CHAPTER 61
AIR COMPRESSORS

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61.1 INTRODUCTION

Compressed air provides power for many manufacturing operations. Energy stored in compressed air is directly convertible to work. Conversion from another form of energy, such as heat, is not involved. Compressed air can be supplied by several different types of compressors (Fig. 61.1). The choice depends on the amount, pressure, and quality of air a plant system requires.

The reciprocating compressor is manufactured in a broad range of configurations. Its pressure range is the broadest in the compressor family extending from vacuum to 40,000 psig. It declined in popularity from the late 1950s through the mid-1970s. Higher maintenance costs and lower capacity, when compared to the centrifugal compressor, contributed to this decline. The sudden rise in energy cost and the downsizing of new process plants have given the higher-efficiency, though lower-capacity, reciprocating compressor a more prominent role in new plant design.

Rotary compressors as a group make up the balance of positive displacement machines. This group of compressors has several features in common despite differences in construction. Probably the most important feature is the lack of valves as used in reciprocating compressors. The rotary is lighter in weight than the reciprocator and does not exhibit the shaking forces of the reciprocating compressor, making foundation requirements less rigorous. Though rotary compressors are relatively simple in construction, their physical design can very widely. Rotor design, both multiple and single, is one of the main items that distinguishes different types.

For certain applications, compression chamber lubricant oils cannot be tolerated in compressed air. The demand for oil-free air in processes where compressed air comes in direct contact with sensitive products, such as electronic components, instruments, food, and drugs, has increased the need for non-lubricated or oil-free air compressors.

Compressors are normally lubricated for a variety of reasons: to reduce wear, provide internal cooling, and effect a seal between moving parts. In reciprocating compressors, lubricant is distributed by a pressure or splash system to connecting rods, crank and piston pins, and main bearings. Rotary screw compressors inject oil into the screw to seal and cool the compressing air. Centrifugal and liquid ring compressors are, by design, oil-free.

Reciprocating, non-lubricated air compressors substitute low friction or self-lubricating materials such as carbon or Teflon for piston and packing rings. Oil-free screw and lobe type compressors are available with a design that does not require lubrication in the compression chamber for sealing and lubrication. Centrifugal air compressors are inherently nonlubricated.

Generally, nonlubricated compressors have a higher initial cost due to special designs and materials. Nonlubricated, reciprocating compressors have higher operating costs due to the increased maintenance of valves and rings, which tend to have short lives.

61.2 TYPES

Reciprocating single-acting compressors resemble automotive engines, are generally of one- or two-stage design, and are constant-capacity, variable-pressure units. They are very popular because of

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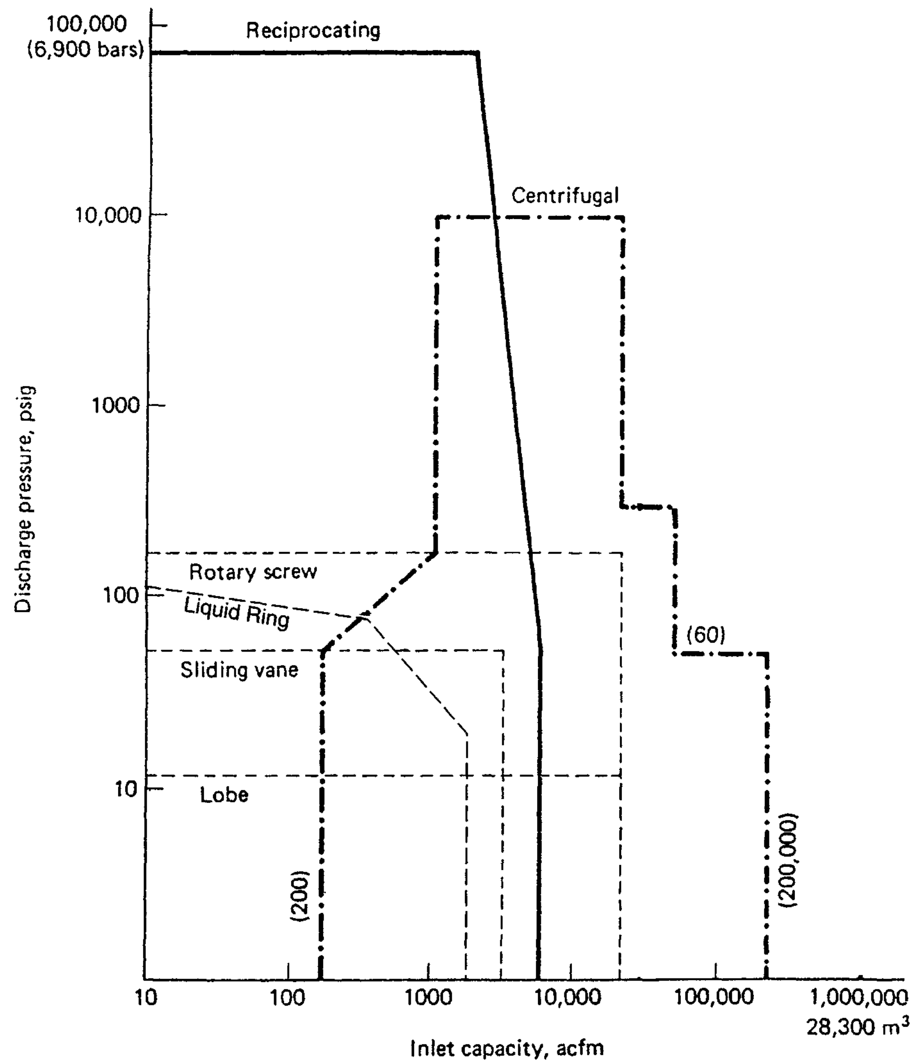


Fig. 61.1 Pressure-capacity chart showing the effective ranges of most compressors.[1]

their simplicity, efficiency, compactness, ease of maintenance, and relatively low price. In a single-stage compressor, air is compressed to the final pressure in a single stroke. This design is generally used for pressures from 25–100 psig. Units can be air- or liquid-cooled.

