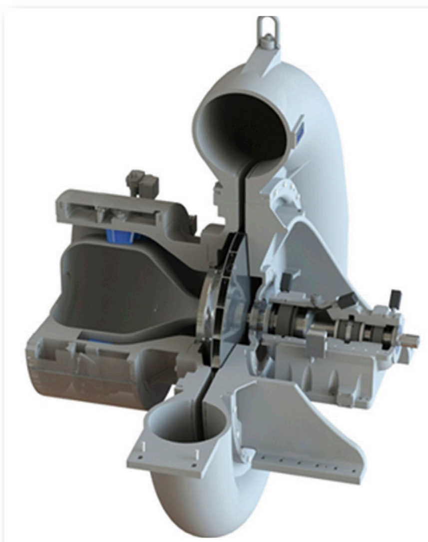
Blowers

Chapter 6



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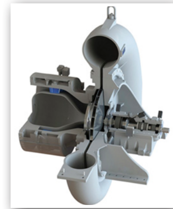
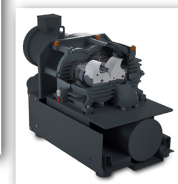
Chapter 6



Blowers

Introduction

This chapter covers industrial blowers or low-pressure air compressors. Most commonly known as blowers, these devices deliver oil free air at pressures below the normal operational limits of air compressors and above the normal operational limits of fans. The defined pressure capacity of a blower is the ability to develop a process system pressure of up to 30 psig. Blower technologies fall into two categories: positive displacement and dynamic. Positive displacement blowers trap fixed volumes of air from the inlet port and convey these volumes to the outlet port, where they are discharged into the process or system. Increased pressure is achieved as the air flow encounters resistance from the system or process. Dynamic blowers work by adding kinetic energy to the air molecules and then converting the kinetic energy into static energy (pressure). The blower technologies discussed in this chapter are outlined below in Figure 6.1.

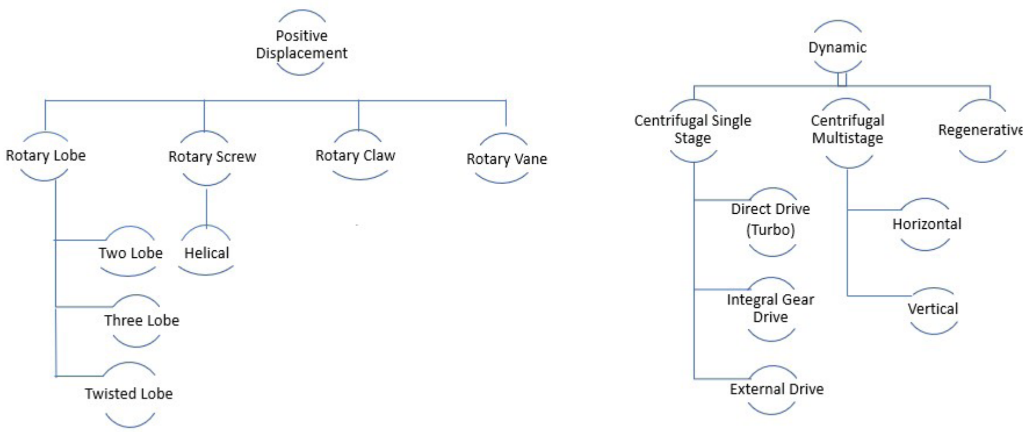


Figure 6.1: Blower technologies

Positive Displacement

Positive Displacement (PD) blowers can be further described by the specific impeller technology used to generate the required air flow at the required pressure. These technologies include rotary lobe, rotary screw, rotary claw, and rotary vane.

Operating Principle

All rotary blowers operate by mechanically ingesting atmospheric air at an inlet port, trapping the air in a sealed cavity, and finally discharging the trapped volume of air into the system or process at the discharge port of the blower. The major difference among the various types of PD blowers is the manner in which the blower moves air through the machine. In the case of rotary lobe, rotary screw, and rotary claw types, the cavities are created by the action of two intermeshing rotors as they rotate in opposite directions within a cylinder. Figure 6.2 describes the operation of a rotary lobe blower. The symmetric rotors, or impellers, are attached to two parallel rotating shafts. Only one rotor is driven, and this rotor drives the second rotor through a set of timing gears. The timing gears also keep the rotors from making contact with each other. Bearings support the shafts and position the rotors so that they do not contact the inner walls of the cylinder within which they rotate. The suction and discharge ports are located on the cylinder and are positioned in line with each other along the center line of the blower.

Focus on the top impeller in Figure 6.2 to understand how air flows through a rotary lobe PD blower. The top rotor rotates clockwise, and the bottom rotor rotates counterclockwise. Position 1: As the impeller passes the suction port (inlet port), a fixed volume of air of is drawn into the blower, filling the void that is created between the impeller and the cylinder. Position 2: As the tips of the impeller seal this pocket of air from the inlet and outlet ports, the pocket remains at the inlet pressure. No compression or volume reduction has taken place. Position 3: As the impeller rotates, the pocket is directed around the outside of the rotor between the impeller and the cylinder. As the impeller opens to the outlet port, a pressure equalization briefly occurs as system pressure fills this pocket. Position 4: The impeller continues to rotate and pushes this accumulation of air molecules into the discharge port. Each rotation of the drive shaft moves four equal volume pockets of air from the inlet port to the discharge port — two pockets for each of the two impellers. The blower achieves compression as these pockets of air are forced against the prevailing discharge pressure of the system.

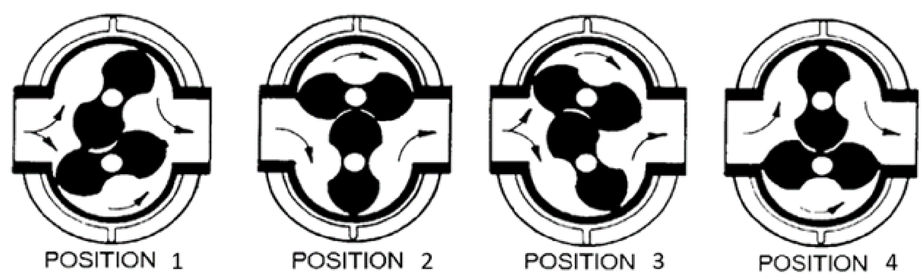


Figure 6.2: Rotary lobe air path

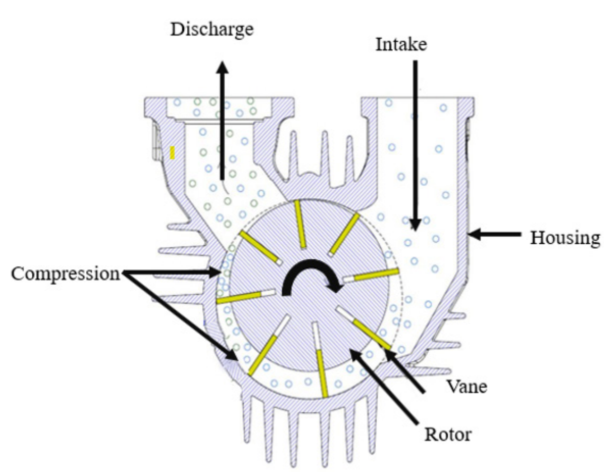
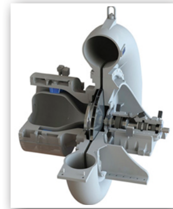
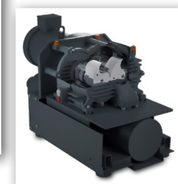


Figure 6.3: Rotary vane air path

In the case of rotary vane PD blowers, the solid cylindrical rotor is placed eccentrically in the cylinder. The rotor has radial slots with vanes (also called blades). Figure 6.3 illustrates the air path through the blower as well as the orientation of the rotor and the cylinder. As the rotor turns, centrifugal forces push the vanes out of their slots,



creating volumetric cells bounded by the rotor, adjacent vanes, and the cylinder. As each cell passes the inlet, a specific volume of air is trapped. Due to the eccentric positioning of the rotor/cylinder, these cells reduce in volume as the machine rotates. As rotation continues, the pressurized volumetric cells are exposed to the discharge port and the compressed air is delivered to the system or process.

Positive Displacement Blower Characteristics

PD blowers provide a relatively constant inlet volume under variable discharge pressure conditions. The blower "pump" is a completely enclosed design composed of one or more impellers surrounded by a machined housing. There are no internal valves, reducing maintenance and replacement costs. The completely enclosed construction achieves compactness, provides protection against the elements, and makes the unit suitable for either indoor or outdoor installations. PD blowers incorporate many design features that contribute to job versatility and economical installation.

Power consumption, measured in horsepower, is nearly proportional to pressure differential and rpm in a direct relationship. At a given pressure differential, the horsepower is directly proportional to shaft speed (rpm). At a constant rpm, horsepower is directly proportional to pressure differential. Thus, torque varies directly with pressure differential. The unit is defined as a "constant torque" machine for purposes of determining the necessary characteristics for drivers, especially variable-speed motors. Drivers can be sized accurately to the pressure or vacuum requirements.

Gasses Handled

While most applications of PD blowers involve handling air, the machine is also capable of handling any number of gases, including hydrogen, steam, natural gas, ethylene, and nitrogen. Blowers for pressure service deliver oil free gas into the system or process since there is no lubricant injected into the compression chamber. Most PD blowers that operate in vacuum service are also oil free, except in the case of some rotary vane blowers, where lubricant is injected into the compression chamber to reduce friction while sealing the internal clearances required for achieving deep vacuum levels.

Pressure and Vacuum Service

PD blowers can be used in both pressure service and vacuum service. An example of pressure service would be wastewater aeration, where the blower delivers air to the wastewater during the secondary treatment process in order to introduce oxygen into the water and thus enhance microbial digestion of the organic material in the wastewater. The blower pressurizes the air within the system delivery by piping to a level that overcomes the static head pressure of the weight of the water atop the blower discharge outlet pipe. An example of vacuum service would be negative-pressure pneumatic unloading of plastic pellets from a bulk tanker into a storage silo. The blower inlet is piped to the receiving silo, and a line is connected from the silo to the bulk tanker. The blower exhausts air from the silo, creating a negative pressure within the silo (vacuum); this pressure differential allows the pellets to flow from the higher-pressure tanker into the lower-pressure silo.

Performance Range

Rotary PD blowers provide flow ranges from 20 cfm to over 26,000 cfm with maximum compression ratios limited by the technology. Rotary lobe blowers, for example, are limited to a compression ratio of about 2:1. Compression ratio is defined as absolute discharge pressure divided by absolute inlet pressure. At sea level, a 2:1 compression ratio will develop pressures up to 15 psig and vacuums up to 15" Hg. Blowers at elevation will see lower pressure levels while maintaining the 2:1 compression ratio limit. A blower can also be subjected to negative pressure on the suction side and positive pressure on the discharge at the same time (again limited by the compression ratio). Exceeding the compression ratio limit of a blower can result in shaft deflections and/or excessive operating temperatures. Higher compression ratios are attainable with specialized designs, cooling, or by operating blowers in series.

Isochoric Versus Adiabatic Compression

In all PD blower systems, system pressure occurs via isochoric compression, meaning that compression takes place downstream of the discharge port of the PD blower (i.e., external compression). System pressure is increased as the flow of air supplied by the blower encounters system resistance. Accordingly, all rotary blowers operate at the pressure required to overcome the resistance within the system to accomplish the intended work. Should this resistance vary, the blower pressure will adjust automatically as long as limits of the blower are not exceeded.

Rotary lobe blowers are 100% isochoric machines, since there is no internal compression ratio occurring within the rotary lobe blower. Some rotary PD blowers are both adiabatic and isochoric machines. Rotary screw, rotary vane, and rotary claw blowers are adiabatic devices in that some compression takes place internally between the inlet and discharge ports — these devices do have an internal compression ratio. Once the pressurized air exhausts from the adiabatic blower, additional system pressure is attained as the flow of air supplied by the blower encounters system resistance (isochoric compression). Final system pressure is developed by a combination of adiabatic and isochoric methods.

