
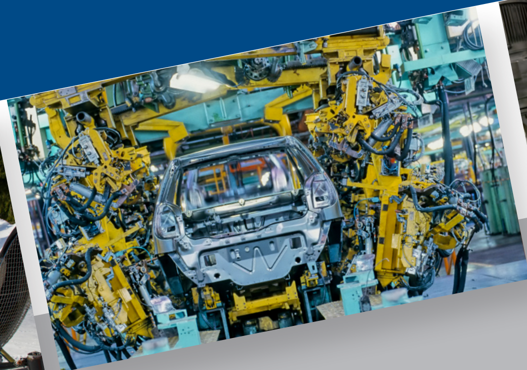


CAGI®
Compressed Air & Gas Institute

ROTARY AIR COMPRESSOR SELECTION GUIDE



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INTRODUCTION

Small, air-cooled reciprocating compressors, 3 hp to 30 hp, are ideal for intermittent service similar to those compressors commonly used in an auto body/tire repair operation. These types of compressors are covered in CAGI's Air Compressor Selection & Application ¼ through 30 HP guide accessible for free download on CAGI's website. Rotary compressors are appropriate for applications that require a continuous, though varying flow, of compressed air. The continuous demand for compressed air can be the result of one or several specific applications that require constant air usage. Examples of such applications are air motors, used for continuous chemical or paint mixing or agitation, or plastic blow molding machines that form gallon plastic milk jugs on a continuous basis. A continuous demand can also be the result of the aggregation of many, individual, randomly occurring intermittent applications. Most general manufacturing facilities have a combination of both demand profiles; continuous and intermittent. The continuous demand represents the base load of the facility, and the aggregated varying demand of the individual applications determine the variance in the flow.

Installing an intermittent-duty compressor into a continuous demand is a recipe for early equipment failure. Likewise, installing a continuous-duty compressor into an intermittent application, results in premature failure of the compressor due to rapid cycling as well as very inefficient operation. Successful compressor selection begins with an accurate analysis of the demand of the system. Knowing how to properly apply a rotary compressor to satisfy the known system demand is the subject of this Rotary Compressor Selection Guide.

This guide is a summary of the detailed information that is in the online version of the Compressed Air and Gas Handbook, Chapter 2. Refer to Chapter 2 for an in-depth explanation of any topic addressed within this guide.

The purpose of this Rotary Compressor Selection Guide is to help users understand the different positive displacement, rotary compressor technologies so that they can make informed decisions regarding the type of compressed air system they install, operate, and maintain. This guide focuses on rotary screw, sliding vane, and scroll compressors that are driven by electric motors, combustion engines, or PTO drives. Content for this Rotary Compressor Selection Guide has been provided by members of the Rotary Positive Compressor Section.

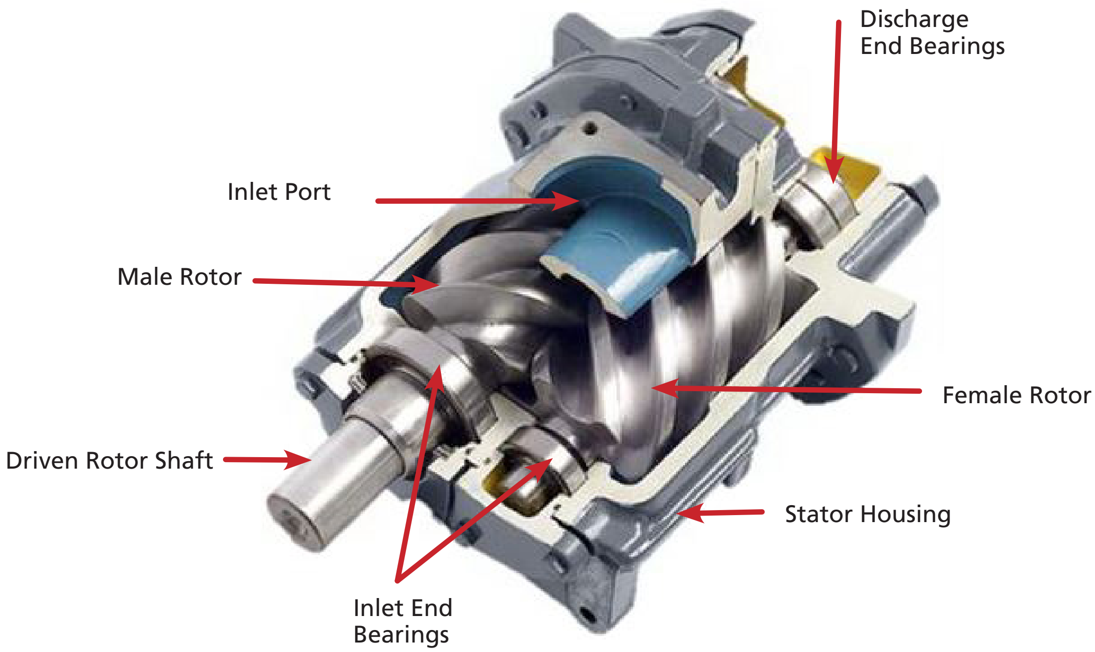
DETERMINING SYSTEM VARIABLES

Proper equipment selection and future system reliability, efficiency, and productivity begin with a thorough understanding of the three system variables that are critical to all compressed air systems: air demand, air pressure, and air quality. Equipment selections made on guesses or estimates regarding these variables may result in a system that is inefficient, unreliable, and costly to maintain. Chapter 4, Compressed Air System Design of the Compressed Air and Gas Handbook describes in detail how to gain knowledge of the three critical system design variables. The most valid and reliable method for gathering critical system information is to perform a thorough air system assessment on both the supply and demand sides of the system before beginning the equipment selection process. Short of performing the system assessment to accurately measure the variables on an existing system, or if the system is for a completely new installation, the user must calculate the demand of the system. This is accomplished by first calculating the maximum, continuous demand for each air operated device. Next, a use-factor is applied to each maximum demand. The use-factor is the percentage of time the device is in operation versus being off. The use-factor adjusted demands of all users are summed to arrive at the calculated demand of the operation. There are tables available in the Compressed Air and Gas Handbook to assist in performing the tedious calculations involved in accurately calculating system demand. Determining the required system air pressure and air quality requires a study of the pressure and air quality requirements of each component of the system and these steps are thoroughly reviewed in Chapter 4 of the Compressed Air and Gas Handbook. Accurate decisions regarding system component selection are possible only after accurate system air demand, air pressure, and air quality are determined.