The two-stage design compresses air to an intermediate pressure in the first stage (Fig. 61.2). Most of the heat of compression is removed as the air passes through an intercooler, which is air or liquid cooled, to the second stage, where it is compressed to the final pressure. Two-stage compressors are generally used for pressures from 100–250 psig.

The reciprocating compressor is a positive displacement, intermittent-flow machine and operates at a fixed volume. One method of volume control is speed modulation. Another, more common, method is to use clearance pockets with or without valve unloading. With clearance pockets, cylinder performance is modified. With valve unloading, one or more inlet valves are physically opened. Capacity may be regulated in a single- or double-acting cylinder with single- or multiple-valve configurations.

Lubrication of compressor cylinders can be tailored to the application. The cylinders may be designed for normal hydrocarbon lubricants or can be modified for synthetic lubricants. The cylinder may also be designed for self-lubrication, in which case it is generally referred to as *nonlubed.* A

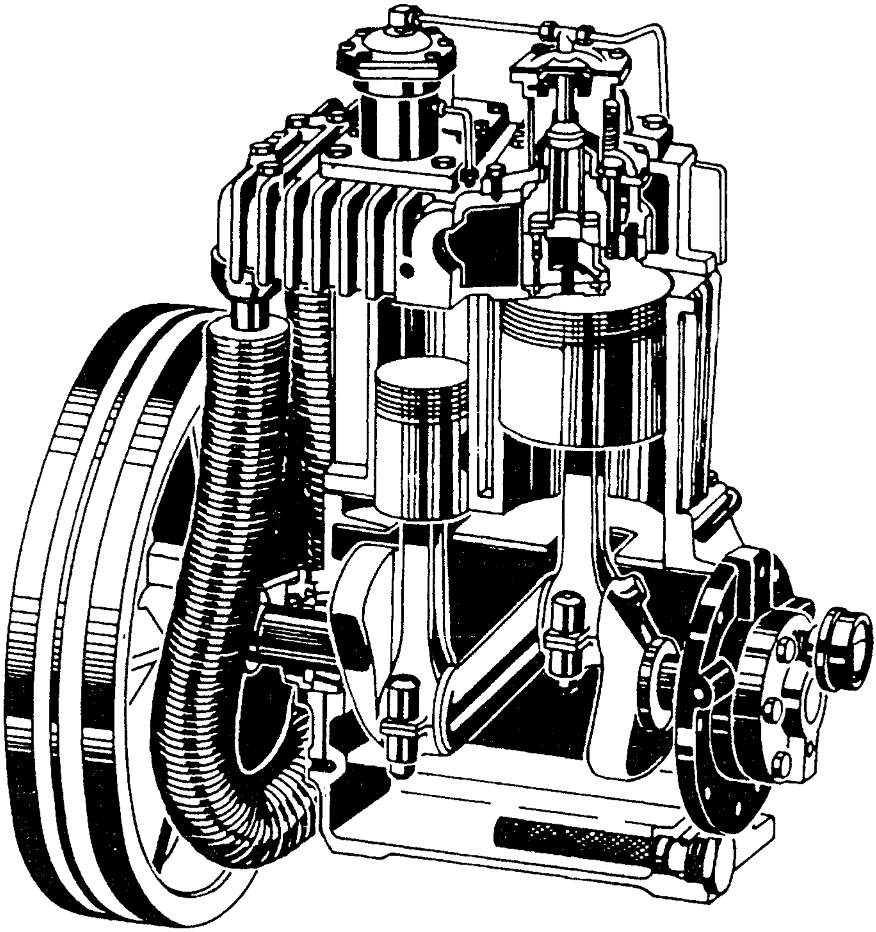


Fig. 61.2 Single-acting, two-stage compressor.[1]

compromise lubrication method that uses the nonlubed design but requires a small amount of lubricant is referred to as the *mini-lube* system.

Another feature necessary to the reciprocating compressor is cylinder cooling. Many compressors are furnished with water jackets as an integral part of the cylinder. Alternatively, particularly in smaller-size compressors, the cylinder can be designed for air cooling.

Reciprocating compressors can be classified into several types. One is the *automotive piston* type. The piston is connected to a connecting rod which is in turn connected directly to the crankshaft. This type of compressor has a single-acting cylinder and is limited to smaller air compressors.

Another common type of compressor for nonlube service is the *crosshead* type. The piston is driven by a fixed piston rod that passes through a stuffing or packing box and is connected to a crosshead. The crosshead, in turn, is connected to the crankshaft by a connecting rod. In this design, the cylinder is isolated from the crankcase by a distance piece. A variable-length or double-distance piece is used to keep crankcase lubricant from being exposed to the compressed air.

Reciprocating compressors usually will not tolerate liquids of any sort, particularly when delivered with the inlet air stream. A suction strainer or filter is mandatory for keeping ambient dirt and pipe scale out of the compressor. Fines from pipe scale and rust make short work of the internal bore of a cylinder and are not good for other components. The strainer should be removable for cleaning, particularly when it is intended for permanent installation. Under all circumstances, provision must be made to monitor the condition of the strainer.

Discharge temperatures should be limited to 300°F, as recommended by API 618. Higher temperatures cause problems with lubricant coking and valve deterioration. In nonlube service, the ring material is also a factor in setting the temperature limit. While 300°F may not seem all that hot, it should be remembered that this is an average outlet temperature and the cylinder will have hot spots exceeding this temperature.

