenance prevents most breakdowns. Following the suggested maintenance requirements of the manufacturer helps to reduce downtime caused by prime mover failure.

5.2.0 Air Compressor Maintenance

Taking into consideration the many types of air compressors encountered in the field, it is impossible to cover all the maintenance requirements of air compressors in this section. Several common factors do apply to all compressors.

The establishment of a lubrication schedule is at the top of the list for ensuring trouble-free operation of compressors. A definite schedule and assignment of responsibility for maintenance personnel to follow are required. The manufacturer’s manual establishes minimum requirements that should be followed.

Bearings, packing, seals, and clearances between moving parts must be within the manufacturer’s specifications and be included on the maintenance schedule. Many compressors allow for adjustment, while others require overhaul when clearances are exceeded.

Visual inspections for dust, dirt, or leaks provide early detection of possible maintenance requirements. Operator maintenance, when conducted properly, can help you catch and correct potential problems early. Ensure all of your operators know how to operate the equipment. In all cases, you should use the manufacturer’s manual when making repairs or adjustments.

5.3.0 Auxiliary Equipment Maintenance

All auxiliary equipment that services the air compressor or is serviced by the compressor requires periodic scheduled maintenance. Air filters should be checked and cleaned at least once a month. Silencers should be checked twice a year for corrosion, paint, and gasket damage. Intercoolers and aftercoolers must be inspected for scale buildup in hub leaks. In general, all auxiliary equipment must be placed on a schedule for inspection and periodic maintenance.

5.4.0 Distribution System Maintenance

Distribution systems require a minimum of maintenance. Checking valve operation and hose connecters, draining condensation (manual or automatic), protecting piping from damage, and repairing leaks are the most common considerations in a maintenance plan.

Summary

You should now be more familiar with air compressor systems, their design, and the components that make up a system. You should now be capable of identifying and directing the proper construction techniques for installation of fittings and components.

You should also have an understanding of the maintenance of previously installed systems. The course also discussed air quality requirements. Remember to always follow all safety requirements and use only the recommended maintenance techniques Quarterly.

Additional Resources and References

- This course is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

- *Compressed Air and Vacuum Systems,* NAVFAC DM-3.5, Naval Facilities Engineering Command, Alexandria, VA , 1983.
- *Maintenance of Steam, Hot Water and Compressed Air Distribution Systems,* NAVFAC MO-209, Naval Facilities Engineering Command, Alexandria, VA, 1989.
- *Operation and Maintenance of Air Compressor Plants,* NAVFAC MO-206, Naval Facilities Engineering Command, Alexandria,VA, 1989