Blower Capacity/Performance

The displacement, or swept volume, of a blower is the theoretical volume that the unit will transport from inlet to discharge in one revolution of the drive shaft. The term is expressed as cubic foot per revolution (cfr). Figure 6.4 shows the area “A” which, when multiplied by the impeller length, represents the volume of each of the four “pockets” created in a two-lobe PD blower as the machine makes one complete shaft rotation. Therefore, this volume times four is the displacement or cfr. The key factors affecting cfr are rotor length and rotor profile. Note that the cfr multiplied by shaft speed (rpm) equals the gross displacement of the machine in cubic feet per minute. All blowers have internal leakage losses due to slip and losses through seal vents, so the actual net delivery of air into the system will be less than the gross displacement. Slip will be discussed later in the chapter.

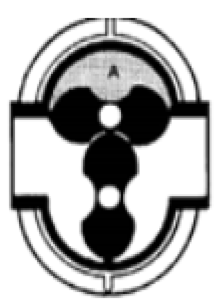
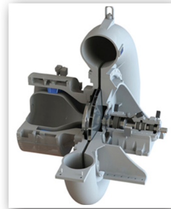
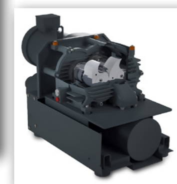


Figure 6.4: Blower displacement





The limits of a blower can be found in a blower performance curve. These curves will provide plots of flow, power, and temperature rise against blower speed, outlining the performance envelope of the blower. Note that the curves are often published at standard conditions. For project-specific conditions, correction factors will need to be applied to these values or project specific data should be acquired from the blower manufacturer.

PD Blower Limitations — Lobe, Screw, and Claw Machines

Slip and Temperature Rise

As the rotors move air from the inlet port of the blower to the discharge port, the air is maintained within the blower by way of tight clearances between the rotors and the cylinder walls. The timing gears and bearings position the rotors to prevent rotor-to-rotor or rotor-to-cylinder contact. The tightness of these clearances is critical to the operational efficiency of the blower. The larger the clearances, the greater the amount of air that passes through the blower from the higher-pressure discharge port to the lower-pressure inlet port. This passage of air is known as slip. The amount of slip is a function of the internal clearances of the blower and the differential pressure. Slip varies directly with both clearance size and discharge pressure. Minimizing the slip of the blower improves efficiency by increasing the blower delivery rate. Minimizing slip also increases reliability by reducing the operating temperature of the blower. Since the air chamber is oil free, all internal cooling of the blower occurs by the passage of air through it. The more air that is recycled in the form of slip, the higher the operating temperature of the blower.

Temperature rise is defined as the differential between outlet and inlet temperatures. Too much temperature rise can cause thermal expansion of the metal rotors until the internal clearances are lost and the rotors contact themselves, the housing, or both. Such contact is often catastrophic to the blower. Higher temperatures also impact the lubricant that is required for bearings and gears within the blower housing. High operating temperature shortens the service life of the lubricant, which can cause premature gear and bearing failure. High discharge air temperature can also negatively affect the process into which the blower is delivering air. Because it can be significant, blower temperature rise should be considered during both the process design phase and the blower selection process.

Noise

A negative aspect of all PD blowers is the noise generated by pulsations created as the blower operates. The pulsations are a result of the pressure equalization event described as the lobes go from position 3 to position 4, as illustrated in Figure 6.2. The back filling or pressure equalization rate, often referred to as a pulse, is proportional to blower speed. This pressure pulse occurs each time a trapped pocket opens to the discharge port, i.e., four or six times per revolution for a two-lobe machine. These pulsations cause vibration and noise, and their magnitude is directly proportional to the pressure differential across the blower. Therefore, as the pressure differential increases, noise and vibration also increase. These vibrations and noise levels are reasonable when the blower is operated within its limits, but excessive values can be destructive. Several methods to eliminate the creation and intensity of the pulsations or to silence them post-creation will be discussed later in the chapter.

Contamination

As previously described, all PD blowers operate with extremely close clearances between impellers and between the impellers and the cylinder wall. Contamination from the inlet air can accumulate within the compression chamber of the blower. Contamination that sticks to the impellers can cause them to go out of balance, which causes an increase in destructive vibration within the blower. Similarly, contamination that reduces the operating clearances between the rotating and stationary components within the blower can cause the impellers to rub and eventually seize, resulting in catastrophic failure. Abrasive contamination, such as fly ash or grain dust, can abrade the sealing surfaces of the impellers, which increases the internal clearances within the blower. This increase in clearance increases slip, reducing blower efficiency and increasing the temperature rise across the blower. Various methods of filtering contamination out of the inlet air before it enters the blower will be discussed later in the chapter.

Rotary Lobe PD Blowers

Two-lobe

The most traditional Rotary Lobe PD blower design is the two-lobe blower. As illustrated in Figure 6.5, the name derives from each impeller shaft being fitted with an impeller that has a finely machined profile based upon a mathematically derived curve. The curve allows the impellers to rotate in conjunction with and in close proximity to one another without coming into contact. As the most prevalent lobe blower design, both historically and in the current market population, they are known for their robust and reliable design. They are also typically 100% symmetrical in the key elements of design: rotor profile, rotor-to-rotor clearances, and the inlet and outlet port geometry. This symmetry allows them to rotate clockwise or counterclockwise, providing for two flow directions in one blower. They can be easily configured for both vertical and horizontal flow. The drive shafts can also be configured for multiple locations, which further increases their versatility.

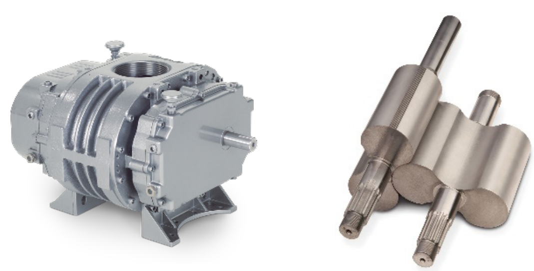


Figure 6.5: Typical blower with two-lobe impeller

Three-lobe

The three-lobe blower was designed specifically to address the noise created by two-lobe blowers. As previously described, the noise-producing pulsations are a result of the pressure equalization event that occurs when the pockets of trapped air go from ambient pressure to system pressure as the rotor tip passes the discharge port. The three-lobe design, with its additional lobe and 120-degree geometry, minimizes the effects of blower pulsations and increases the strength of the rotor. Figure 6.6 illustrates the design of a typical three-lobe rotary blower. The reduction in

pulsation energy is the result of the lower volume per trapped air pocket. Increasing the lobes to three from two increases the number of pulsations per revolution from two to three for each rotor. Accordingly, the three-lobe blower produces six pressure pulsations per revolution compared to the four pressure pulsations created by the two-lobe blower. The six, three-lobe events are of smaller volume than the four, two-lobe events, which reduces the magnitude of each pulsation event, ultimately generating less noise.

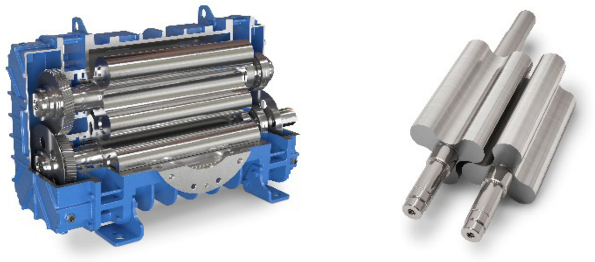
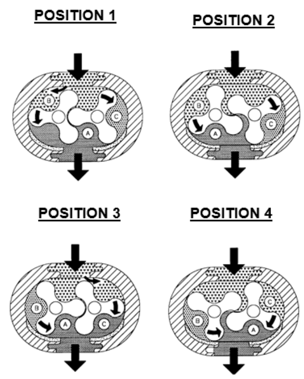


Figure 6.6: Typical blower with three-lobe impellers

The addition of a third lobe reduces the per-revolution displacement of the three-lobe blower compared to a similarly sized two-lobe design. To compensate for the lost swept volume per rotation, the three-lobe blower operates at higher speeds, made possible by the increased rotor strength and rigidity imparted by the addition of the third lobe. This increased speed results in an increased pulsation frequency. The noise from higher pulsation frequencies is easier to dissipate with common silencer technologies and noise-attenuation enclosures. The combination of lower pulsation energy and higher pulsation frequencies that can be attenuated with standard silencing methods results in a quieter operation of the three-lobe blower. More advanced three-lobe designs further reduce the magnitude of the pulsation event by slowly equalizing the pressures between the trapped pocket of air and the system pressure in a process called precompression.

Figure 6.7 illustrates the precompression process with a three-lobe blower and provides a step-by-step explanation of the process. Precompression is accomplished by machining a radius into the cylinder housing near the discharge port. This radius extends the full length of the housing except for a small area at the edges of the cylinder. As the impeller tip passes the leading edge of radius, the clearance between the impeller and the radius increases, allowing the higher-pressure system air to slowly equalize with the lower-pressure air trapped in the blower cavity. Slowing the equalization results in a lower pressure pulse and lower noise. Due to the complex geometries that are machined into the housing to accomplish the precompression effect, such blowers have dedicated inlet and discharge ports and cannot be operated in both directions.



In position 1

Flow is from the top (blower inlet) to the bottom (blower discharge). The left impeller rotates counterclockwise, and the space (B) between the impeller and the cylinder wall is filling with volume of air at inlet pressure. Space (B) is about to be sealed off by the counterclockwise rotation of this impeller. At the same time, the space (C) is progressively filled and compressed with discharge volume through the precompression passage.

In position 2

The inlet area is sealed in (B), and discharge compression starts to enter space (A) as the rotation of precompression passage continues at (C).

In position 3

Volume (C) is now delivered to the discharge port at pressure in the same manner as volume (A) had been previously. Because of the almost complete pressure equalizaion via the precompression passage, no sudden shock or pulsation will occur.

In position 4

The inlet area volume is sealed on the right-side shaft at (C) and the discharge pressurized volume entering space (B) starts to enter through the precompression passage on the left-hand shaft. Volume (A) is delivered to the discharge port and the volume in (B) will also start delivering with (A) as soon as the rotaion reaches the outlet side.

Figure 6.7: Precompression process with a three-lobe blower

Twisted Three-lobe

Machining a three-lobe blower impeller with a geometric twist, as illustrated in Figure 6.8, results in the rotor having an increased sealing surface against the cylinder versus a straight rotor of equal length. The longer sealing strip reduces blower slip, increasing efficiency. The progressive meshing of the twisted-geometry lobes provides for a smooth delivery of air to the discharge port, which is designed in a triangular shape to further minimize the magnitude of pressure pulsations. The result is a PD blower that reduces noise and power. The suction and discharge ports remain inline despite the complex rotor and port geometries. Due to the inclusion of a specially designed discharge port, the twisted three-lobe blower cannot operate in both directions and has dedicated inlet and discharge ports.

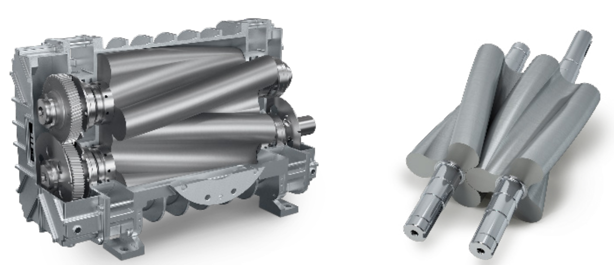


Figure 6.8: Typical blower with three-lobe, twisted impellers

PD Rotary Lobe Blower Construction

The typical PD rotary lobe blower is constructed almost entirely of cast iron, with the exception of shafts, bearings, and timing gears. The rotor assembly consists of an impeller mounted to a shaft, as illustrated in Figure 6.9. As previously discussed, there are different impeller designs and profiles for special functions. The rotor can be machined from one piece of cast iron or steel, or the impeller can be fitted with a separately machined shaft. The rotors are precisely positioned and supported by

either antifriction bearings seated within the end plates or headplates positioned on either end of the rotors. These bearings support the load of the rotors and maintain the close clearances between the rotating impellers.