OIL INJECTED ROTARY SCREW COMPRESSORS

The oil injected rotary screw compressor is a positive displacement type, which means that a given quantity of air or gas is trapped in a compression chamber and the space which it occupies is mechanically reduced, causing a corresponding rise in pressure prior to discharge. The compression element (airend or pump) consists of two intermeshing rotors in a stator housing having an inlet port at one end and a discharge port at the other. The male rotor has lobes formed helically along its length while the female rotor has corresponding helical grooves or flutes.

Air flowing in through the inlet port fills the spaces between the lobes on each rotor. Rotation then causes the air to be trapped between the lobes and the stator as the inter-lobe spaces pass beyond the inlet port. As rotation continues, a lobe on the male rotor rolls into a groove on the female rotor and the point of intermeshing moves progressively along the axial length of the rotors toward the discharge port. The space occupied by the air is reduced, resulting in increased pressure. Compression continues until the inter-lobe spaces are exposed to the discharge port when the compressed air is discharged. A typical rotary screw airend is shown below.



Oil Injected Rotary Screw Airend

Oil is injected into the compression chamber. This oil lubricates the intermeshing rotors and associated bearings, removes most of the heat caused by compression, and seals in the clearances between the meshing rotors and the stator housing.

A mixture of compressed air and injected oil leaves the airend and is passed to a sump/separator where the oil is removed from the compressed air, resulting in only a few parts per million of oil carry-over in the compressed air that is delivered into the system. Rotary screw compressors are supplied as complete packages containing all the components necessary to provide the full load capacity of the compressor at its rated pressure on a continuous basis. Air treatment equipment, filters, and dryers are used to treat the compressed air to specific air quality requirements.

Oil injected rotary screw compressor packages are available from 3 to 700 hp, with flows of 8 to 4,000 cfm, providing discharge pressures from 50 to 250 psig. Both single stage and two stage designs are available, with two stage designs beginning at 125 hp. Two stage versions can improve specific power up to 15% and some can achieve higher discharge pressures. Rotary screw vacuum pumps are available from 80 to 3,000 cfm delivering vacuum levels to 29.7 in Hg.

The oil injected rotary screw compressor has become the workhorse of modern manufacturing and industry globally. They are reliable and easy to install, operate, and maintain. In addition, enclosed models offer quiet operation. When properly applied, they provide excellent efficiency. The most common use of compressed air today is in manufacturing. Compressed air has two primary purposes in manufacturing: 1) a mode of force or, 2) an ingredient in a process.

The use of compressed air as a mode of force is known as pneumatics, and compressed air that is used to perform work in an industrial or manufacturing facility is often called "plant air." Plant air provides the power to operate the multitude of pneumatically powered devices operating within the facility. Although the usage of air within the facility is continuous, the actual demand varies according to the dynamics of the components operating within the system. Rotary compressors are designed to operate continuously to supply the total and varying demands for compressed air within the typical industrial installation. Whenever the demand for compressed air is continuous, either from one continuous user such as mixers or from the sum of several users combined, the rotary compressor is the technology of choice.

There are various methods of supply control that rotary compressors use to match their output to the actual demand of the system. This adjustment is known as capacity control and this feature is discussed later in this selection guide. Capacity control allows the rotary compressor to operate on a continuous basis, rather than an ON-OFF, intermittent basis as is the case with air cooled reciprocating compressors. Continuous operation is a key characteristic of a rotary screw compressor.

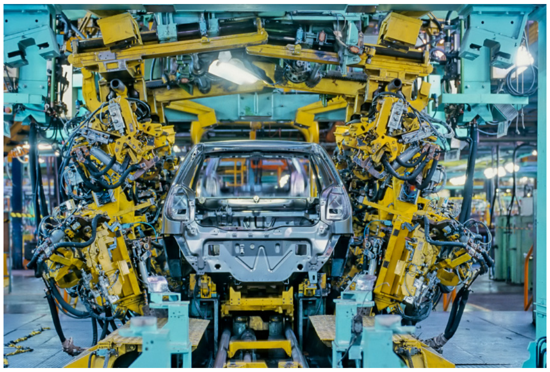
Below are some examples of plant air usage, where rotary screw compressors supply a continuous supply of clean compressed air at a stable pressure that is used as a power source.

- Powering pneumatic tools: impact wrenches, screwdrivers, grinders, drills. Used extensively in the automotive industry and general manufacturing.

- Powering pneumatic equipment: air operated diaphragm pumps to pump ketchup in a food processing plant, air motors to drive mixers in paint manufacturing facilities, operating pneumatic cylinders on robots that position work pieces accurately in an assembly operation.

- Dense-phase pneumatic conveying of bulk powders and granules: sand conveying in foundries, Portland cement conveying in a cement plant, conveying prills in a large fertilizer manufactory.

- Operating massive presses in the steel industry that forge red-hot metal into components for industry.



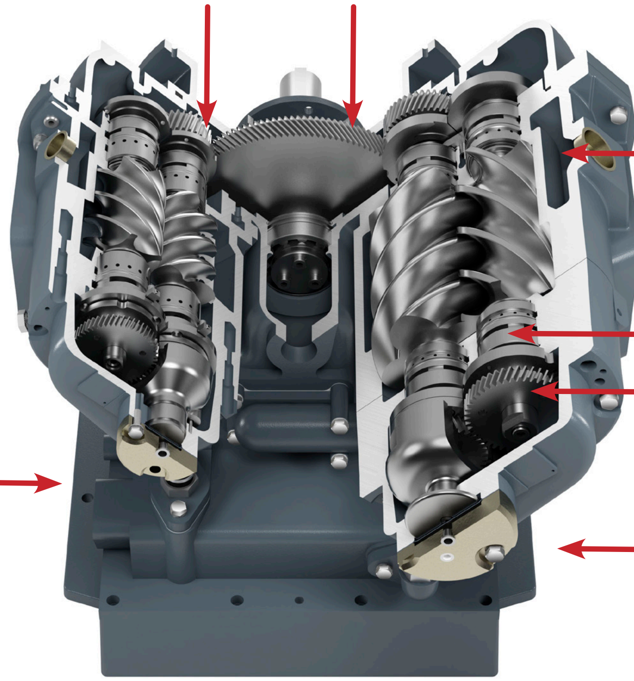
Compressed Air Powers Pneumatic Tools in Automotive Assembly Plants

The use of compressed air as an ingredient in a process is known as "process air". Below are some examples of process air usage, where rotary screw compressors supply a continuous supply of clean compressed air at a stable pressure that is used as a vital ingredient in a continuous process or reaction.