Lubricated compressors use either a full-pressure or splash-lubricating system with oil in the crankcase. Oil-free compressors have a crosshead or distance piece between the crankcase and cylinders. Nonlubricated compressors use nonmetallic piston rings, guides, and sealed bearings with no lubricating oil in the crankcase.

Reciprocating double-acting designs compress air on both strokes of the piston and are normally used for heavy-duty, continuous service. Discharge pressures range from above atmospheric to several thousand psig. The largest single application is continuous-duty, supplying air at 100 psig. This design is available with the same modifications as single-acting compressors.

Double-acting crosshead compressors, when used as single-stage, have horizontal cylinders. The double-acting cylinder compressor is built in both the horizontal and the vertical arrangement. There is generally a design tradeoff to be made in this group of compressors regarding cylinder orientation. From a ring-wear consideration, the more logical orientation is vertical; however, taking into account size and the ensuing physical location as well as maintenance problems, most installations normally favor a horizontal arrangement (Fig. 61.3).

Rotary screw compressors use one or two rotors or screws and are constant-volume, variable-pressure machines. Oil or water injection is normally used to seal clearances and remove the heat of compression. Oil-free designs have reduced clearances and do not require any other sealing medium.

In single-screw designs, the rotor meshes with one or two pairs of gates (Fig. 61.4). The screw and casing act as a cylinder, while the gates act like the piston in a reciprocating compressor. The screw also acts as a rotary valve, with the gates and screw cooperating as a suction valve and the screw and a port in the casing acting as a discharge valve. Single-stage sizes range from 10–1200 cfm with pressures up to 150 psig. 250-psig designs, supplying 700–1200 cfm, are available.

Dual rotor designs use two intermeshing rotors in a twin-bore housing (Fig. 61.5). Air is compressed between the convex and concave rotors. The trapped volume of air is decreased along the rotor, increasing pressure. Single- and multistage versions are available with and without lubrication.

The power consumption of rotary screw compressors during unloaded operation is normally higher than that of reciprocating types. Recent developments have produced systems where the unloaded horsepower is 15–25% of loaded power. These systems are normally used with electric motor, constant-speed drives. Use as a base load compressor is recommended to avoid excessive unloaded power costs.

A dry screw compressor may be selected for applications where a high air-flow rate is required but space does not allow a reciprocating compressor, or where the flow requirement is greater than can be supplied by a single-unit, oil-flooded screw compressor. Packaged versions of dry screw compressors require a minimum of floor space.

Dry screw compressors generate high frequency pulsations that affect system piping and can cause acoustic vibration problems. These would be similar to the type of problems experienced in reciprocating compressor applications, except that the frequency is higher. While volume bottles work with the reciprocator, dry-type screw compressors require a manufacturer-supplied proprietary silencer to take care of the problem.

There is one problem this compressor can handle quite well: unlike most other compressors, it will tolerate a moderate amount of liquid. Injection for auxiliary cooling can be used, normally at a lower level than would be used in a flooded compressor. The compressor also works well in fouling service, if the material is not abrasive. The foulant tends to help seal the compressor and, in time, may improve performance.

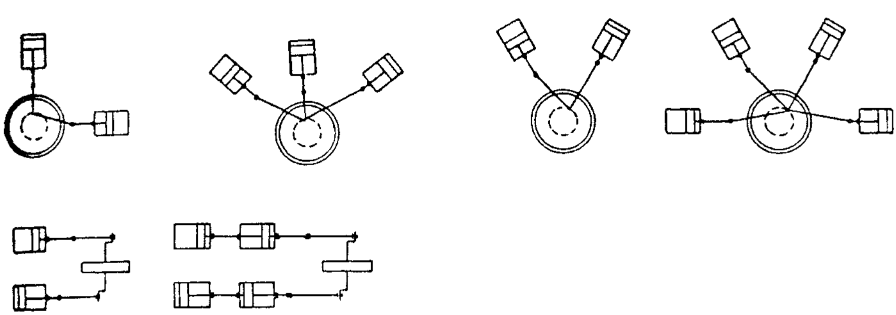
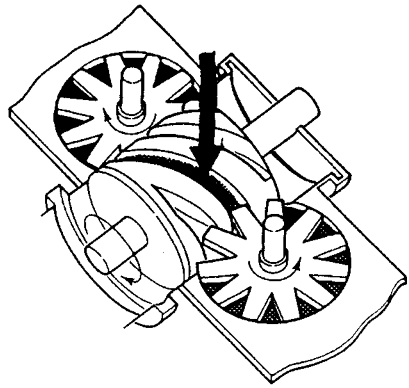
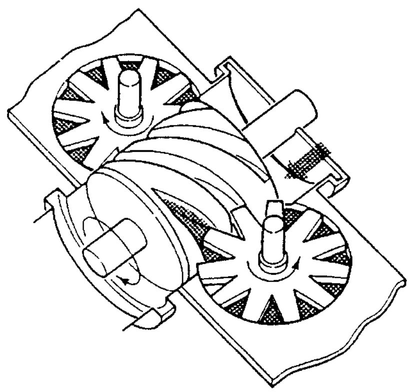


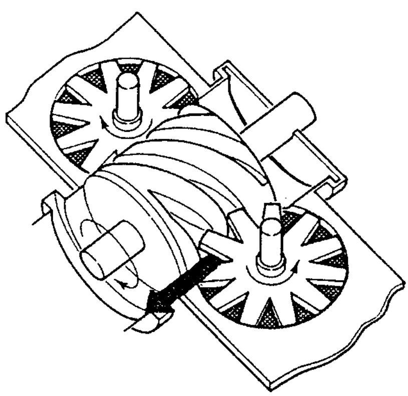
Fig. 61.3 Various cylinder arrangements used in displacement compressors. Some are suitable for single-acting compressors, while others are double-acting and require a crosshead and guide.[1]