The cylinder surrounds the rotors and is held in place by the headplates to create the sealed compression chamber. The cylinder also contains the inlet and discharge ports. Mounting feet are located on either the headplates or the cylinder.

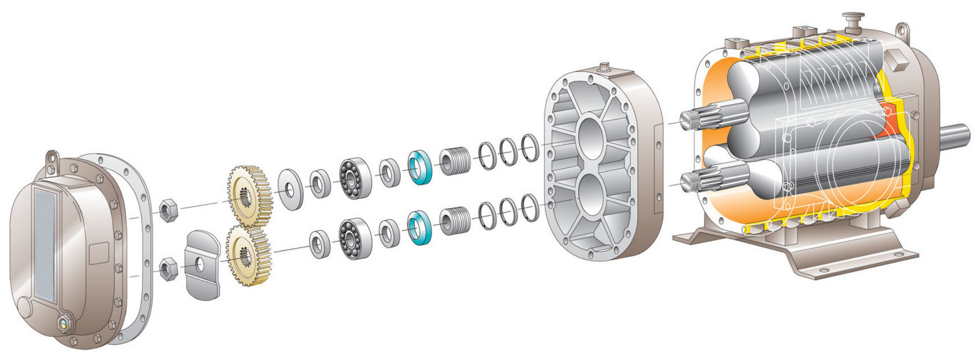


Figure 6.9: Typical PD rotary lobe blower construction

Timing gears are affixed to one end of each rotor and located outside of the blower compression chamber. These critical components are responsible for maintaining the finite clearances between the rotating impellers. They are attached to the shafts by various means depending upon the design. Attached timing gears prevent any slippage, as slippage may cause the impellers to go out of time allowing rotor-to-rotor contact — a serious condition that often results in catastrophic failure. Timing gears and gear end bearings are oil-lubricated. The gearcase attaches to the head plate to create a gear-house or gearbox. Lubrication is usually splash-type, but pressure lubrication is also used on different models. The bearings in the headplate at the opposite end of the unit are either grease- or oil-lubricated depending upon the design of the blower.

Where the shafts pass through the headplates, rotor shaft seals are used to restrict leakage of lubricant into the compression chamber, making the air from these blowers oil free. The seals also restrict the leakage of higher-pressure air into the gearcase. Rotor shaft seals are typically lip-type, labyrinth, or mechanical-type designs. As a precaution against allowing lubricant from entering the airstream in the event of a damaged or worn seal, a seal vent to atmosphere is located between the lubricant seal and the air seal.

All rotary blowers generate radial loads that are carried by the bearings. Additional axial loads are generated by the use of helical timing gears or by twisted impellers that impart axial thrust loads. Two- and three-lobe, straight-lobe blowers with straight timing gears do not generate axial thrust loads, so no special bearing designs are required. When both axial thrust loads and radial loads are generated, the bearing design must be such to accommodate these bidirectional loads.

Rotary Screw PD Blowers

Rotary screw blowers, also known as helical screw blowers, function as low-pressure, oil free blowers with discharge pressures up to 36 psig. The flows and pressures of rotary screw blowers overlap with other blower technologies. Commercial offerings of rotary screw blowers are available from 20 cfm to 6,000 cfm and are available from a wide number of manufacturers.

The rotary screw blower utilizes two intermeshing rotors (or screws) positioned parallel to each other inside a machined cylinder. The rotors consist of two separate precision-machined profiles: a male rotor and a female rotor, as illustrated in Figure 6.10. The male rotor rotates inside the cavity formed between the two flutes of the female rotor. The trapped cavity between the two rotors and the wall of the cylinder forms the compression chamber. As the rotors rotate, the trapped cavity is "screwed" down the length of the rotors from the inlet to the discharge port. Unlike straight- or twisted-lobe blowers, where the airflow through the blower is perpendicular to the rotor shafts, rotary screw blowers have an axial airflow, parallel to the rotor shafts.

The male rotor is the drive rotor, and it typically has fewer lobes than the female rotor has flutes. Timing gears on both rotors allow the two rotors to turn at different speeds without contact. The relative speed of the drive rotor to the female rotor is a ratio of the number of lobes to flutes. For instance, if the male rotor has two lobes and the female rotor has four flutes, a 2+4 design, and the male rotor is driven at a speed of 1800 rpm, the female rotor will have a speed of 3600 rpm (1800 divided by 2/4).

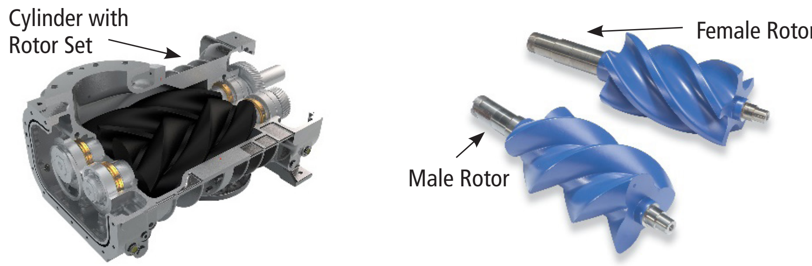


Figure 6.10: Typical rotary screw blower design

Rotary screw blowers have an internal compression ratio. The internal compression of gas means that in these types of blowers, there will be a pressure differential between the suction and discharge sides of the unit. Compression ratios are generally 3:1 or lower. The volume of air trapped between the meshed rotors and the case is reduced, as illustrated in Figure 6.11, which shows a "4+6" rotor arrangement where the male rotor has four lobes and the corresponding female rotor has six flutes.

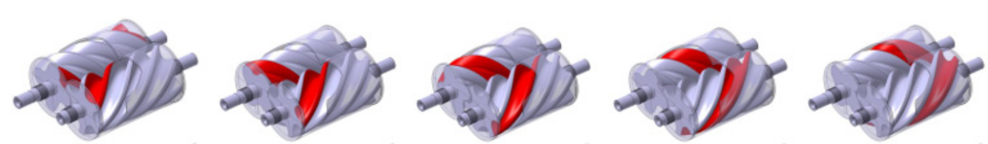


Figure 6.11: Volume is compressed as air moves from inlet to outlet

The rotors turn into each other and rotate in opposite directions. The lobed shaft is turning counterclockwise and the fluted shaft clockwise.

Once the male rotor lobe completely meshes between the two female flutes at the inlet, a fixed volume of air is trapped in the space created by the two rotors, the cylinder wall, and the cylinder endplate at the discharge of the blower. As the rotors rotate, the male lobe forms a moving piston that progressively reduces the volume of the air pocket. By the time the trapped volume of air reaches the discharge end of the blower, it is at an increased pressure due to the reduction in its volume. The rotors expose a discharge port, and the compressed air exits the blower.

Figure 6.12 shows the same set of rotors as viewed from underneath. Position #1 shows the trapped volume of air that fills the pocket created between the lobe and the flutes of the rotors and sealed at the discharge end by the flat surface of the cylinder wall. As the rotors mesh, the male rotor lobe pushes the pocket down the length of the rotors toward the discharge port, position #2. Note that the escape of air is prohibited until the rotation of the rotors exposes the discharge port, position #3, and the air exits the blower at a pressure higher than that at the inlet. In position #4, a new pocket is being formed at the inlet and the process repeats continuously.

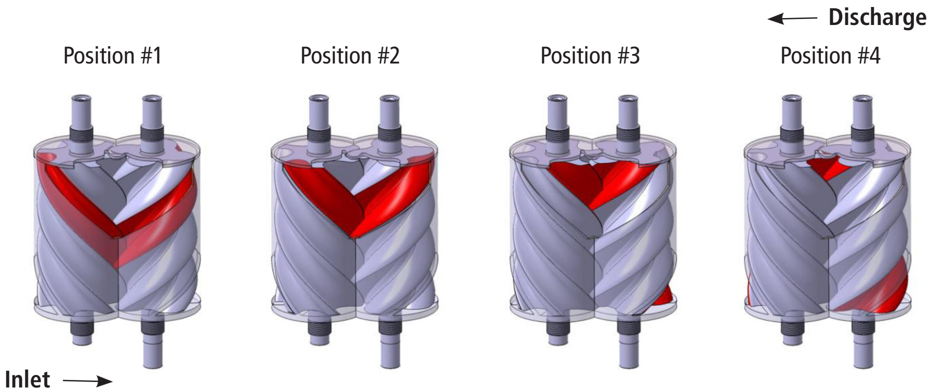


Figure 6.12: Volume is compressed internally and discharged into the system

Rotary Screw Blower Characteristics

Most of the same operating characteristics and limitations described for lobe-type PD blowers also pertain to rotary screw blowers. Rotary blowers have some unique differences in efficiency and noise generation.

Efficiency

Unlike the lobe-type blowers that develop system pressure strictly by the previously described isochoric process, rotary screw blowers use both the adiabatic and isochoric processes to develop system pressure. Rotary screw blowers have an internal compression ratio of 3:1 or lower. If the required system pressure is lower than the designed-in blower discharge pressure, the higher-pressure discharge air will re-expand to match the lower system pressure. If the required system pressure is higher, then external backflow compression will raise the pressure of the discharge air up to the pipeline pressure following the isochoric cycle of the rotary lobe blower. With rotary screw blowers, final system pressure is developed by a combination of adiabatic and isochoric methods.

Rotary screw blowers can be machined to tighter clearances than can be attained in lobe-type blowers. Tighter clearances are possible due to two factors: reduced operating temperature and reduced rotor deflection. The increased efficiency of a rotary screw blower results in less energy being consumed to do a given amount of work. Lower energy consumption reduces heat, which results in lower operating temperatures. Lower rotor temperature reduces thermal expansion and reduces the risk of rotor-rotor and rotor-housing impact during operation. Due to the reduced thermal expansion, the clearances machined into the rotary screw rotors and cylinder are tighter. These tight clearances reduce slip and further increase efficiency.

The rotors in a lobe-type blower tend to deflect more under differential pressures than the rotors in a rotary screw blower. The rotors of both designs must withstand the compression forces of the air. The rotary lobe impeller has to resist bending by the force generated from the discharge pressure along its full length. The rotary screw rotor experiences a lower bending force as the compressed air in the compression pocket moves along its length. Tighter tolerances are achievable in a rotary screw blower since there is less rotor deflection than in a similarly sized lobe-type blower.

The rotors of a rotary screw blower are generally smaller in diameter and length than in a similar performance, lobe-type blower. Having smaller rotors, the rotary screw blower develops the needed displacement volume through increased speed.

Noise

Blower noise is caused by the backflow of higher-pressure system air into the trapped pocket of lower pressure air that gets pushed into the system. This backflow pressure equalization results in a sound pressure wave that is heard as noise. Possessing adiabatic internal compression, rotary screw blowers have less of a pressure differential between discharge port and system pressure than lobe-type blowers. This characteristic reduces the noise emitted from rotary screw blowers. Rotary screw blowers achieve their minimum noise levels when their compression ratio and system pressures match.