- Blanketing a flammable liquid with nitrogen that has been separated from a continuous supply of compressed air by a nitrogen-generating membrane.
- Increasing yeast production by introducing a continuous supply of compressed air into the fermentation process which provides the oxygen that the reaction requires.
- Compressed air atomizes water in the continuous snowmaking process.
- Compressed air is introduced into the continuous combustion process to improve the efficiency of the melt furnace in the glass container industry.

Compressed Air Atomizes Water in the Continuous Snowmaking Process

OIL FREE ROTARY SCREW COMPRESSORS



Oil Free, Two-Stage Rotary Screw Airend

The oil free rotary screw compressor is a positive displacement type of compressor. The principle of the compression is similar to the oil injected rotary screw compressor, but without oil being introduced into the compression chamber. Two distinct types are available: 1) dry type, and 2) water-injected type.

In the dry type, the intermeshing rotors are not allowed to touch, and their relative positions are maintained by means of lubricated timing gears located externally to the compression chamber. Since there is no injected fluid to remove the heat of compression, most designs use two stages of compression with an intercooler between the stages and an aftercooler after the second stage. The lack of a sealing fluid also requires higher airend rotating speeds than for the oil injected type.

Dry type oil free rotary screw compressors have a range from 20 to 1,000 hp or 80 to 5,000 acfm. Single stage units can operate up to 50 psig while two-stage units generally can achieve 150 psig.

In the water injected type, similar timing gear construction is used, but water is injected into the compression chamber to act as a seal in internal clearances and to remove the heat of compression. This allows pressures in the 100-150 psig range to be accomplished with only one stage. The injected water, together with condensed moisture from the atmosphere, is removed from the discharged compressed air by a conventional moisture separation device. The water system can be either closed loop or once through. Closed loop systems require water quality management to maintain adequate water purity. Once through systems have a significant effect on water usage and wastewater disposal costs.

Similar to the oil injected type, oil free rotary screw compressors are supplied as complete packages containing all of the components necessary to provide the full load capacity of the compressor at its rated pressure on a continuous basis. Air treatment equipment, such as filters and dryers, are used to treat the compressed air to specific air quality requirements.

An oil free rotary screw compressor provides all the benefits of an oil injected rotary screw compressor with the addition of providing discharge air that is the same quality as the air that is ingested into the compressor. An oil free compressor does not introduce contaminants into the compressed air as do oil injected rotary screw compressors. In any application where plant or process air contacts the finished product, care must be exercised to make certain that the compressed air does not impart contamination onto the finished product. Accordingly, oil free rotary screw compressors are used in applications where clean air is of primary importance to avoid product or process contamination caused by contaminated air. Such applications are found in the food, beverage, pharmaceutical, electronics, and medical/dental industries.

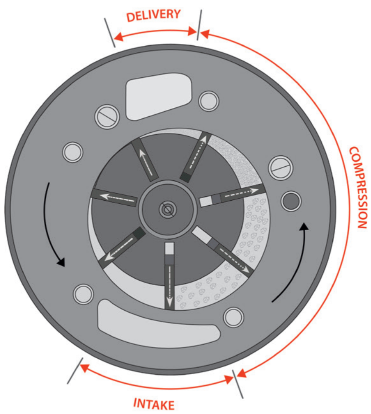
Compressed Air is Commonly Used in Dental Offices for a Contaminant-free Atmosphere

Clean Air is Critical in the Food & Beverage Industry

Although more expensive in initial cost than a comparable oil injected rotary screw compressor, the oil free compressor can provide system benefits due to the lack of oil contamination within the system. With oil free compressors, extensive filtration by coalescing filters may be reduced. Filtration may be required to remove any unwanted contamination that might be present in the inlet air or that is added to the airstream post-compression. Fewer filters reduce the pressure drop associated with such filtering. There are no oily condensate disposal issues; the performance of air treatment equipment is improved; and with proper maintenance, air quality remains constant over the life of the compressed air system. For these reasons, oil free solutions are being specified into once traditional oil injected applications. Decisions whether to select oil free or oil injected compressors need to be made based on a total cost of ownership (TCO) over the life of the system and the application.

OIL INJECTED ROTARY SLIDING VANE COMPRESSORS

The sliding vane compressor is a positive displacement compressor consisting of a circular stator in which is housed a cylindrical rotor, smaller than the stator bore and supported eccentrically in it. The rotor has radial slots in which vanes, or blades, slide. Rotation of the rotor exerts centrifugal force on the vanes, causing them to slide out to contact the bore of the stator, forming “cells” bounded by the rotor, adjacent vanes and the stator bore. Some designs have means of restraining the vanes so that a minimal clearance is maintained between the vanes and the stator bore.

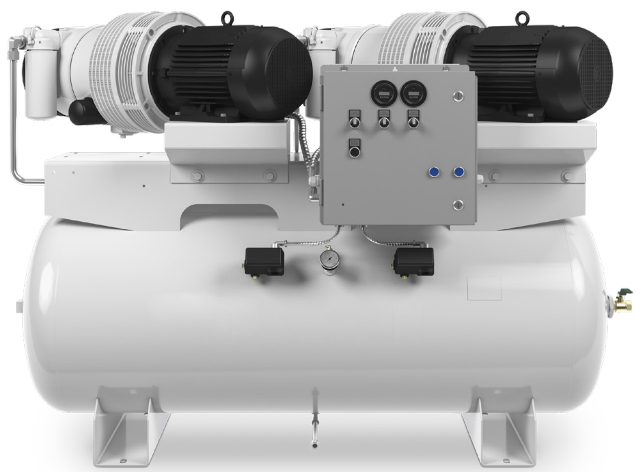


Operating Principal of Sliding Vane Rotary Compressor

An inlet port is positioned to allow air to flow into each cell exposed to the port, filling each cell by the time it reaches its maximum volume. After passing the inlet port, the size of the cell is reduced as rotation continues, as each vane is pushed back into its slot in the rotor. Compression continues until the discharge port is reached when the compressed air is discharged.