(*a*) Suction



(*b*) Compression



(*c*) Discharge

Fig. 61.4 Diagram showing the operation of the rotary, single-screw compressor.[1]

In dry screw compressors, the rotors are synchronized by timing gears. Because the male rotor, with a conventional profile, absorbs about 90% of the power transmitted to the compressor, only 10% of the power is transmitted through the gears. The gears have to be of good quality both to maintain the timing of the rotors and to minimize noise. Because the compressor will turn in reverse on gas backflow, keeping gear backlash to a minimum is important. A check valve should be included because compressors are sometimes subjected to reverse flow. To control backlash in the gears, a

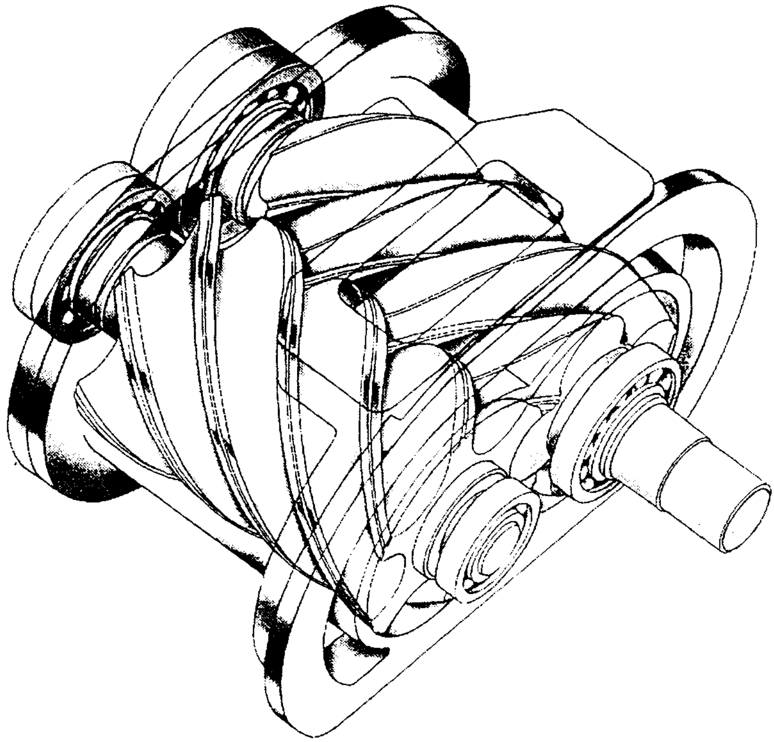


Fig. 61.5 Rotary, helical-screw compressor, typical single-stage design.[1]

split-driven gear is used to provide adjustment to the gear lash and maintain timing on reverse rotation. To provide timing adjustment, the female rotator's timing gear is made to be movable relative to its hub.

The gears are helical, which also helps control noise. The pitch line runout must be minimized to control torsional excitation. Gears are housed in a chamber outboard from the drive end and are isolated from the compressed air.

Oil-flooded versions are an increasingly popular variation of the screw compressor and are used in a variety of applications. This type of compressor is less complex than the dry version because timing gears have been eliminated. This can be done because the female rotor is driven by the male rotor through an oil film. Another advantage is that the oil acts as a seal for internal clearances, which means a higher volumetric and overall efficiency. The sealing improvement also results in higher efficiency at lower speeds. This means quiet operation and the possibility of direct connection to motor drivers, eliminating the need for speed increasing gears.

When gears are needed, they are available internally on some models. Higher pressure ratios can also be realized because of the direct cooling from injected oil. Pressure ratios as high as 21:1 in one casing are possible. Besides the inherently quiet operation from lower speed, oil dampens some of the internal pulses aiding in the suppression of noise.

The injected oil is sheared and pumped in the course of moving through the compressor. These power losses can be minimized by taking advantage of slower speed performance. There is an optimum speed where improvement in operation from oil offsets potential energy losses.

The points of injection are quite important for efficient operation. Oil should be injected in the casing wall at or near the intersection of the rotor bores on the discharge side of the machine.

Flooded compressors use a symmetric profile rotor extensively because of the rotor's efficiency. Flooded compressor size has recently been increased. The upper range is in the 7000 cfm range. While most applications are in air and refrigeration, certain modifications can make it applicable for process gas service. One consideration is the liquid used for flooding.

The fluid in a compressor is normally a petroleum-based lubricating oil, but not always. Factors to consider when selecting the lubricant include:

- Oxidation
- Condensation
- Viscosity
- Outgassing in the inlet
- Foaming
- Separation performance
- Chemical reaction

Some problems can be solved with specially selected oil grades. Another solution is synthetic oils, but cost is a problem, particularly with silicone oils. Alternatives need to be reviewed to match service life of the lubricant with lubrication requirements in the compressor.

One consideration for flooded compressors is the recovery of liquid. In conventional arrangements, the lubricating oil is separated at the compressor outlet, cooled, filtered, and returned to the compressor. This is fine for air service, where oil in the stream is not a major problem, but when oil-free air is needed, the separation problem becomes more complex. Because the machine is flooded and the discharge temperature is not high, separation is much easier relative to compressors that send small amounts of fluid at high temperature down stream. Usually part of the lubricant is in a vaporized form and is difficult to condense except where it is not wanted. To achieve quality oil-free air, such as that suitable for a desiccant-type dryer, separators that operate at the tertiary level should be considered. Here, the operator must be dedicated to separator maintenance, because these units require more than casual attention. Separation by refrigeration is not as critical if direct expansion chillers are used. In these applications, the oil moves through the tubes with the refrigerant and comes back to the compressor with no problem, if the temperature is not too low for the lubricant.