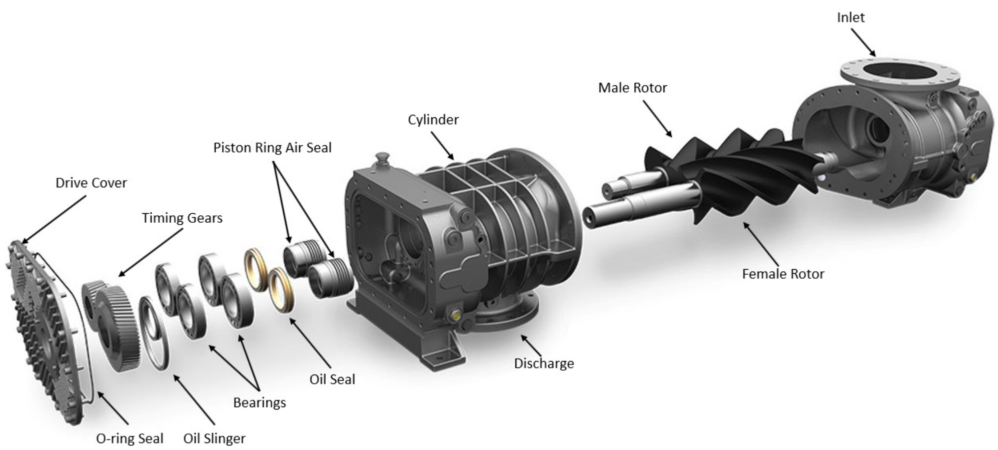


Figure 6.13: Typical rotary screw blower construction

Rotary Screw Blower Construction

The typical rotary screw blower is constructed almost entirely of cast iron, with the exception of the bearings and timing gears. The terms impellers and rotors are used interchangeably to describe the complete rotor assembly (rotor plus shaft). The rotors are generally machined from one piece of cast or ductile iron. The rotors are precisely positioned and supported either by antifriction bearings seated within the end plates or headplates that are positioned on either end of the rotors. Cylindrical roller bearings support the radial loads and maintain the close clearances between the rotating impellers. Angular contact bearings support the axial loads generated by the helical gears and thrust loads.

Generally, the axial load of the timing gears offsets some of the axial thrust load. These bearings maintain the close clearances between the cylinder end plates and the ends of the rotors. The cylinder surrounds the rotors and is held in place by the headplates to create the sealed compression chamber. The cylinder commonly contains cast-in flanges for air inlet and outlet ports. Mounting feet can be located on the headplates or the cylinder. In flange-mount designs, the inlet or discharge port flanges serve as the mounting surface. Some manufacturers design the compression element to fit to a purpose-built gearbox as their support method.

Timing gears are affixed to one end of each rotor and located outside of the blower compression chamber. These critical components are responsible for maintaining the finite clearances between the rotating impellers. They are attached to the shafts by various means depending on the design. Attached timing gears prevent any slippage, as slippage may cause the impellers to go out of timing, allowing rotor-to-rotor contact — a serious condition that often results in catastrophic failure.

Timing gears and gear-end bearings are oil-lubricated, and a cover attaches to the headplate to create a sealed gear-house or gearbox. Lubrication is usually splash-type, but pressure lubrication is also used on higher-pressure models. The bearings in the headplate at the opposite end of the unit are either greased or oil-lubricated, depending upon the design of the blower. Figure 6.13 depicts a splash-lubricated unit with oil lubrication at both ends.

In the areas where the shafts pass through the headplates, rotor shaft seals are used to restrict leakage of lubricant into the compression chamber, making the air from these blowers oil free. Additional air seals restrict the leakage of higher-pressure air into the gearcase. Rotor shaft seals are typically lip-type, labyrinth, or mechanical design. As a precaution against lubricant entering the airstream, and in order to relieve the pressure across the rotor shaft seals, an area vented to atmosphere is located between the lubricant seal and the air seal.

Rotary Claw PD Blowers

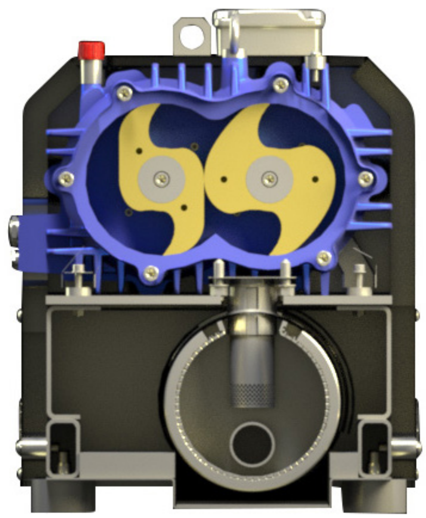


Figure 6.14: Side view cutaway of a rotary claw blower

Rotary claw pumps are oil free, positive-displacement machines that are capable of operating in pressure service up to 30 psig and vacuum applications up to 24" Hg. The volumetric flow associated with this technology is relatively low, generally 650 cfm or less, so as a blower it has limited applications. However, as a vacuum pump, the rotary claw sees extensive service in vacuum applications. A rotary claw pump consists of two claw-shaped impellers, as illustrated in Figure 6.14. A drive rotor transfers power to the impellers through a set of timing gears, ensuring that the impellers do not contact each other. Extremely tight machined clearances allow the claws to maintain minuscule gaps between themselves and the cylinder during their rotation, minimizing slip and making rotary claw blowers one of the most efficient blower technologies. Similar to lobe-type and rotary screw blowers, rotary claw blowers employ oil lubrication for bearings and gears. Shaft seals keep the lubricant from entering the compression chamber and the high-pressure process air from pressurizing the gearcase.

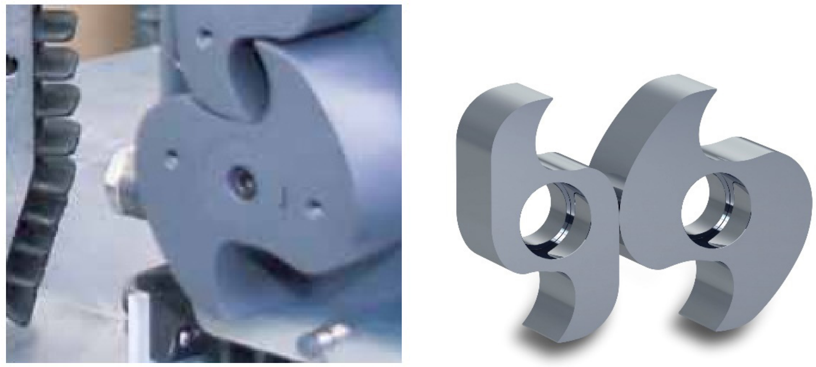


Figure 6.15: Two-lobe rotary claw

As illustrated in Figure 6.15, rotary claw blowers generate pressure or vacuum using two rotors spinning in opposite directions, similar to a PD lobe blower. The claw shape of the impeller allows them to generate internal compression adiabatically within the compression chamber before opening the path to the discharge outlet.

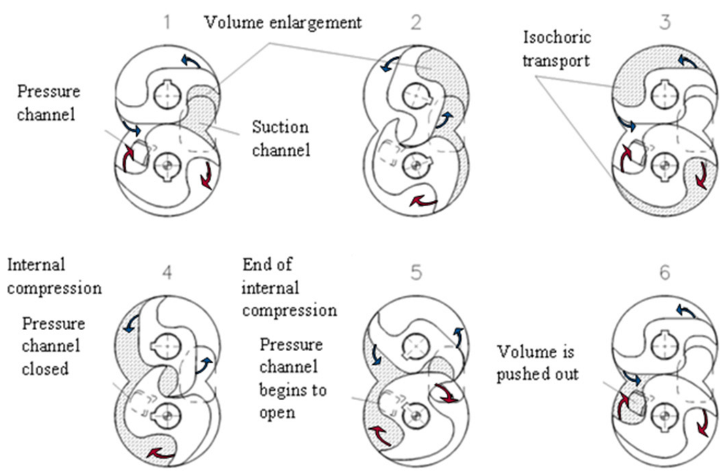


Figure 6.16: Air flow path through a rotary claw blower

As illustrated in Figure 6.16, a fixed volume of air enters the compression chamber via the suction intake (position 1). The two impellers rotate in opposite directions, sweeping the air around the outside of the cylinder (positions 2-3). The impellers mesh together on the discharge side of the chamber, reducing the volumetric space and compressing the air (positions 4-5). The rotating impellers expose the discharge port and the compressed air discharges through the outlet (position 6). Since the rotary claw blower utilizes both adiabatic and isochoric compression to generate both system vacuum and pressure, it provides efficiency and noise characteristics similar to the rotary screw blower.

Claw pumps typically are supplied as fully packaged units, as shown in Figure 6.17. Packages commonly include the claw airend, integrated motor, inlet filter, and discharge silencer. These machines are typically run on two-pole motors at an operating speed of 3600 rpm. By using variable speed motors, rotary claw blowers can be tuned to match a precise flowrate requirement. For flowrates in excess of 650 cfm, multiple claw airends can be operated in parallel.

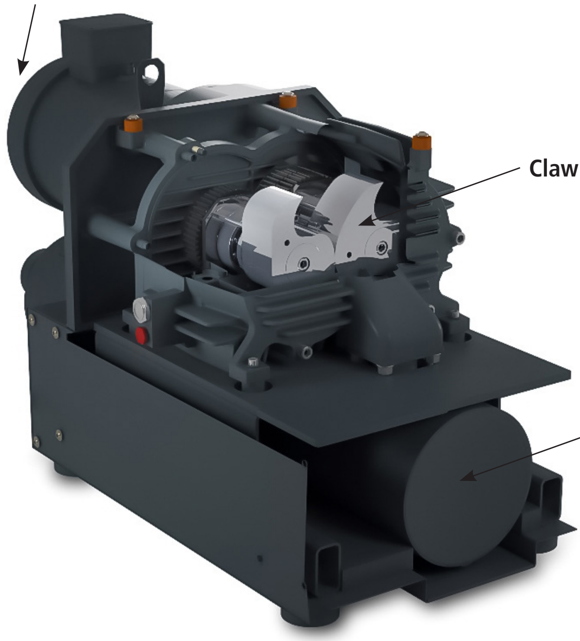


Figure 6.17: Rotary claw blower package

Rotary Vane Blower

Rotary vane pumps are positive displacement machines that are capable of operating in pressure or vacuum applications. Pressures are typically 30 psig or lower, and rotary vane pumps are available in oil free and oil injected designs. Oil free rotary vane pumps have flows less than 100 cfm, with maximum pressure of 36 psig and maximum vacuum of 24" Hg. Oil injected pumps have flows up to 900 cfm with pressure capability of up to 24 psig and vacuum capability of up to 28" Hg. Oil injected designs used in vacuum service are the most commonly applied usage of rotary vane pumps due to their ability to attain a constant vacuum of 28" Hg. The rotary vane blower develops internal compression and utilizes both adiabatic and isochoric compression to generate both system vacuum and pressure. Accordingly, rotary vane blowers provide efficiency and noise characteristics similar to rotary screw and rotary claw blowers.

The rotary vane pump, also known as a sliding vane pump, consists of a housing, a rotor, and vanes as major components. The rotor diameter is usually 10-15% smaller than the housing diameter, and it is installed eccentrically inside the housing, having a radial face almost tangent to the face of the housing as shown in Figure 6.18. This arrangement of housing and rotor creates a crescent-shaped cavity in the housing. Vanes are installed in the radial slots machined in the rotor. The vanes slide radially into the slots, and the centrifugal force developed during rotor rotation keeps the vanes tips pressed against the inner wall of the housing. Oil is injected through ports in the housing at the air intake and serves to lubricate, seal, and cool the pump. In smaller designs, the oil is not recirculated and is separated from exhaust air by means of filtration. Larger designs employ an oil separation and recirculating system similar to an oil injected rotary screw compressor. In oil free designs, the vanes are made of carbon-graphite, and as they wear against the housing they deposit a self-lubricating film of carbon. Such vanes are wearitems and require periodic replacement.

The crescent chamber is divided into compartments by vanes — each compartment is enclosed by the rotor, housing, and consecutive vanes. As the rotor turns, each compartment sweeps past the intake manifold with increasing volume, pulling in the air until the trailing vane passes the intake manifold and seals the cavity. While the rotor keeps turning, the gas compartment starts to decrease in volume, and the gas compresses. As the leading vane passes the exhaust port, the compressed air is discharged into the system. A rotary vane pump can be naturally convection-cooled, forced-fan cooled, or liquid-cooled. Air-injection cooling is sometimes added to a pump as a design feature to improve cooling during continuous high-vacuum operation.