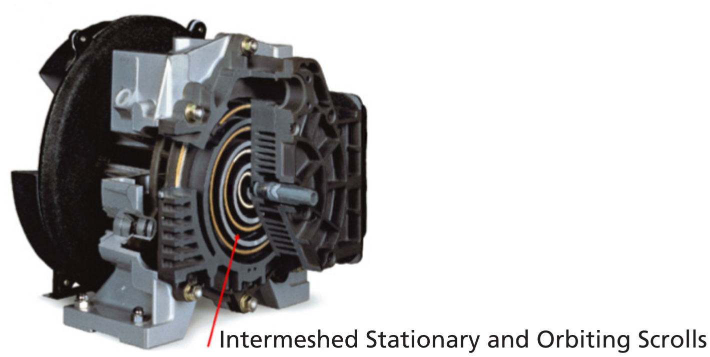
Similar to the oil injected rotary screw compressor, oil is injected into the compression chamber to act as a lubricant, as a seal, and to remove the heat of compression. Lubricated sliding vane compressors are available in either once-through or closed loop oil lubrication systems. Once-through systems meter lubricant into the compression process which is removed with downstream filtration and not reclaimed and recycled through the compressor. The once-through versions are typically deployed in extremely harsh and dirty environments such as cement processing and vapor recovery. The once-through lubrication system continuously and consistently coats the compressor internals with new lubricant to protect them from abrasive contaminants as well as sour, acidic, and wet gases. Industrial class sliding vane compressors and vacuum pumps utilize a closed loop oil lubrication and cooling system to reclaim, filter, cool, and reuse the oil, similar to a rotary screw compressor. Single and two stage versions of sliding vane compressors are available with either in-line or over-under arrangement of the stages.

The sliding vane compressor is normally packaged as a completely pre-engineered package in the range from 2 to 275 hp with capacities from 5.1 to 1,251 acfm and discharge pressures from 85 to 188 psig. Operating pressure for standard designed sliding vane compressors is limited to 150 psig. This type of compressor does see limited service in portable air compressors, but the majority of airends used in portable compressors are the rotary screw type. Sliding vane compressors can be used in any application where rotary screw compressors operate. Sliding vane compressors are normally less expensive to purchase than a similarly sized rotary screw compressor, and both technologies require similar routine maintenance. The vanes within the sliding vane compressor are wear items and require replacement if their wear becomes excessive due to poor lubrication or ingestion of particulate-contaminated air. The sliding vane design does see significant service as a vacuum pump for many industrial and medical applications requiring vacuum. For more information on this service see Chapter 6, “Blowers,” in the Compressed Air and Gas Handbook.



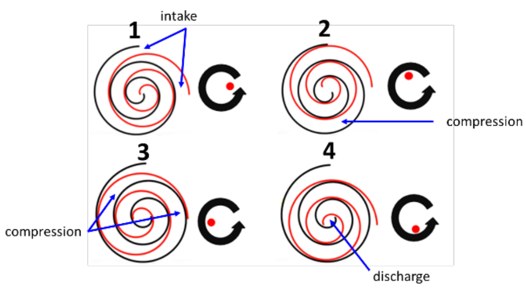
Tank Mounted Duplex Sliding Vane Compressor Package

ROTARY OIL FREE SCROLL COMPRESSORS



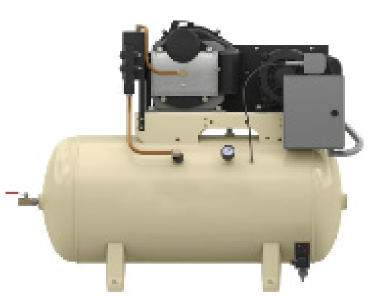
Oil Free Rotary Scroll Airend

Rotary oil free scroll compressors are a simple design that provide oil-free air, low noise, and low maintenance operation. Compression is accomplished by means of two intermeshing coils or scrolls, one scroll being fixed and the other orbiting in relation to the fixed scroll as shown in the illustration below. The fixed scroll is shown in black and the orbiting scroll in red. The four stages represent one complete orbit of the orbiting scroll. The bold circular flow diagram with the red dot shows the relative positions of the scrolls as the red scroll (red dot) orbits 360 degrees within the stationary black scroll (bold black circle). The red scroll does not rotate within the stationary scroll, but rather it orbits or oscillates within the stationary scroll. At #1, both intake ports are open, and they fill with atmospheric air. At #2, the red scroll has orbited 90 degrees counterclockwise and has sealed off a pocket of air, the volume of which is reduced as the red scroll completes another 90-degree, counterclockwise orbit, #3. Both pockets are now sealed. As orbiting continues, the volumes occupied by the air become progressively reduced and the pockets move progressively toward the discharge port in the center of the stationary scroll. At #4, a previously trapped pocket of air has been reduced in volume and pressurized and it discharges out of the scroll discharge port. Flow through the suction and discharge ports is continuous, providing pulsation free delivery of compressed air to the system. There is no metal-to-metal contact between the scrolls, eliminating the need for lubrication in the compression chamber, and ensuring oil free air delivery from the scroll compressor.



Scroll Compressor Operating Compression Principle

Scroll compressors are single stage, air-cooled compressors. Airends range from 2 hp to 10 hp with flows from 4 acfm to 25 acfm at a discharge pressure of 145 psig. Due to design limitations, the current maximum airend size is 10 hp. A Simplex compressor contains one scroll-motor unit. For larger capacities, multiple scroll-motor units are combined in a modular, Multiplex design. Simplex models are available from 2 to 10 hp, 4 to 25 acfm at 145 psig. Multiplex models are available from 10 to 60 hp, 25 to 130 acfm at 145 psig. Multiplex models can have as many as 8 scroll-motor units in one compressor package. Noise levels with a sound attenuating canopy are extremely low, in the range of 48 - 61 dBA at 1 meter.