Advantages of helical screw compressors include smooth and pulse-free air output, compact size, high output volume, low vibration levels, and long life.

Centrifugal compressors are second only to reciprocating compressors in numbers of machines in service. Where capacity or horsepower rather than numbers is considered as a measure, the centrifugal, without a doubt, heads the compressor field. During the past 30 years, the centrifugal compressor, because of its smaller relative size and weight compared to the reciprocating machine, became much more popular for use in process plants, which were growing in size. The centrifugal compressor does not exhibit the inertially induced shaking forces of the reciprocator and therefore does not need the same massive foundation. Initially, the efficiency of the centrifugal was not as good as that of a well maintained reciprocating compressor. However, the centrifugal established its hold on the market in an era of cheap energy when power cost was rarely, if ever, evaluated.

The smaller compressor design was able to penetrate the general-process plant market, which had historically belonged to the reciprocating compressor. As the compressor grew in popularity, developments were begun to improve reliability, performance, and efficiency. With the increase in energy cost in the mid-1970s, efficiency improvements became a high priority. Initially, most development had concentrated on making the machine reliable, a goal that was reasonably well achieved. Run time between overhauls currently is three years or more, with six-year run times not unusual. As plant size increased, the pressure to maintain or improve reliability was very high because of the large economic impact of a nonscheduled shutdown.

Centrifugal compressors are dynamic types with rotating impellers that impart velocity and pressure to air (Fig. 61.6). Their design is simple and straightforward, consisting of one or more high-speed impellers with cooling sections. The only lubrication required is in the drive system, which is sealed off from the air system.

Integral gear-type centrifugal air compressors are generally used in central plant air applications requiring volumes ranging from 1000–30,000 cfm and discharge pressures from 100–125 psig.

Centrifugal air compressors are normally specified on the basis of required air-flow volume. However, there are several ways to calculate volume and serious problems can result unless both user and manufacturer use the same method. At the very least, the user can have problems comparing bids from competing manufacturers. At worst, he may choose the wrong compressor.

These problems can be avoided by specifying capacity in terms of actual inlet conditions and by understanding how compressor capacity is affected by variable ambient conditions such as inlet pressure, temperature, and relative humidity. Factors such as cooling water temperature and motor load must be considered before a compressor and its drive motor can be sized.

A multistage arrangement for integral gear-type compressors is shown in Fig. 61.7. The flow path is straight through the compressor, moving through each impeller and cooler in turn. This type of centrifugal compressor is probably the most common of any found in process service, with applications ranging from air to gas.

Sliding-vane compressors consist of a vane-type rotor mounted eccentrically in a housing (Fig. 61.8). As the rotor turns, the vanes slide out against the stator or housing. Air compression occurs when the volume of the space between the sliding vanes is reduced as the rotor turns. Single- and multistage versions are available.

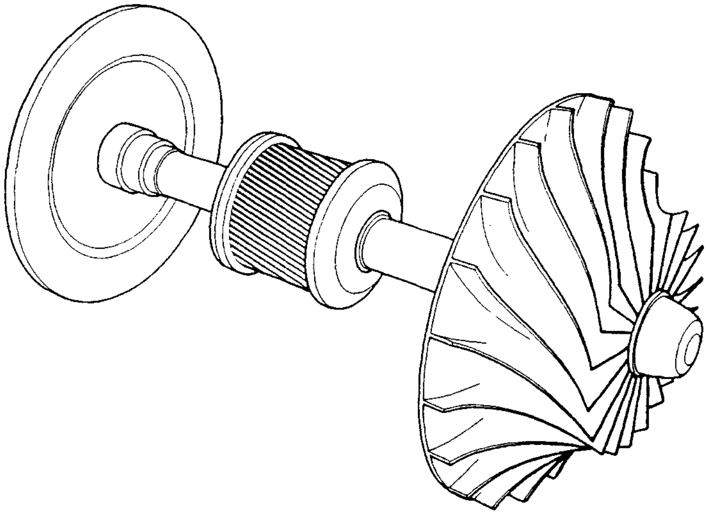


Fig. 61.6 Pinion of an intergral-gear unit having open, backward-curve-bladed impellers.[1]

The sliding-vane compressor consists of a single rotor mounted eccentrically in a cylinder slightly larger than the rotor. The rotor has a series of radial slots holding a set of vanes. The vanes are free to move radially within the rotor slots. They maintain contact with the cylinder wall by centrifugal force generated as the rotor turns.

The space between a pair of vanes, the rotor, and the cylinder wall forms crescent-shaped cells. As the rotor turns and a pair of vanes approach the inlet, air begins to fill the cell. The rotation and subsequent filling continue until the suction port edge has been passed by both vanes. Simultaneously,