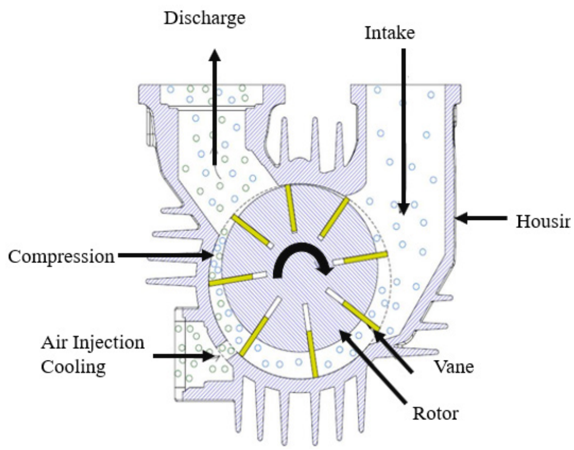


Figure 6.18: Operating principle of a rotary vane vacuum blower with air-injection cooling

Rotary vane blowers are available as bare pumps, as shown in Figure 6.19. These types of blowers are often used in mobile transport industry applications for higher-pressure bulk material conveying and for vacuum-assisted onload and pressure-assisted offload of both bulk solids and liquids. For mobile applications, additional accessories are needed for a complete system. These accessories are oftentimes packaged into a compact, fully packaged system for ease of installation on a truck chassis, as shown in Figure 6.20.

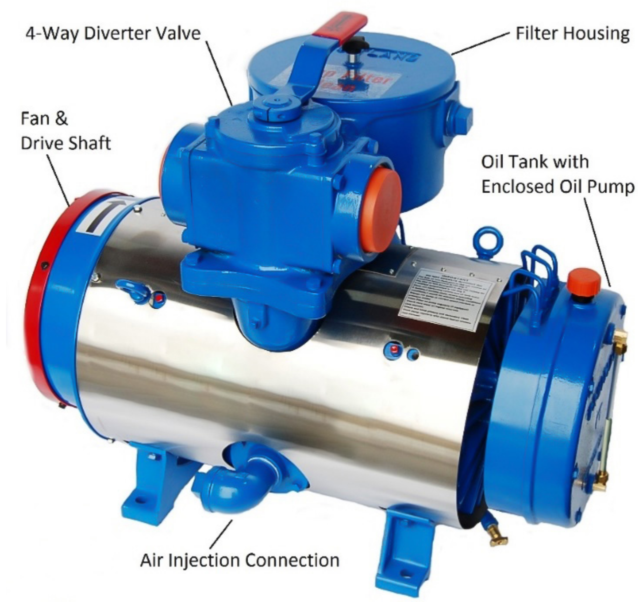


Figure 6.19: Rotary vane pump typically designed for mobile applications

Figure 6.20: Typical compact rotary vane package designed for mobile applications

PD Blower Packaging

The OEM market is a large user of blowers. Such OEMs provide the industry with pneumatic conveying systems, aeration systems, and vacuum hold-down systems, to name a few. These OEM packages can be found in all types of industries around the world. The OEM applies a blower as a component part of their system. The blower can be an integral component fitted to other pieces of equipment, or it can be supplied as a standalone package that supplies the required airflow.

When the blower is packaged, the package generally contains the following basic components: blower, base, drive motor, drive, inlet air filter, silencers, pressure/vacuum relief devices, and gauges (temperature, pressure, vacuum). These basic components are illustrated in Figure 6.21. Depending on the required function and sophistication of the package, the package might also include full enclosures and advanced controls.

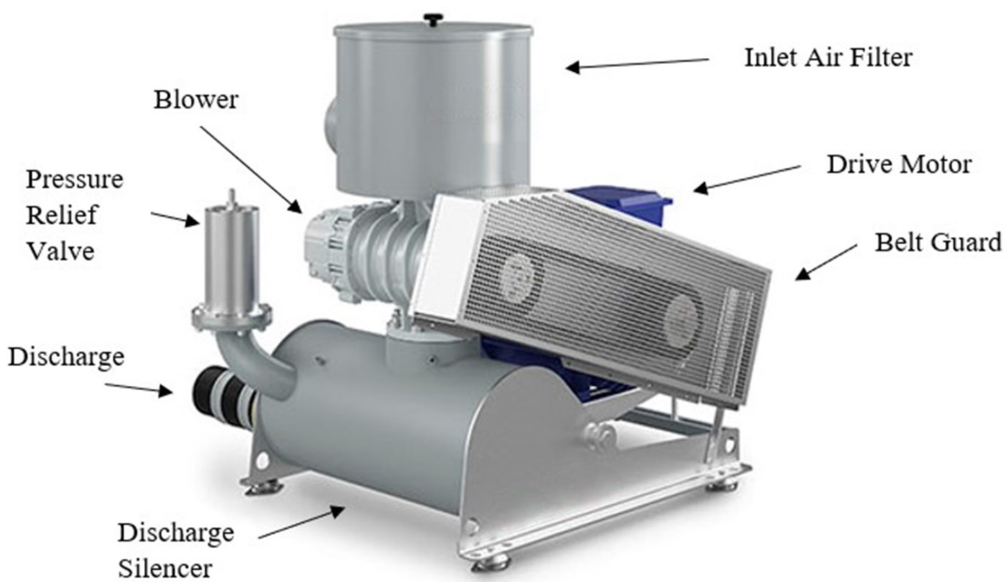


Figure 6.21: Basic unenclosed pressure blower package

Inlet air filters are required to keep airborne contaminants from entering the blower compression chamber. As previously described in this chapter, contamination within the compression chamber is to be avoided due to its negative effects on the operation and life of the blower.

The most common drive arrangement for basic blower packages is the simple v-belt drive, as shown in Figure 6.21. Belt drives provide the needed flexibility to accommodate a wide range of blower speed requirements at a relatively low cost. Other drive types are also used, such as direct drives, coupled drives, or gear drives. Typically, motor starters or variable frequency drives (VFD) are not provided with these machines. These items are normally provided by the customer or their contractor.

Due to the sound pressure pulsations that all blowers create, most blower packages include a discharge silencer to reduce the blower noise. Oftentimes, both an inlet and discharge silencer are included. Because all blowers are positive-displacement pumps that deliver a constant flow at variable pressure, the blower package must include a pressure or vacuum relief device to keep the blower from experiencing a pressure or vacuum level that exceeds its design limitations.

Most blower manufacturers offer fully assembled blower packages. The packages are most often utilized in industrial and wastewater applications. As such, their configurations are tailored towards the specific requirements of these markets.

Although the basic unenclosed package addresses the most basic needs of the blower, and while these packages drastically reduce the blower noise generated by pulsations, mechanical noise remains an issue. To further reduce the noise emitted from the blower package, a sound enclosure can be provided, as illustrated in Figure 6.22. The enclosed blower package will include the same components as described in the basic package. However, all of the items are now contained within the sound enclosure. The enclosure panels will be lined with dense noise-attenuating material, which absorbs the residual pulsations and mechanical noises.

Consequently, a blower package inside an enclosure creates a closed environment that presents an overheating issue. To minimize heat within the sound enclosure, cooling ducts allow fresh air into the enclosure, and an exhaust fan removes the hot air. Again, as with the unenclosed machine, starters and/or variable frequency drives are not included with these packages and must be sourced by the customer or their contractor. Aftermarket enclosures can be sourced, but they often lack the superior form, fit, and function that are designed into the enclosures produced by OEMs specifically.

Figure 6.22: Enclosed blower package with side sound-attenuating panels removed

For customers requiring a blower package that includes all of the components required to operate a complete blower system combined into one structure, manufacturers offer complete machines, as shown in Figure 6.23. These machines include all of the components described for the unenclosed and enclosed packages but will also include the starter and/or variable frequency drive for the drive motor as well as provisions for the cooling fan and machine controller.

In many cases, gauges and instruments are replaced with sensors that input into the machine controller. The controller becomes the central point of the unit for operation and protection. Many of these controllers are fitted with modern communication protocols that allow these machines to be connected to plant networks for real-time monitoring and control.

Figure 6.23: Complete blower machine packages

Blower Applications

Rotary lobe blowers can be found in numerous applications worldwide. Aeration, agitation, combustion, vacuum hold down, drying, carpet cleaning, and dairy milking barns are just a few of the many applications where PD rotary blowers provide reliable and efficient service. The two applications that use the greatest number of blowers are pneumatic conveying and wastewater treatment. For pneumatic conveying, blowers generate air velocity in a pipe, where the moving airstream picks up the desired material and transports it from one location to another. Pneumatically conveying flour throughout the milling process might require twenty-five separate blower packages in a flour mill. This is an example of dilute phase pneumatic conveying, a process where there is more air in the pipe than material. Dilute phase conveying generally operates between 2 psig to 15 psig. These relatively low operating pressures make rotary lobe PD blowers an excellent choice for this service. The rotary lobe PD blower is used in both vacuum and pressure dilute phase pneumatic conveying applications.

Vacuum systems are typically used for unloading bulk trucks or railcars over short distances, while pressure systems are used for delivery over longer distances. Rotary screw PD blowers, due to their higher-pressure capability, are used to pneumatically convey denser materials, such as fly ash or fertilizer, which create greater backpressure within the systems. For pneumatic conveying systems, the OEM supplies a blower package that is built into the receiving silo or onto the bulk tanker truck. Larger industrial installations will consist of many stationary blower packages.

One specialized industry for both rotary lobe and rotary screw PD blowers is the bulk tanker truck industry. Blowers are oftentimes mounted under the truck frame and powered by a power-take-off (PTO) from the truck engine. These blowers operate in the pressure mode to unload a bulk tanker or in the vacuum mode to load a bulk tanker. Individual electric-motor-driven blower packages may also be mounted on the chassis of the bulk tanker.

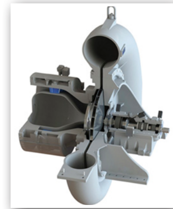
The other primary market for the rotary PD blower is the wastewater treatment industry. In the wastewater treatment process, blowers are used in numerous applications ranging from filter back-washing, tank agitation, and main aeration — with main aeration being the prominent use. In main aeration, the blower pumps atmospheric air through a series of pipes and diffusers located at the bottom of the treatment basin to provide oxygen to the microorganisms living in the solution. This is a critical part of the treatment process, and rotary blowers have proven to be reliable and low-maintenance devices for providing the high volume of oil free air needed for aeration.

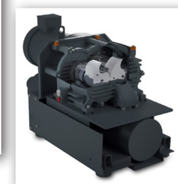
Rotary PD blowers are applied in many niche, industrial applications. These include vacuum boosters, vapor compression, and combustion air. These blowers can utilize standard cast iron construction, as previously described, or they can be made from specialty metals with customized seal arrangements to satisfy the niche application.

Common applications for rotary vane and rotary claw pumps are found in the transport industry, where they provide air as the fluid to assist in the offloading of both liquids and solids from bulk tankers. Due to their higher-pressure capabilities, rotary vane pumps are applied for pneumatic conveying of dense materials, such as Portland cement, especially in high altitude locations where a traditional lobe or screw truck blower will not perform. Vacuum systems are mounted on tank trucks ranging in sizes from a few gallons to thousands of gallons. These tanks are specifically designed to withstand maximum vacuum and limited pressure. Mobile vacuum systems are designed to vacuum liquid and slurry materials in a variety of applications, such as septic tank pumping, environmental spill remediation, portable sanitation, restaurant grease trap vacuuming, and general vacuum service in both the oil and gas and industrial markets.

Figure 6.24: Vacuum truck with mounted vacuum blower

Figure 6.24 shows a mobile vacuum truck. The rotary vane vacuum pump is powered by a hydraulic motor driven by the truck engine. Alternatively, the vacuum system can be powered directly from the PTO from the truck transmission by means of a drive belt or right-angle gear box. Industrially, rotary vane and rotary claw blowers are more commonly applied to vacuum service than to pressure service. Vacuum applications are many within the food and beverage industry, the medical and pharmaceutical industries, and in CNC applications for hold-down purposes.