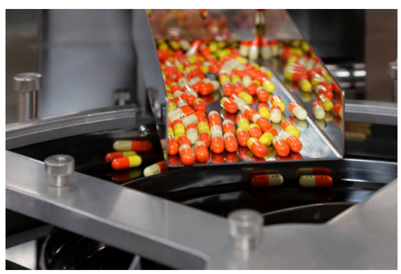
5 hp Simplex Compressor

30 hp Multiplex Compressor

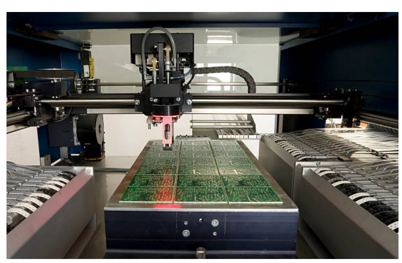
Scroll airends are intermittent duty compressors and they operate in the Stop/Start capacity control method. This means that the airend is always operating at full load capacity when it is operating. Continuous duty operation requires a minimum of two airends operating in a multiplex design and sharing the demand. Rotary scroll air compressors deliver approximately 3 acfm per rated hp @100 psig. Although this performance is less than the 4-5 acfm per hp supplied by rotary screw compressors, the multiplex design of scroll compressor packages assures that all airends always operate in their most-efficient, full-load capacity. To eliminate the inefficient condition where all of the individual pumps in a multiplex design start and then immediately turn off one by one in response to rapidly rising pressure, the multiplex compressor requires sufficient storage to eliminate this rapid cycling condition.

Scroll Compressor Applications

Because of their small footprint and low noise generation, scroll compressors are ideal for providing a supply of oil free compressed air to individual or dedicated applications within the medical and dental, pharmaceutical manufacturing, food and beverage, and electronics industries.



Compressed Air Used in the Pharmaceutical Industry



Scroll Compressors Supply Oil Free Air for the Electronics Industry

DRIVE ARRANGEMENTS FOR ROTARY COMPRESSORS

Electric Motor

The majority of rotary compressors use an electric motor as the source of power to drive the airend. The motors can be fixed-speed or they can be variable speed. The majority of smaller horsepower compressors are belt-driven with larger sizes utilizing gear drives or direct coupled drives.

Combustion Engine
Compressors that are designed to operate in remote regions without a source of power can be driven by combustion engines, gasoline, or diesel. Diesel engine-driven rotary screw portable compressors are common at construction sites, road-work sites, and as emergency backup compressors at industrial sites.

Power Take-Off (PTO)
Compressors can be mounted on a vehicle and use the power of the truck engine to drive the compressor. Using the transmission countershaft (usually 2nd or 3rd gear), power is transmitted from the engine to the compressor shaft, either directly or through a pulley and belt drive arrangement. The desired speed and torque can be obtained through the PTO gear box to drive the compressor. Rotary screw and sliding vane airends are most commonly used for PTO compressors. The most common application for PTO compressors is on utility and telephone company trucks to allow for operation in remote locations. Capacities range from 85 to 250 acfm and pressures from 75 to 110 psig.

Vehicle-mounted compressors may also be driven by an independent hydraulic motor which receives its power from a hydraulic pump driven by the truck PTO. Vehicle compressors can be mounted either above or below the truck "deck," depending on truck design and available space.

CAPACITY CONTROL FOR ROTARY DISPLACEMENT TYPE AIR COMPRESSORS

All rotary compressors contain positive displacement airends and the capacity of the compressor is determined by the displacement of the airend in cubic feet and its rotational speed as measured in revolutions per minute (rpm). Compressors are typically most efficient when providing their full-load capacity of compressed air into the system. Demand for compressed air in most industrial systems is very dynamic, changing constantly over time, and the demand for compressed air seldom matches the full-load output of the compressor.

Accordingly, compressors must have a method that allows the compressor to adjust its designed-in, full load capacity supply to the varying demand of the system. Capacity control is the term used to describe the method by which the compressor matches its output to the demand of the compressed air system in order to keep a stable system pressure.

The type of capacity control that a compressor utilizes is based on both the type and size of the air compressor, the application, and the number of compressors in the system. Many compressors can operate under several capacity control methods as selected from their onboard controllers. Typical capacity controls method for rotary air compressors are as follows:

Start/Stop Control. Stop/start control is the simplest form of control, in which the drive motor of the compressor is started and stopped in response to a pressure signal directly after the compressor discharge. When started and running, the compressor delivers its full rated capacity. When stopped, the compressor delivers zero compressed air into the system. System pressure varies between the start pressure and the stop pressure, which is controlled by a manually adjusted pressure switch. To prevent too frequent starting and stopping of the electric motor, an air receiver sized to limit excessive motor starts, is required. The number of motor starts per hour is defined by the motor manufacturer and varies based on motor size and other factors. Exceeding the recommended starts per hour degrades the life of the motor insulation due to the heat generated by the high inrush current consumed at each start. This motor limitation becomes more critical as motor hp and motor speed increase. Accordingly, Stop/Start control is normally limited to compressors in the 30 hp and under range. Its advantage is that power is used only while the compressor is running, but this efficiency is partially offset by having to compress to a higher receiver pressure to allow air to be drawn from the receiver while the compressor is stopped.

Load/Unload Control. In this type of control, the compressor runs constantly and the inlet valve on the air-end opens and closes in response to a pressure signal directly after the compressor discharge. When the inlet valve is open (compressor loaded), the compressor delivers its full rated capacity. When the inlet valve closes (compressor unloaded), the compressor delivers zero compressed air into the system. System pressure varies between the load pressure and the unload pressure, which are two, user-set pressure settings. Depending upon the controls utilized on the compressor, these pressure settings can be programmed into the onboard controller, or manually set on a pressure switch or pressure regulator. In most Load/Unload compressors, a blowdown valve is opened when the compressor unloads to reduce the internal pressure within the compressor. The lower internal pressure reduces energy requirements while the compressor is running in the unloaded condition. With both oil injected and oil free rotary compressors, a properly sized air receiver is required to limit compressor load cycles to a number that does not exceed the allowable motor starts per hour. Rapid cycling can cause lubricant foaming and excessive carryover in the case of oil injected compressors and with oil free compressors, rapid cycling negatively impacts airend life.