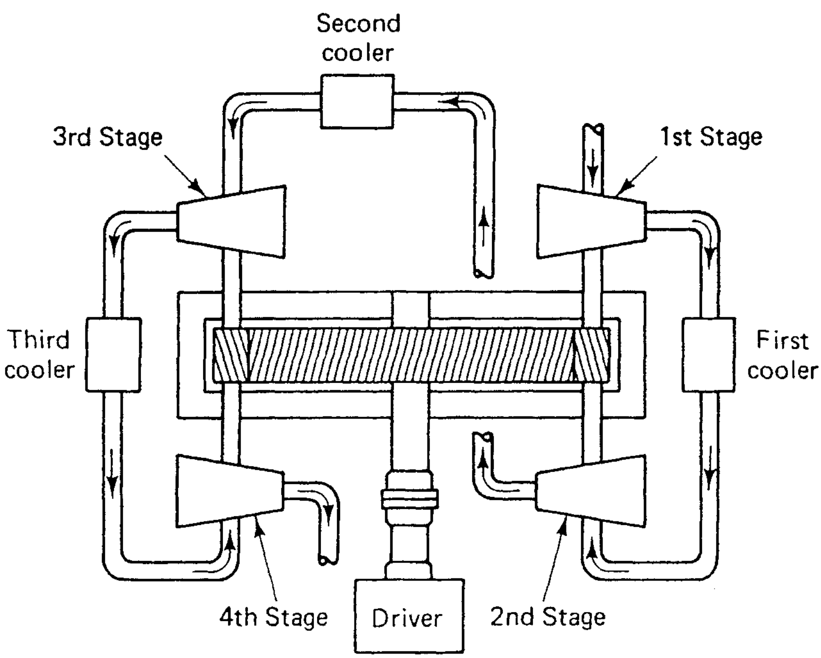


Fig. 61.7 Flow diagram of an integral-gear-type compressor showing stages of compression and including the cooling arrangement.[1]

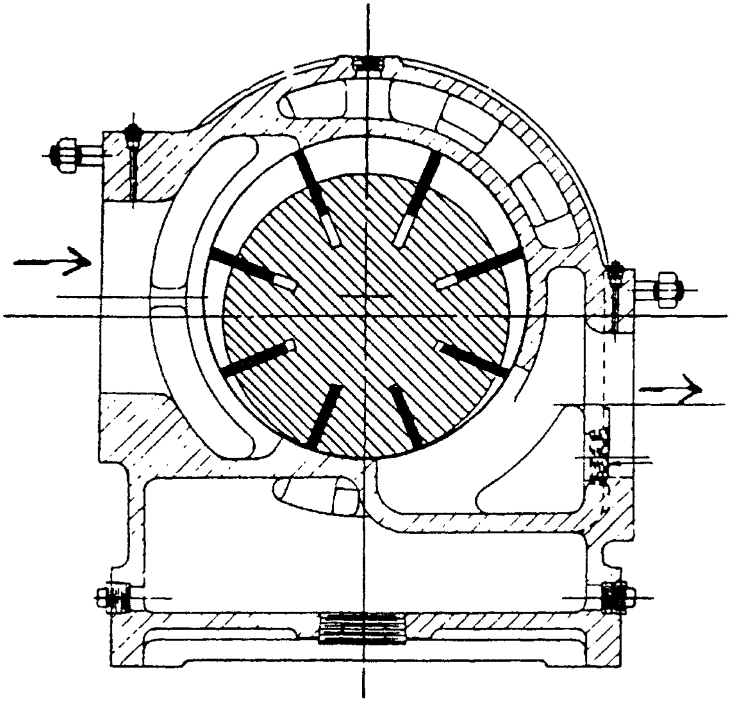


Fig. 61.8 Cross section of a sliding vane compressor (courtesy of A-C Compressor Corporation, Milwaukee, Wisconsin).[2]

the vanes have passed their maximum extension and begin to be pushed back into the rotor by the eccentricity of the cylinder wall. As the space becomes smaller, the air is compressed. The compression continues until the leading vane crosses the edge of the discharge port, and compressed air is discharged.

The sliding-vane compressor can be used to 50 psig in single-stage form and when staged can be used to 125 psig. An often overlooked application for the sliding-vane machine is that of vacuum service, where, in single-stage form, it can be used to 28 in. Hg. Volumes in vacuum service are in the 5000-cfm range. For pressure service, at the lower pressures, volumes are just under 4000 cfm and decrease to around 2000 cfm as the discharge pressure exceeds 30 psig.

The sliding-vane compressor efficiency is not as good as that of the reciprocating compressor, but the machine is rugged and light and lacks the foundation or skid weight requirement of the reciprocator.

Vane wear must be monitored in order to schedule replacement before the vanes become too short and wear the rotor slots. If the vanes are permitted to become too worn on the sides or too short, the vane may break and wedge between the rotor and the cylinder wall at the point of eccentricity, possibly breaking the cylinder. Shear pin couplings or equivalent torque-limiting couplings are sometimes used to prevent damage from a broken vane under sudden stall conditions.

As in most jacket-cooled compressors, the coolant acts as a heat sink to stabilize the cylinder dimensionally. The jacket outlet temperature should be around 115°F and be controlled by an automatic temperature regulator if the load or the water inlet temperature is prone to change.

Most of the drivers used with the sliding-vane compressor are electric motors. Variable-speed operation is possible within the limits of vane-speed requirements. The vanes must travel fast enough to seal against the cylinder wall but not so fast that they cause excessive wear. For smaller units, under 100 hp, V-belts are widely used. Direct connection to a motor, however, is possible for most compressors and is used throughout the size range.

For lubricated machines, vanes are made of a laminated asbestos impregnated with phenolic resin. For a nonlubricated design, carbon is used. The number of vanes influences the differential pressure between adjacent vane cells. The influence becomes less as the number of vanes increases.

Antifriction bearings are widely used, generally a roller type. Seals are either a packing or mechanical contact type. Packing and bearings are lubricated by a pressurized system. For nonflooded, lubricated compressors, a multiplunger pump, similar to one used with reciprocating compressors, is used. Lubrication is directed from the lubricator to drilled passages in the compressor cylinder and heads. One feed is directed to each of the bearings. Other feeds meter lubrication onto the cylinder wall. As the vanes pass the oil-injection openings, lubricant is spread around the cylinder walls to lubricate vane tips and eventually the vanes themselves. Oil entering the gas stream is separated in the discharge line. Because of high local heat, the lubricant may break down and not be suitable for recycling.