Dynamic Blowers

Dynamic blowers are used in many different areas of industry. They provide reliable, oil free compressed air service and are used to distribute and process a wide variety of gases in addition to air. All dynamic blowers achieve a pressure rise by adding velocity (kinetic energy) to a continuous flow of air through the action of a high-speed rotating impeller. This kinetic energy is then converted to an increase in static pressure (potential energy) by slowing the flow of air through a diffuser. Rapidly spinning impellers use centrifugal force to sling air molecules at high speed into a vaneless or vaned diffuser. The sudden slowing down of the high-speed air molecules at the diffuser creates a static pressure as molecules pack-in against each other in a process called impingement. This process follows Bernoulli's principle, which states that a decrease in the velocity of a fluid will result in an increase in pressure within the fluid. Similar to positive displacement rotary screw blowers, dynamic blowers are adiabatic compressors that generate an internal pressure differential between the inlet and the discharge of the blower. Accordingly, when used in a pneumatic system, dynamic blowers develop system pressure both adiabatically and isochorically, as previously described.

A dynamic blower can operate as a blower or as a vacuum exhauster depending upon how it is piped. When it is used to move air or gas under pressure, it is referred to as a blower and its performance is rated in pounds-per-square-inch-gauge, psig. When it is used to move air or gas under a negative pressure, it is referred to as an exhauster, and its performance is rated in inches-of-mercury (Hg) vacuum. 29.9" Hg represents absolute vacuum (0 psig). Dynamic blowers can also be subjected to negative pressures on the suction side and positive pressures on the discharge at the same time, subject to the limitation of the developed compression ratio.

The flows and pressures of dynamic blowers overlap with other blower technologies. Dynamic blowers are classified as being centrifugal blowers or regenerative blowers, depending upon the internal process used to impart velocity onto the airstream. Regenerative blowers are often found in relatively small airflow blower applications, up to 1700 cfm with pressures up to 15 psig and vacuum levels up to 16" Hg. Centrifugal blowers develop flows ranging from 500 cfm to upwards of 300,000 cfm. At sea level, centrifugal vacuums up to 15" Hg and pressures up to 18 psig are normal. Although discharge pressures of 65 psig are attainable with dynamic technology, dynamic blowers are designated to operate at 30 psig or less.

Centrifugal Blowers

Centrifugal blower designs range from single-stage blowers to multi-stage blowers. Centrifugal blowers can handle air, steam, and other non-air gases. The single-stage centrifugal blower compresses air with a single overhung impeller working inside a volute, as illustrated in Figure 6.25. The multi-vane impeller is attached directly to a high-speed shaft. The shaft is supported by two or more bearings; therefore, the compression element of a centrifugal blower has essentially one moving part. The shaft is typically connected to a drive unit that provides the rotation force to spin the shaft and impeller. The air or gas will travel through a straight pipe and enter the centrifugal blower in a straight and uniform flow with vorticities. The flow will pass through the impeller, which forces the flow to move faster along the blades. The flow will leave the impeller with increased speed and is slowed down in the diffuser part of the volute and also, possibly, in other diffuser elements.

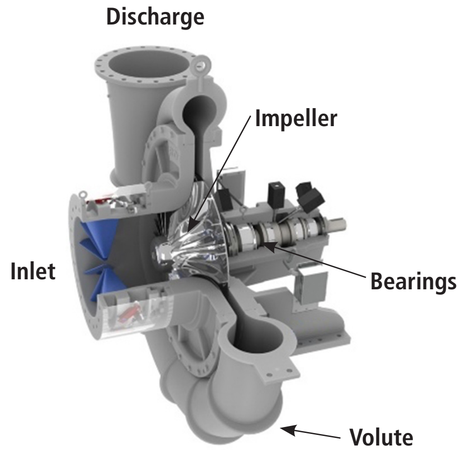


Figure 6.25: Single-stage centrifugal blower

Multistage centrifugal blowers consist of two or more impellers fixed to a keyed common shaft, which rotates within a housing, as illustrated in Figure 6.26. Multistage centrifugal machines create airflow and pressure by drawing gas into the center of the first stage via an inducer/volute. The air is accelerated by the rotating vanes of the impeller and flows outward via centrifugal force toward the periphery of the shrouded impeller. The air is then discharged into the diffuser section, where it is slowed down to create a pressure rise. The pressurized air is guided into the eye of the next impeller by a baffle ring. This process is repeated through all stages of the blower until the gas reaches the outlet header of the machine, where it is collected into a volute and then fully discharged into the system.

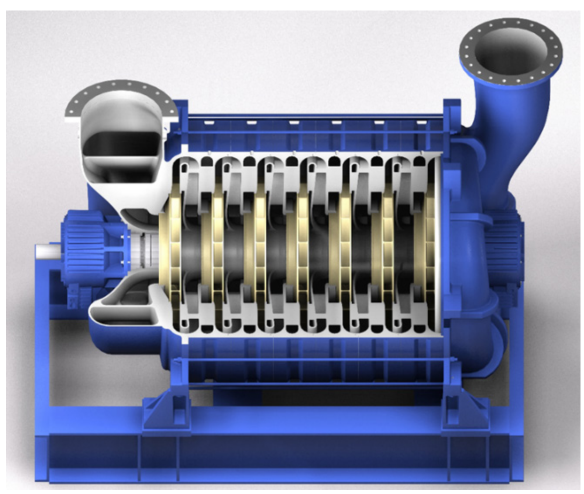


Figure 6.26: Multistage centrifugal blower

Single-Stage Centrifugal Blowers

Single-stage centrifugal blowers come in three types depending upon how they are driven:

1. Integral gearbox
    a. Vertically Split Gearbox
    b. Horizontally Split Gearbox (Meet API — 617 and 672 specification requirements)
2. Standalone gearbox
3. High-speed VFD motor (turbo blower)

All three of these single-stage designs have a cantilever shaft impeller arrangement.

Constant-speed blowers (#1 and #2 above) utilize gearboxes with speed-increasing gearsets to allow the impeller to achieve the high speed required to compress the air. Two gearbox configurations can be found in the marketplace — integrally geared and standalone. In the integrally geared configuration, the speed-increasing gearbox and the blower are integrated together. The gearbox shaft is flexible-coupled to a conventional induction motor, as shown in Figure 2.27. The overhung impeller is mounted on the secondary shaft of the gear box. The gearboxes are typically equipped with journal bearings or roller bearings to help increase the impeller speed. Integral gearboxes can be either vertically split or horizontally split.

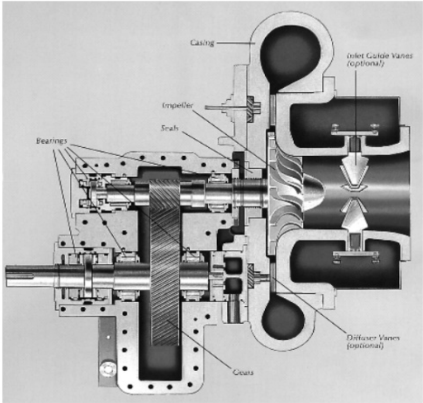


Figure 6.27: Integral geared single-stage centrifugal blower

In standalone gearbox designs, as shown in Figure 6.28, the gearbox and the blower are two separate units where the drive shaft from the speed-increasing gearbox is flexible coupled to the blower drive shaft. In this arrangement, the blower has its own bearing stand, which is typically horizontally split. This design is used instead of an integral gear type for critical purpose applications and for large-flow applications requiring high horsepower where an integral gear drive is not practical. This style also allows for a larger sealing area along the shaft than is typically possible with an integral gear blower. This design can accommodate a more sophisticated gas seal for applications requiring a higher degree of seal confidence.

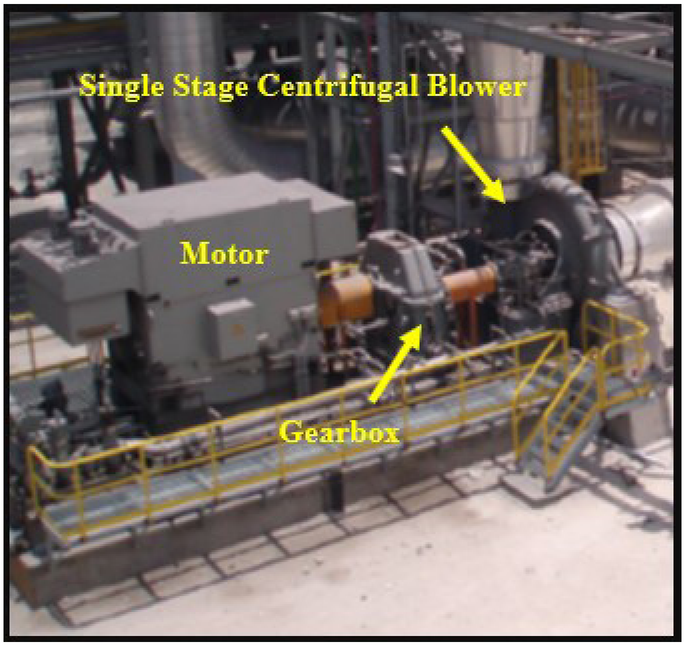


Figure 6.28: Standalone gearbox drive single-stage centrifugal blower

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A turbo blower includes a single-stage centrifugal airend similar to a constant-speed, gearbox-driven blower, but instead of using a gearbox to drive the impeller, the impeller is driven directly by a high-speed, permanent magnet motor, as shown in Figure 6.29. Eliminating the gearbox reduces the overall footprint of the blower compared to the gearbox-driven designs. When powered by a variable frequency drive, these motors are able to achieve speeds ranging from 10,000 to 70,000 rpm by utilizing either air foil bearings or magnetic bearings. The benefits of these types of bearings include oil free design, low maintenance needs, and a long service life. In turbo blowers, flow and pressure control is primarily achieved by controlling the speed of the rotating shaft and impeller.

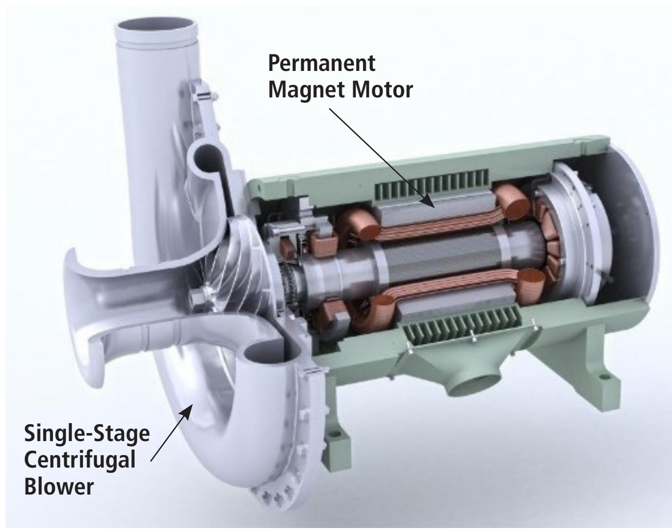


Figure 6.29: Turbo blower with integral, high-speed permanent magnet motor

Single-Stage Centrifugal Blower Performance

If the rotating speed of a centrifugal blower is held constant, its performance can be plotted on a graph with flow along the x-axis and pressure rise on the y-axis, as shown in Figure 6.30. The slope of this curve drops as the flow increases as noted by curve **n**. Several factors cause this natural flow curve. First, the design of the passages in the volute will create an optimal condition, which is usually at the mid-range capacity of the blower. The efficiency drops off at either end of the curve. In addition, there are leakage losses from the high-pressure side to the low-pressure side of the volute due to the small mechanical clearances between the rotating and stationary parts. Also, the inlet losses and outlet velocity vary with the capacity of the blower since frictional losses vary with the square of the velocity. In the case of variable-speed, high-speed blowers, increasing the speed of the impeller moves the performance curve upward, as noted by curves $\mathbf{n}^{+}$.