Inlet Valve Modulation Control. In this type of control, the compressor runs constantly and the inlet valve at the inlet of the airend throttles the amount of air allowed to enter the airend in response to a pressure signal directly after the compressor discharge. As pressure rises, indicating that supply is greater than demand, the inlet valve closes proportionally. As pressure drops, indicating that demand is greater than supply, the inlet valve opens proportionally. Throttling the inlet valve causes a pressure drop across it, reducing the inlet pressure at the compressor. Since the pressure at the compressor inlet is reduced while the discharge pressure is rising slightly, the compression ratio is increased which offsets some of the energy savings gained by reducing flow. Inlet valve modulation normally operates linearly between 100% rated capacity to about 40% of rated capacity. Below 40% of rated capacity, the discharge pressure will have reached full unload pressure and the compressor will be unloaded as previously described.

Variable Displacement Control. In this type of control, the compressor runs constantly, and a mechanical device varies the effective length of the rotors by allowing some air to bypass the rotors at the inlet, resulting in a proportional change in compressor displacement. The displacement-adjusting mechanical device can be a helical valve, or it can be a poppet /lift valve. This effective length change is in response to a pressure signal directly after the compressor discharge. Rising discharge pressure causes the variable displacement control mechanism to reduce the effective length of the rotors and compressor capacity. Decreasing discharge pressure causes the variable displacement control mechanism to increase the effective length of the rotors and increase capacity. The inlet pressure and compression ratio remain constant, so part load power requirements are less than those obtained with inlet valve modulation for a similar capacity reduction. Variable displacement control normally operates linearly between 100% rated capacity to about 40-50% of rated capacity, below which the compressor may operate in inlet modulation or load/unload operation as previously described.

Variable Speed Control. In this type of control, the compressor runs constantly, and the capacity of the compressor is controlled by varying the speed of the airend by varying the speed of the drive motor. Since rotary compressors use positive displacement airends, the capacity of the compressor is directly proportional to the speed of the airend. Airend speed adjustment is in response to a pressure signal directly after the compressor discharge. Variable speed control normally operates linearly between 100% rated capacity to about 30% of rated capacity. At reduced capacities, especially at capacities below 95%, the part-load efficiency of the variable speed compressor is greater than efficiencies obtainable with other capacity control methods for similar capacity reductions. The efficiency of a variable speed compressor degrades as air-end speed approaches its minimum allowable speed. To prevent inefficient low-speed operation and possible overheating issues, the compressor may stop or unload when system demand is below the minimum speed and capacity of the variable speed compressor. Minimum air-end speed varies by manufacturer.

Capacity Control Variations. Several other terms are often used when describing variations to the above outlined capacity control methods. Constant Speed or Continuous Run refer to a compressor in which the main motor is constantly running and the airend cycles between loaded and unloaded conditions depending upon the mode of capacity control used. Dual Control is a term used to describe a rotary air compressor with a selector switch to enable selection of either Start/Stop, Modulation, or Load/Unload capacity control. This selection can be manual or automatic. This arrangement is suitable for locations where different shifts have substantially different compressed air requirements. Automatic Dual or Auto Dual Control refers to any capacity control method that limits the inefficient, unloaded operation of the compressor by stopping the main motor in response to a timer. The compressor will re-start automatically when system pressure falls to the predetermined load setting.

Master Controllers. Master control systems can be used to control multiple compressors in a system, with multiple capacity control methods, by starting, stopping, loading, and unloading them in a sequence that assures maximum efficiency within a tight pressure band. Master controllers may also monitor operating hours, maintenance schedules, alerts, warnings, shutdowns, temperatures, and many other operating parameters. Some master controllers can be programmed to send text or e-mail alerts should a problem occur. These controllers can record power, flow, and pressure, and can generate reports on the efficiency of the system and of individual compressors in the system. Additionally, most controllers can be monitored remotely and can be set up to communicate with a user's building automation system.

VSD AND FIXED SPEED

Variable frequency drive or variable speed drive compressors (VFD, VSD) have become extremely popular since their introduction in 2001. They provide the most efficient part-load operation of any rotary compressor, their sophisticated electronic controls have become more reliable, and all major air compressor manufacturers offer VSD technology. Although being very popular, VSD compressors are not a cure-all and they do have several characteristics that must be considered before installing a VSD compressor into a system. These characteristics are as follows:

- Operating environment and power supply
- Full load inefficiency
- Control gap

VSD electronics are very sensitive to heat, moisture, contaminants, and "dirty" supply power. Care must be exercised when installing a VSD so that the electronics are protected from harmful environments. The general rule-of-thumb for VSD installation is not to place a VSD compressor in an environment where you would not place a laptop computer. Power spikes, transients, and frequent brownouts are situations that will cause a VSD compressor to fault out or even fail. Power spikes and transients are often caused by other equipment attached to the same power supply as is the VSD compressor. Arc welders are especially troublesome at creating "dirty" power within the supply. Frequent lightning strikes can also create power spikes that will harm VSD compressors. It is wise to perform a thorough power analysis of the supply power before installing a VSD compressor.

VSD controlled air compressors provide significant benefits to end-users when properly applied. Due to the electrical losses that result from the VSD electronics, VSD compressors utilize 3-5% more power to deliver the same **full load** capacity than does a similar-sized, fixed speed compressor. Accordingly, a VSD compressor should not be used as a full load compressor. VSD controlled compressors are typically limited to a minimum capacity that is 30% of the full load capacity. At capacities lower than their minimum capacity, VSD controlled compressors lose efficiency. Accordingly, the VSD compressor should be designed to perform strictly as a trim compressor within its turndown range.

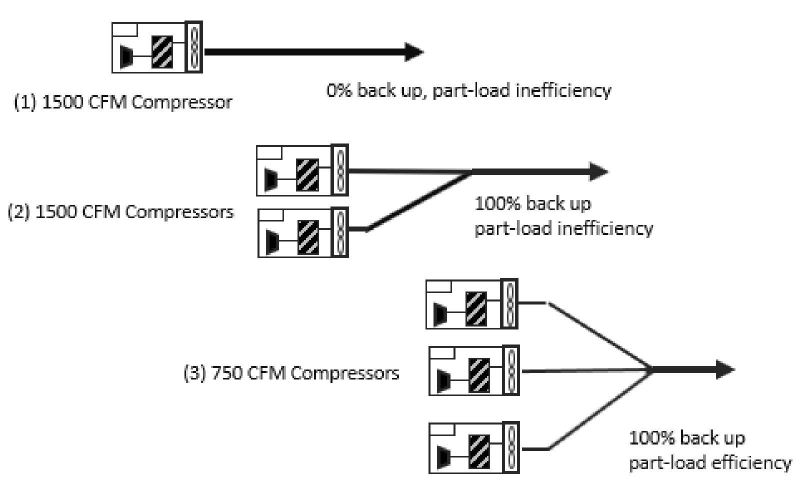
When properly applied in a system as a trim compressor, working in conjunction with a fixed speed, base-load compressor, or compressors, the VSD compressor performs efficiently, provided it is sized properly to avoid an inefficient control gap. A control gap exists whenever the demand of the system forces the VSD compressor to operate below its minimum turndown speed. This results in the VSD compressor rapid cycling, stopping and starting or unloading; all of which are inefficient and possibly damaging to the equipment. To avoid control gaps in a system operating both VSD and fixed speed compressors, the operating range in cfm of the VSD compressor must be larger than the cfm capacity of the largest fixed speed compressor in the system. The control gap formula is as follows: the full-load cfm of the VSD compressor minus the full-load cfm of the largest fixed speed compressor must be equal to or greater than the minimum turndown cfm of the VSD compressor. For example, the following two compressors are installed:

100 hp, 125 psig fixed speed rotary: 450 cfm full load delivery
100 hp, VSD rotary: 140 cfm minimum speed delivery – 450 cfm maximum speed delivery

In the situation where both compressors are required to operate to satisfy the system demand, there will be a control gap of 139 cfm, between 451 cfm and 590 cfm. Whenever system demand falls within the control gap range, one or both compressors will operate inefficiently. The fixed speed compressor will rapid-cycle or the VSD compressor will unload or stop/start excessively; or both will occur simultaneously. Control gap operation is a frequent occurrence in systems that operate both VSD and fixed speed compressors. Control gap can be avoided by understanding the system demand profile and sizing the compressors accordingly.

NUMBER AND TYPE OF COMPRESSORS

Once the system demand profile has been established and the type of compressor technology selected, the question becomes one of how many compressors to apply.



One of the most important aspects when designing or upgrading any compressed air system is to consider the cost of lost production should the supply of compressed air fail. In engineering, redundancy is the duplication of critical components or functions of a system with the intention of increasing reliability of the system, usually in the form of a backup or fail-safe. In many installations, the cost of installing redundancy to the system, including both compressors and air treatment equipment, is far outweighed by the cost of lost production.

Consider this example utilizing fixed speed compressors: Plant air demand varies from 500 cfm to 1500 cfm throughout the day during three, 8-hour shifts of operation. In a single, 1500 cfm compressor installation, should it fail, there would be no compressed air and no production. Also, with this one-compressor installation, the 500-cfm demand would lightly load the compressor, and depending upon its capacity control method, this could be very inefficient operation. With two, 1500 cfm compressors there is 100% redundancy, but the part-load inefficiency still exists. With three, like-sized compressors, each sized at 50% of the maximum 1500 cfm demand, there is 100% redundancy in the event of any one compressor failing. This arrangement also provides part-load efficiency since running the 750-cfm compressor to handle the 500-cfm demand is more efficient than supplying the 500-cfm demand from a 1500 cfm compressor.

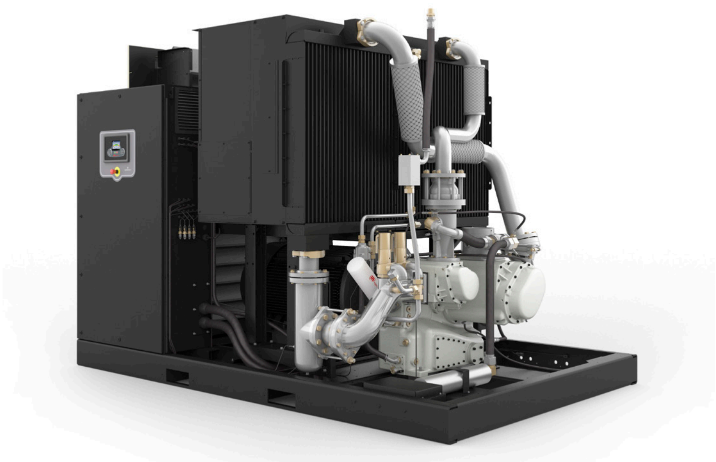
In the above example, if two VSD compressors are utilized, each with a capacity of 435 cfm to 1800 cfm (350 hp oil injected rotary screw compressors), then both redundancy and efficiency can be obtained by installing just two, 350 hp VSD compressors. However, since the cost of VSD technology significantly increases the purchase price of the compressor, analysis must be done to determine which mix of technology best fits the application.

With any of the above options, it is always a best practice to have a rental compressor port installed into the supply side of the system to facilitate a quick installation of a rental compressor should the need arise, which it will. Many rental compressors are diesel driven and do not provide the air quality that most compressed air installations require. Care must be taken to select and size air treatment equipment to be able to accommodate the added heat, moisture, and contamination load that rental compressors often deliver. Maintenance needs also must be taken into consideration and multiple identical air compressors can minimize replacement parts inventory considerations.

This same redundancy logic should be applied to the air treatment equipment (filtration and air dryers).

AIR COOLED AND WATER COOLED

Another decision to make when selecting a rotary compressor is whether to install an air-cooled compressor or a water-cooled compressor. The compression process creates heat and there must be a way to remove this heat of compression from both the lubricant and the discharge, process air. Rotary compressors have heat exchangers, commonly referred to as coolers, that are used to perform the heat removal process. The cooling medium can be either ambient air or water. Provided that the ambient air is relatively contaminant-free and has a temperature below the manufacturer's recommended maximum ambient temperature, standard-duty air cooled compressors can be expected to perform well and are commonly used in such applications.



Air-Cooled Compressor (Enclosure Removed)

If the ambient air is dusty, dirty, or contaminated with harsh chemicals, air-cooled heat exchangers might present a reliability issue due to blinding or corrosion. Similarly, if ambient temperatures exceed the manufacturer's recommended maximum ambient temperature, standard design, air-cooled compressors may experience high temperature shutdowns and reduced lubricant life. Below are some examples of conditions that might pose reliability issues for rotary compressors with air cooled coolers.