Flooded compressors pressure-feed a large amount of lubricant into the compressor, where it both cools the air and lubricates the compressor. It is separated from the air at discharge and recycled.

Oil-less designs are restricted to low-pressure applications due to high operating temperatures and sealing difficulties. Higher pressures are obtained with lubricated designs. Capacities range from 5–600 cfm at pressures from 80–150 psig.

Advantages of sliding-vane compressors include cool, clean, pulse-free air output, compact size, low noise levels, and low vibration levels. In some applications, there may not be a need for an air receiver.

Lobe compressors are a positive displacement, clearance-type design. They do not require lubrication in the compression chamber, only for the bearings and gears. The lobes do not drive one another and have intermeshing profiles that form a decreasing volume while rotating. Units are relatively vibration-free.

Lobe compressors are low-pressure machines. A feature unique to these compressors is that they do not compress air internally, as do most of the other rotaries. The straight-lobe compressor uses two rotors that intermesh as they rotate (Fig. 61.9). The rotors are timed by a set of gears. The lobe shape is either an involute or cycloidal form. A rotor may have either two or three lobes. As the rotors turn and pass the inlet port, a volume of air is trapped and carried between the lobes and the outer cylinder wall. When the lobe pushes air toward the exit, the air is compressed by back pressure in the discharge line.

Volumetric efficiency is determined by tip leakage past the rotors, not unlike the rotary screw compressor. This leakage, referred to as *slip,* is a function of rotor diameter and differential pressure.

Lobe-type compressors are used both in pressure and vacuum service. Larger units are direct-connected to their drivers and the smaller units are belt-driven. The drivers are normally electric motors. The main limitation of this rotary compressor is differential pressure on longer rotors, where deflection can be large. For a two-lobe machine, caution should be used when the rotor length is more than 1.5 times the rotor diameter at pressures in excess of 8 psi differential. Three-lobe compressors inherently have stiffer rotors and can sustain a higher pressure differential. A practical upper limit is about 10 psi differential for units above 3000 cfm and 12 psi differential for smaller units.

This type of compressor has a constant leakage rate for a fixed set of clearances, pressure, and temperature. Capacities range from 200–1500 cfm at 125 psig.

Liquid ring compressors employ a rotor to drive a captive ring of liquid within a cylindrical housing. The inner surface of the liquid ring serves as the face of a liquid piston operating within

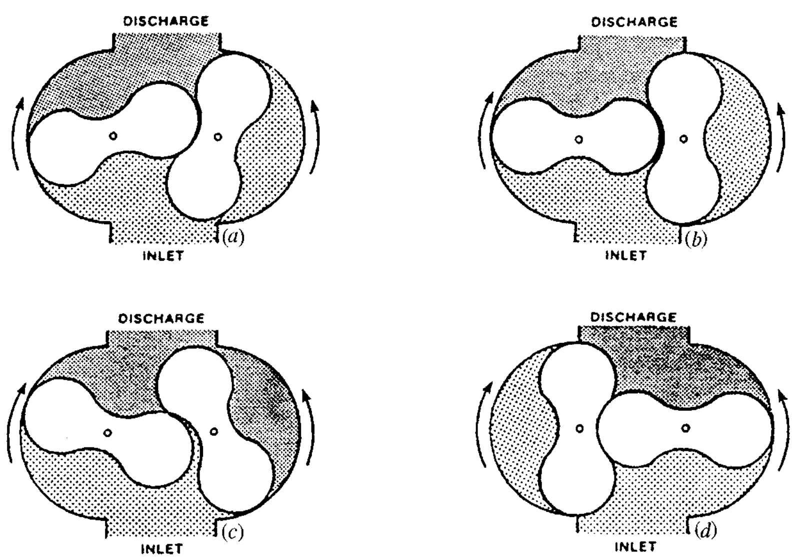


Fig. 61.9 Operating cycle of a straight-lobe rotary compressor (modified; courtesy of Ingersoll-Rand).[2]

each rotor chamber. At the inner diameter, these rotor chambers have openings that are sealed by, and revolve about, a stationary central plug or cone. This plug has permanently open ports that permit air to be taken into, and discharged from, the revolving rotor chambers.

As with the sliding-vane compressor, the single rotor is located eccentrically inside a cylinder or stator. The rotor has, extending from it, a series of vanes in a purely radial profile, or radial with forward-curved tips. Air inlet and outlet passages are located on the rotor. A liquid compressant partially fills the rotor and cylinder and orients itself in a ring-like manner as the rotor turns. Because of eccentricity, the ring moves in an oscillatory motion. The center of the ring connects with the inlet and outlet ports and forms an air pocket. As the rotor turns and the pocket moves away from the rotor, air enters through the inlet and fills the pocket. As the rotor turns, it carries the air pocket with it. Further turning takes the liquid ring from the maximum clearance area toward the minimum side. The liquid ring seals off the inlet port and traps the pocket of air. As the liquid ring is moved into the minimum clearance area, the pocket is compressed. When the ring uncovers the discharge port, the compressed pocket of air is discharged.

Efficiency of the liquid piston is about 50%, which is not very good compared to other rotary compressors. But because liquid is integral to the liquid piston compressor, taking in liquid with the air stream does not affect its operation as it would in other types of compressors. The liquid ring compressor is most often used in vacuum service, although it can also act as a positive pressure compressor. The compressor can be staged when the application requires more differential pressure than can be generated by a single stage. Liquid piston compressors can be used to compress air, in single-stage units of 35 psig and two-stage units of 125 psig. Vacuums of 26 in. Hg are possible. Flow capacity ranges from 2–16,000 cfm.