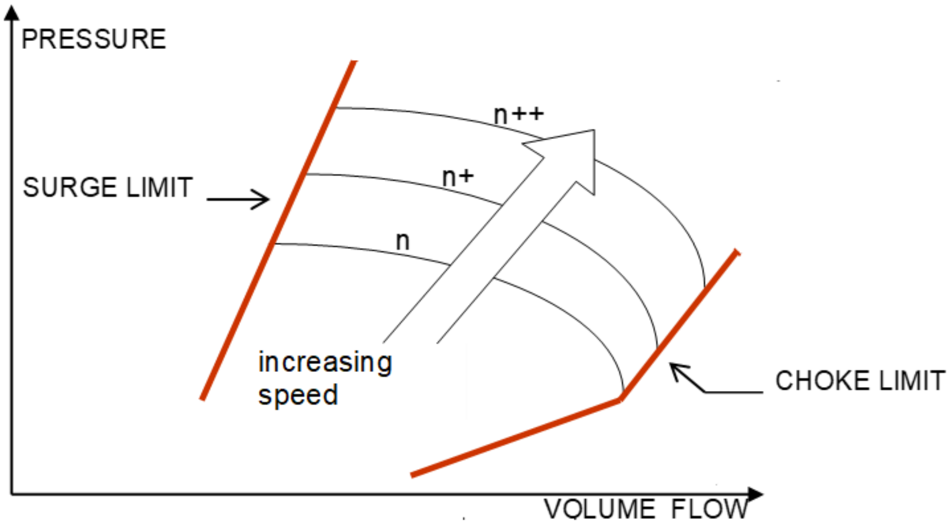


Figure 6.30: Typical single-stage centrifugal blower performance curve

The natural curve operates between two conditions: surge and choke. With speed held constant, there is a minimum volume of flow below which the blower will not operate smoothly. This is the surge limit as noted on the left-hand surge limit line on the performance curve. Surge occurs when the flowrate is too low to create enough pressure to overcome the discharge-system pressure. If this happens, flow reversal occurs when the compressed gas rushes back from the discharge towards the lower-pressure inlet of the volute, resulting in a pressure drop at the discharge. This reduction in the discharge pressure then re-establishes the flow, allowing the impeller to impart energy back onto the moving fluid until flow reversal once again occurs back to the discharge. If nothing in the system changes, then this cycle is repeated, placing high amounts of force on the mechanical components and increased temperature that can lead to inefficient operation, premature wear, or through prolonged or repeated occurrence, even machine failure. Surge control must therefore be incorporated into the design of all centrifugal blower packages.

The choke limit is located at the right end of the performance curve. Choke is the point at which maximum flow has been reached. This point is where the blower can no longer increase its gas flow without dropping discharge pressure. The pressure versus flow curve essentially becomes vertical. This occurs as the gas velocity reaches the speed of sound in the smallest passage of the blower and cannot go any faster, which prevents any additional gas flow from going through the blower.

The other limits of operation are the speed limit and power limit. The speed limit represents the maximum rotation speed at which the blower impeller can safely operate. The power limit is the maximum amount of power that can be transferred from the driver to the shaft and impeller. Beyond this limit, the blower impeller will be unable to provide the energy needed to increase capacity and/or increase the pressure rise.

Constant-Speed Single-Stage Centrifugal Blowers

Performance Range

Single-stage centrifugal blowers have a very broad flow range, with a low end of around 1,000 cfm and a high end of up to 300,000 cfm. Integral geared blowers are more prevalent in lower flows, and standalone gearbox drive blowers are more prevalent in the higher flows. Single-stage centrifugal blowers can achieve discharge pressures of approximately 30 psig based on atmospheric air.

Capacity Control

The designed-in capacity of constant-speed centrifugal blowers is determined by impeller speed and impeller profile. Controlling capacity off of the designed capacity is achieved by adjusting the geometry of the intake, discharge, or both. The intake geometry can be adjusted by moving inlet guide vanes that are positioned in the inlet flow, as shown in Figure 6.31. Such guide vanes add a pre-swirl to the air or gas stream entering the impeller. It will also change the angle at which the gas approaches the wings of the impeller and will thus act to lower the flow at which surge will occur while also efficiently reducing the pressure capability. The movement of the inlet guide vanes is accomplished by the use of a linkage system, which regulates the angular position of the guide vanes. On the discharge, adjustable diffuser vanes can be used. By adjusting the angle from fully open to fully closed, the flow can be reduced to 40% or so of design flow while maintaining pressure rise capability. Utilizing both variable inlet guide vanes and variable discharge diffuser vanes provides optimized efficiency over a wide operating range of flow and pressure. Note the performance changes achieved by using inlet and diffuser guide vanes in Figures 6.32 through 6.34.

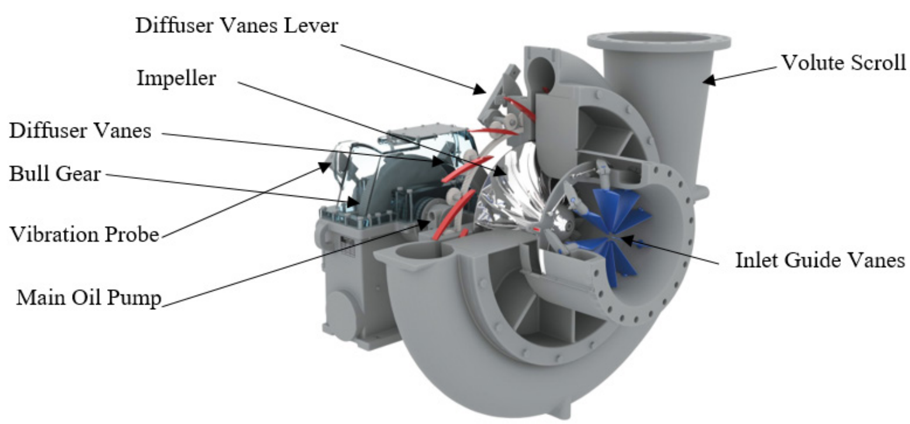


Figure 6.31: Inlet and diffuser guide vanes on a single-stage centrifugal blower

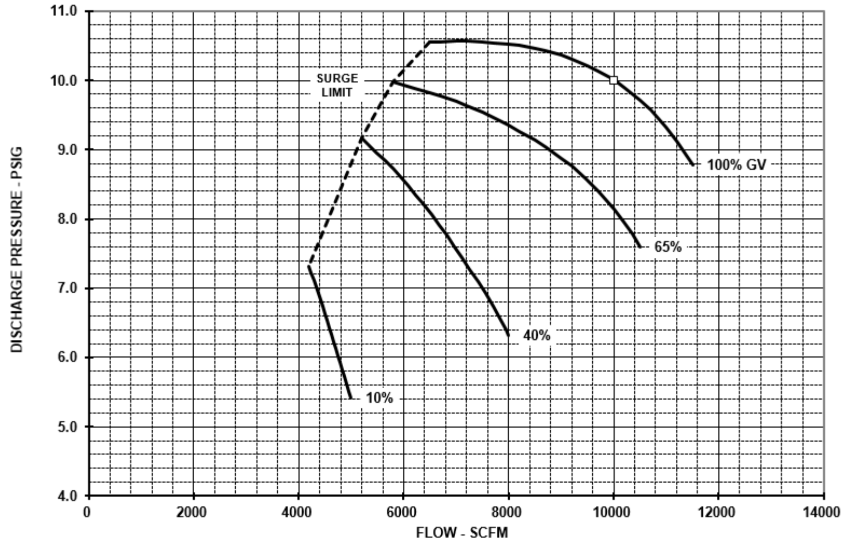


Figure 6.32: Single-stage centrifugal blower performance with inlet guide vanes

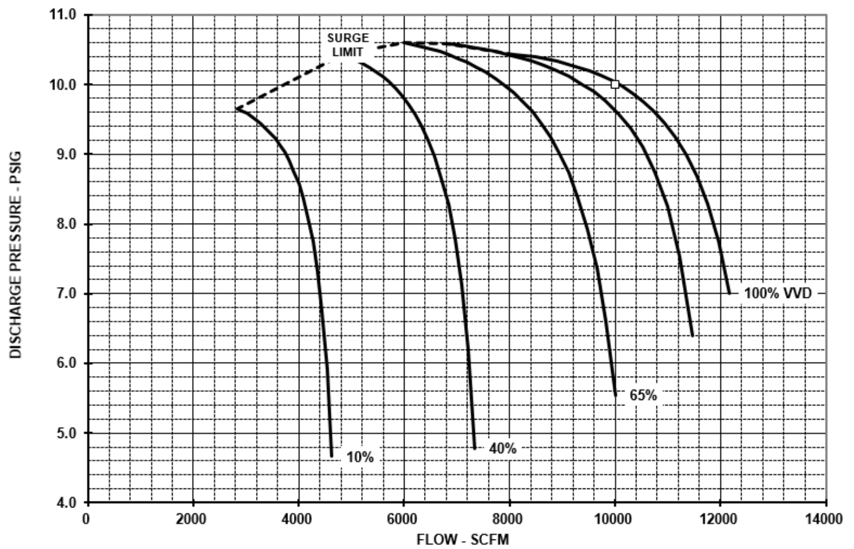


Figure 6.33: Single-stage centrifugal blower performance with discharge diffuser vanes

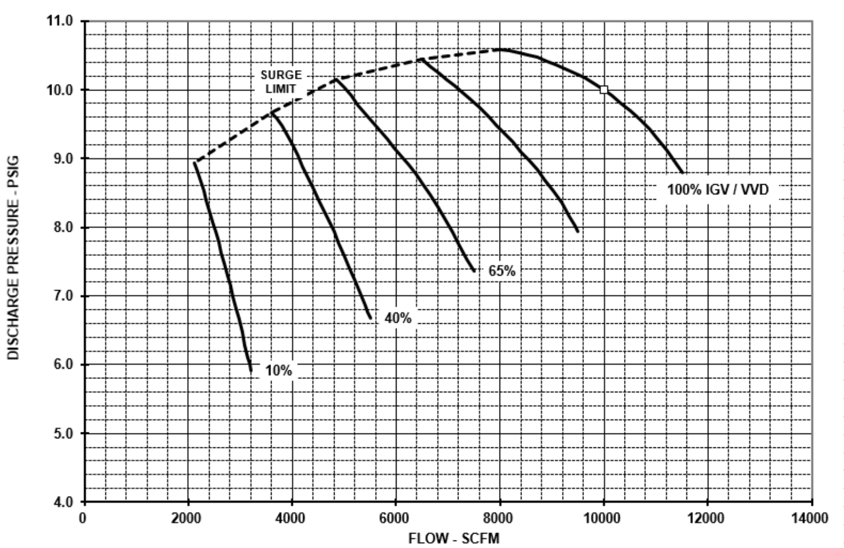


Figure 6.34: Single-stage centrifugal blower performance with dual vanes (inlet and discharge)

Inlet Guide Vanes (IGV) can be the standard axial type, or the peripheral or annular type, as shown in Figures 6.35 and 6.36. The peripheral IGV may offer a small increase in efficiency but will likely be more expensive.