Dirty environments that will blind coolers:

- Commercial laundry with high lint concentration
- Rubber compounding plant with high carbon black concentration
- Cement plant with high Portland cement concentration

High temperature environments:

- Small, poorly ventilated compressor room in the center of the facility
- Compressors placed in boiler rooms
- Outdoor sheds in direct sunlight

Corrosive environments:

- Outdoor, seacoast exposed
- Chemical plants

When the operating environment presents reliability issues for air cooled compressors, water cooled compressors provide a reliable solution. A thorough analysis of the operating environment of the compressor should be undertaken before deciding on the compressed air equipment, both compressors and dryers.

Water Cooled Rotary Screw Compressor

Dry, oil free rotary compressors are commonly provided with water cooled coolers due to the high heat of compression created in these oil free designs. Although some oil free, dry rotary compressors are offered in air cooled designs, care must be taken to assure that the operating environment does not compromise operating reliability of the compressor or air treatment equipment. Consult the equipment manufacturer with accurate operational data for the proper cooling recommendation.

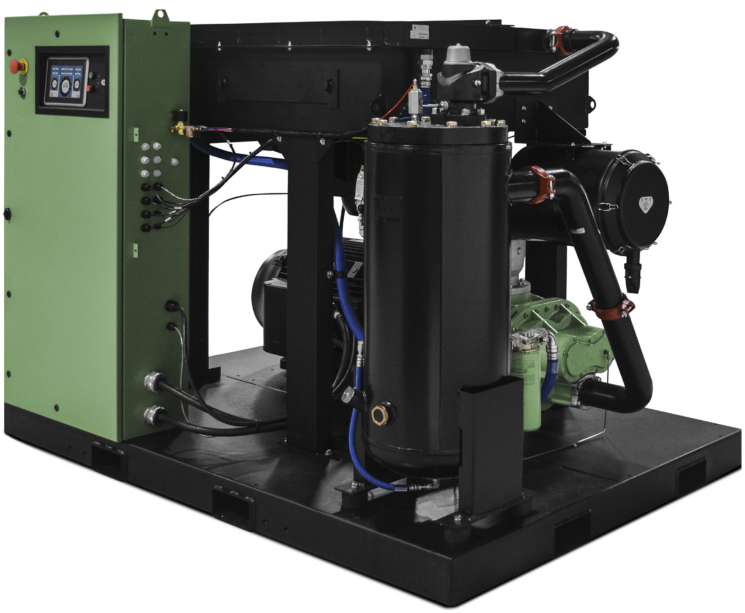
Water injected oil free compressors can be offered in both air cooled and water cooled designs.

ENCLOSED AND UNENCLOSED

Most rotary compressors are provided with a complete enclosure cabinet. The enclosure performs the following functions:

- Reduces noise
- For air cooled compressors, it channels the cooling air to achieve maximum cooling. The hot air can easily be ducted for HVAC heating.
- Protects from rotating or hot components
- Protects from outdoors weather and contamination

Enclosed Air Compressor



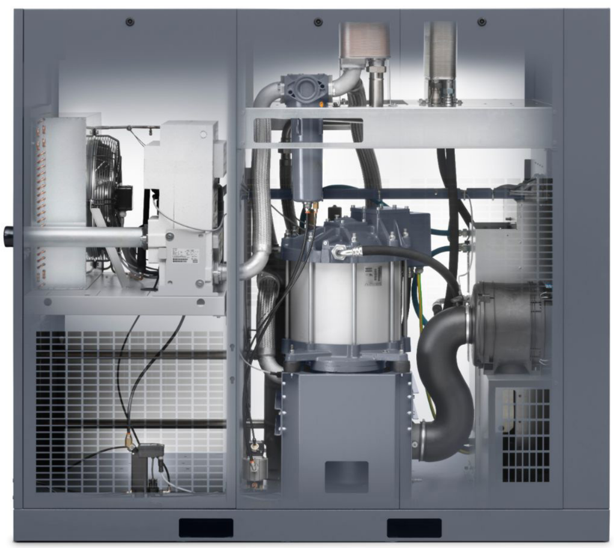
Unenclosed Air Compressor

Some manufacturers provide both enclosed and unenclosed designs for their compressors. Unenclosed compressors provide easier access for routine maintenance and allow operators to visually inspect the compressor (primarily for leaks) without removing enclosure panels.

Enclosures are an added expense and if the above considerations are not germane to the application, an unenclosed design can be an effective, less-costly choice.

INTEGRATED DRYER AND STANDALONE DRYER

Integrated compressor packages, ones that contain both the compressor and a refrigerated dryer in one enclosure, have become common. They offer reduced floorspace versus a compressor and its standalone dryer, and many integrated packages offer single-point electrical hook up. Care must be taken to ensure that the dryer is properly sized to the actual, worst-case operating conditions of the compressor, maximum flow, maximum discharge air temperature, and minimum discharge pressure. If the operating conditions of the integrated dryer do not deliver the required air quality dryness, then the standalone dryer is the preferred option.



Ghost View of Water-Cooled Air Compressor with Integrated Dryer

SELECTING THE PROPER ROTARY COMPRESSOR

Rotary positive displacement compressors, especially rotary screw compressors, have become the workhorses of modern industry. As described in this Rotary Air Compressor Selection Guide, there are three different rotary compressor technologies to select from when choosing your air compressor: (1) rotary screw, both lubricated and oil free, (2) lubricated sliding vane, and (3) oil free scroll. The process of selecting the most reliable, efficient, and productive rotary compressor begins with a thorough understanding of the three fundamental parameters of all compressed air systems: air flow, air pressure, and air quality. Once these parameters are determined, the selection process can weigh the benefits of each rotary compressor technology as they pertain to achieving the goal of supplying a reliable source of clean, dry compressed air at a constant pressure.

As outlined in the selection guide, each rotary technology provides unique characteristics that should be weighed against the specific conditions of the application in order to make the right compressor selection. Realizing that the air compressor is only one part of an efficient compressed air system, the system designer needs to be aware that the other components of the system are as equally important to the overall effectiveness and efficiency of the system as is the compressor.

Care must be taken to consider the ambient conditions, the air treatment equipment, the storage within the system, the piping-distribution network, and the capacity control method of the compressor(s). Guessing at any of these critical stages can result in an unreliable, inefficient, and costly-to-maintain system.

For a greater understanding of compressed air systems, please see the online Compressed Air and Gas Handbook on the CAGI website (www.cagi.org). Chapter 2 covers compressed air production; Chapter 3 covers air treatment and Chapter 4 covers air system design.