These compressors have only one solid moving part, the rotor. There is no metallic contact between the rotating and stationary elements. This design provides a continuous source of pressure without pulsation.

Delivered air is oil-free because the liquid ring is the piston and requires no lubrication. The liquid scrubs the air and removes solid particulates down to micron sizes. Many solids can pass through the compressor without doing damage. However, abrasive solids can shorten compressor life and should be removed with an inlet filter.

61.3 SIZING

Two conflicting factors influence the determination of total compressor capacity needed to supply a system: compressor efficiency and system demand. Constant-speed air compressors are most efficient when operated at full load or maximum capacity. The most efficient compressor is sized to handle the average load and would operate normally at full load. Undersized compressor capability results in reduced system-operating pressures. The inability to meet peak demands could result in decreased production and much greater overall plant operating cost.

Multiple compressors with sequential controls offer one solution to the dilemma of variable system demand by providing a better match of load and compressor capacity. Multiple compressors also permit compressor backup for maintenance and repairs. For example, three compressors, each with a capacity of 50% of peak load, is a configuration that offers these advantages. Disadvantages of multiple compressors are that full-load efficiency of smaller compressors is generally less than that of larger ones and that multiple units are more costly, per unit of capacity, to purchase and install.

If a new compressed-air system is being designed, system capacity is determined by analysis, where all known air users are identified and their expected consumption calculated. Air-consumption

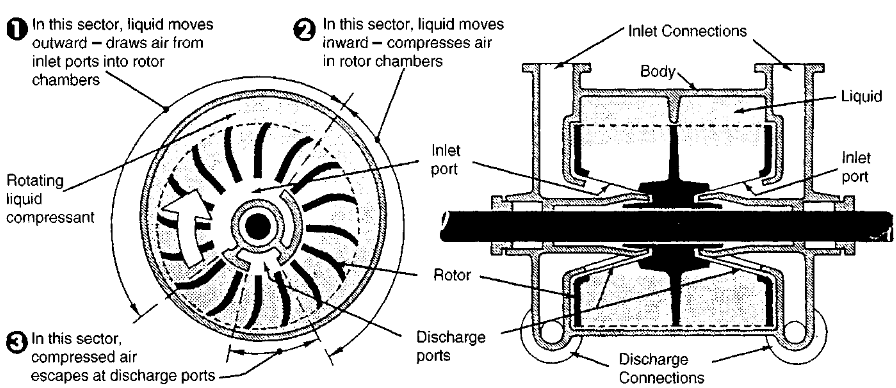


Fig. 61.10 A sectional and end view of a liquid ring compressor (courtesy of Nash Engineering Co.).[2]

rates of tools are available from manufacturers. A load factor is used to modify consumption by estimating the percentage of time that a pneumatic device is operating. Additional allowances must be made for leakage, typically no more than 10%, and for future plant growth.

The volumetric efficiency of a compressor is the ratio of the actual air delivered to total displacement. This efficiency is from 4–4.2 scfm/hp. The 4-scfm/hp figure can be used in calculations that will be sufficiently accurate for all practical applications.

It is normal practice to size water-cooled compressors 30% over system requirements and air-cooled compressors 40% over system requirements. These margins can be cut back if load estimates are based on specific plant experience rather than estimates.

If an existing system is being enlarged, load factors and required additional capacity are more easily and accurately measured and determined from operating experience. The proportion of the load handled adequately by the existing compressor system to that of the enlarged system can provide guidance for estimating additional capacity required. This is done by monitoring pressures at various locations throughout the plant during peak operating times.

61.4 SELECTION

The compressed air system is frequently a key utility in which reliability is absolutely essential. In turn, the air compressor is the heart of the compressed air system, and the proper compressor for the application is of paramount importance. Compressors vary widely in design or type, each with a fixed set of operating characteristics. It is the task of the air system designer to match the compressor type to system requirements.

Air compressor selection must take into account a wide variety of factors besides the type of machine. Topics that must be considered include

- Air requirements
- Driver
- Location
- Number of compressors
- Regulation
- Distribution
- Storage
- Piping
- Aftercoolers
- Separators
- Dryers
- Maintenance
- Noise limitations
- Subsoil or potential foundation problems
- Power rates or costs
- Hours per day of operation
- Percentage of time loaded
- First cost
- Lubricating oil costs
- Outdoor installation
- Attendance
- Resale value
- Installation time
- Ventilation
- Water availability and costs
- Depreciation

It is suggested that an individual assessment of the foregoing be taken as they are related to the user's needs.

61.5 COST OF AIR LEAKS

Leaks in valves and joints on a compressed-air system waste a considerable amount of air. A number of leaks that seem small in themselves may waste a tremendous volume of air. Table 61.1 shows the dollar-and-cents value of this wastage. For cost other than 10 cents per 100 cu ft, a ratio may be applied.

Table 61.1 Cost of Air Leaks

Size of Opening, in.	Cu Ft Air Wasted per Month at 100 psi, Based on an Orifice Coefficient of 0.65	Cost of Air Wasted per Month, Based on $0.10 per 1000 ft^3
3/8	6,671,890	$667.19
1/4	2,920,840	292.09
1/8	740,210	74.01
1/16	182,272	18.21
1/32	45,508	4.56

Often it is possible to determine the exact extent of air losses in a plant by finding what portion of the compressor capacity is required to keep pressure in the air lines when no equipment is being operated. Careful maintenance of air lines will more than pay for itself and may in some cases make unnecessary the replacement of the present compressor with one of larger capacity.

REFERENCES

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3. J. L. Foszcz, "A Guide to Air Compressors," Plant Engineering, 1995 (December, 1995).