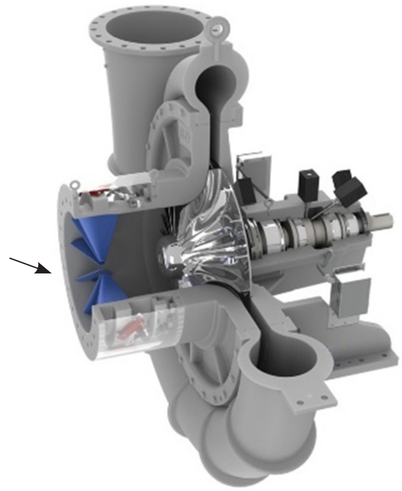


Figure 6.35: Axial inlet guide vanes

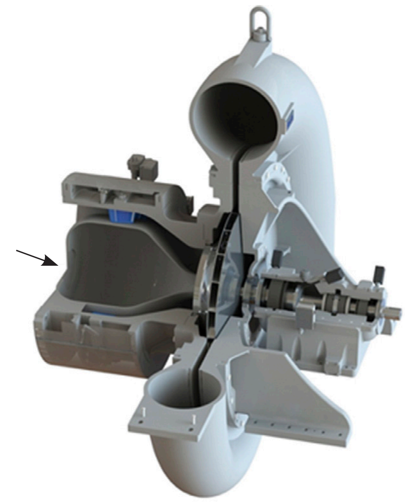


Figure 6.36: Peripheral inlet guide vanes

Constant-speed single-stage centrifugal blower construction

Casing

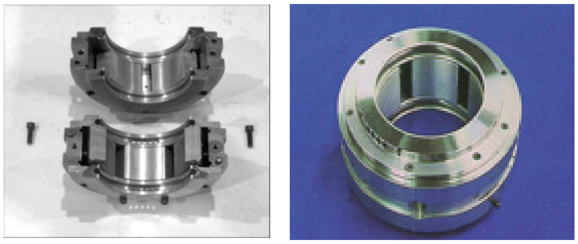
The single-stage centrifugal blower can typically be manufactured from a wide range of materials to meet the process application. The cast casing can be provided in cast iron, ductile iron, cast steel, or stainless steel. Some manufacturers have the capability to provide fabricated casings and can offer a greater range of material options for overcast casings. Casings can be designed to handle elevated pressures and temperatures in closed-loop process gas applications.

Impellers

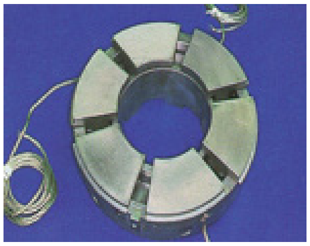
The single-stage impellers are typically the open type with configurations ranging from simple radial designs to three-dimensional backward-leaning vane profiles. A wide range of impeller materials are typically available to meet the process requirements. Impeller material can be aluminum, standard high strength carbon steel, stainless steel, or even more corrosion-resistant high strength materials.

Bearings

The single-stage bearings, both radial and thrust, are the hydrodynamic design as shown in Figure 6.37. Radial bearings can be either sleeve or tilting pad. The thrust bearing can be tapered-land design or a “Kingsbury” design with a double-acting tilting pad.



Exploded and assembled views of tilting pad radial bearing



Tilting pad thrust bearing with RTD temperature sensor

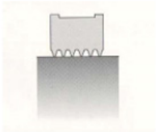
Figure 6.37: Hydrodynamic centrifugal blower bearings

Lubrication

Single-stage centrifugal blowers require pressure lubrication for the hydrodynamic bearings described in Figure 6.37. The oil provides a lubricating film between the babbitted bearing pad surface and the shaft journal. The shaft rides on this film of oil in the clearance between the shaft journal and bearing pad surface. The pressure lubrication system typically has a mechanically driven main oil pump driven from the drive train. An auxiliary electric oil pump is required to provide lubrication at startup and shutdown. The lubrication system includes filtration and cooling. The oil cooler is typically a water-cooled heat exchanger, but air-cooled heat exchangers are options. In both integrally geared and standalone gearbox blower designs, the pressure lubrication will supply oil to the gearing as well as the bearings. In cases where the blower is directly driven by a steam turbine, the lubrication system will also supply oil to the turbine.

Seals

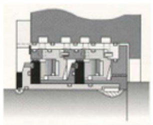
Single-stage centrifugal blowers can handle both air and non-air gases. Gas seals are used within the blower to prevent leakage of higher-pressure gas to atmosphere. For air service, the typical gas seals are simple labyrinth types. For non-air service, there are several gas seal types available. The non-air gas seals include multiple carbon ring and mechanical types. Various seal types are shown in Figure 6.38. Single-stage centrifugal blowers also require oil seals to keep bearing lubrication from entering the compressed gas stream. Oil seals are typically non-contacting slinger type.



Simple Labyrinth

Double Labyrinth with Buffer

Multiple Carbon Ring with Optional Buffer



Mechanical and Dry Gas Seal

Figure 6.38: Different types of seals used in centrifugal blowers

Drivers

Blower drivers for integral gearbox blowers are typically standard NEMA motors. For standalone gearbox designs, drivers can be electric motors, engine drives with speed increasing gearboxes, or steam or gas turbine direct drives.

Constant-Speed Single-Stage Centrifugal Blower Packaging

Single-stage centrifugal blowers (both integral gear drive and separate gearbox drive designs) are packaged in many different ways, largely dependent on the physical size of the blower package and the industry being served.

A typical package will consist of a structural steel base for mounting the drive motor and gearbox/blower. Flexible couplings are used to connect the drive shafts of each piece of equipment with appropriate guards. On the smaller frame size packages, the lubrication system is generally integrated into the structural steel base. On larger frame size packages, and depending on the industry being served, the lubrication system may be an off-mounted console type system with interconnecting piping installed by the user onsite. Higher-capital-cost units will likely be supplied with pressure, temperature, and vibration monitoring devices that are wired to junction boxes at the edge of the skids for interconnection. The drive motor starter and/or variable frequency drive are usually owner-supplied and not part of the blower package.

Piping accessories, such as the following, could be supplied as ship-loose items to be mounted by the customer:

- Air intake filters or filter silencers
- Manual, motorized, or pneumatic inlet (throttling) valve
- Manual discharge (isolation) valve
- Discharge check valve
- Discharge/inlet isolation sleeves or expansion joints
- Inlet silencer
- Discharge silencer for noise-sensitive areas
- Discharge blow-off assembly with manual, motorized, or pneumatic blow-off valve; blow-off silencer, and bird screen
- Pressure and temperature instruments that feed the machine controller

Turbo, High-Speed Motor Blowers

Turbo blowers utilize a single-stage centrifugal airend similar to the gearbox-driven units previously described. Flow and pressure are generated in exactly the same fashion as previously described. The difference is in how the impeller in the direct-drive blower is driven. Instead of using a speed-increasing gearbox to attain the high rpm impeller speeds, the direct-drive blower uses a high-speed motor that is directly attached to the impeller shaft. These motors are variable-speed motors and can rotate from 10,000 to 70,000 rpm by varying the frequency of the power supplied to the motor.

Performance Range

Turbo blowers are driven by high-speed VFD motors and, accordingly, are limited to low voltage motors (600 volts or less) due to the prohibitive cost of variable-speed drives on motors above this low-voltage threshold. This limits the maximum horsepower of turbo blowers to 500 hp. Turbo blowers are produced from 50 hp to 500 hp with pressure capability of up to 20 psig and vacuum capability of up to 17" Hg.

The flow range for turbo blowers is from 1,000 cfm for the 50 hp turbo to upwards of 20,000 cfm for the 500 hp turbo. The majority of turbo service is for pressure applications.

Capacity Control

In direct-drive, high-speed turbo blowers, efficient capacity control is primarily achieved by controlling the speed of the rotating shaft and impeller. By varying the speed of the impeller, the centrifugal blower can be made to perform at any flow and pressure point on its natural performance curve. By speed control only, the turbo blower can perform from 100% capacity to 50% capacity. With the addition of inlet guide vanes and variable-diffuser vanes, capacity reduction to 40% of rated capacity can be achieved. A blow-off valve located after the discharge can also be utilized to prevent the machine from going into surge during low-flow requirements. If the valve is operated via the onboard package controller, the high-speed motor turbo blower can provide variable capacity control down to zero flow. This level of control is highly inefficient, as it results in venting expensive compressed air to atmosphere.

Turbo, High-Speed Blower Construction

The blower casings are cast pieces, which can be made from close-grained cast iron, such as ASTM A536, or an aluminum alloy, such as ASTM A356. Both inlet and discharge connections can be cast integrally with the casing. The discharge is usually a flanged-type connection to handle the higher pressures.

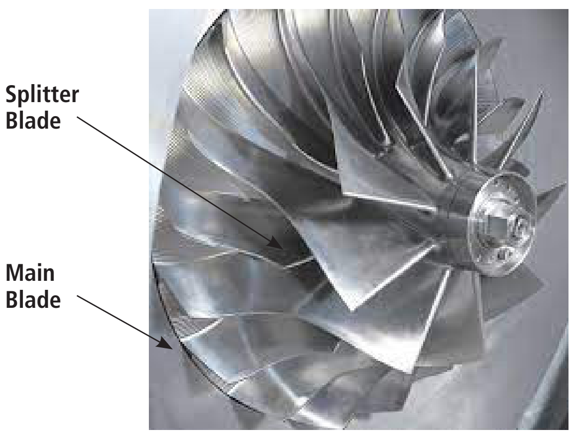


Figure 6.39: Milled backwards-leaning profile impeller with splitter blades

Impellers are typically milled with an open, backward-leaning profile with splitter blades between the main blades, as shown in Figure 6.39. Impeller profile, materials of construction, and manufacturing process will vary by manufacturer. The impeller is directly mounted onto the shaft, which rotates the blades at shaft speed. The production of impellers can be done by various manufacturing methods. These include cast construction or five-axis milling. The preferred method is five-axis milling due to the precise tolerances that can be maintained. Impellers are usually made from stainless steel or high-strength aluminum alloys.

Blower shafts are constructed from heat-treated materials, such as forged steel, steel alloys, or titanium. The shafts are precision-machined to ensure the proper fits that are required for mounting the motor rotors, impeller, spacers, seals, and bearings. The shaft is designed to be as stiff as possible, and all rotating elements and assemblies must be dynamically balanced to eliminate unwanted vibration at high speeds.

Labyrinth seals are used to minimize high-pressure air leakage from the blower volute to the atmosphere, the gearbox, or the motor. The sealing action works by allowing a very small amount of high-pressure gas to escape into a chamber formed by a row of rings, as illustrated in Figure 6.40. The set of rings can be on the rotating shaft, stationary casing, or both. Figure 6.40 depicts a labyrinth seal with the rings on the stator. As the air or gas enters the chamber, it is slowed down and its direction is changed as it navigates the tortuous labyrinth path. This action creates a pressure drop. As the pressure of the escaping air decreases, so too does the amount of leakage past the labyrinth seal. The length of the labyrinth varies according to the required pressure drop. The higher the pressure drop, the longer the required seal. Because these labyrinth seals are noncontact, they do not wear out. The seal parts can be made of brass, aluminum, or carbon steel.

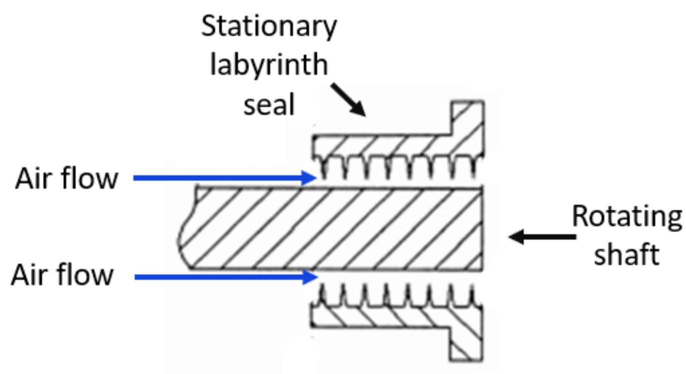


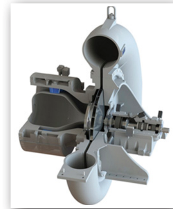
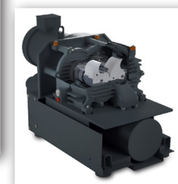
Figure 6.40: Typical straight through labyrinth seal

High-speed motor turbo blowers use oil free, non-contacting bearing technology. The two basic types of oil free bearing technologies are air-bearing type and magnetic-bearing type. The air bearing creates an air pressure film barrier between the shaft journal and bearing surface as the shaft rotates. The shaft is essentially riding on air as it rotates. The magnetic bearing uses magnetic force to suspend the shaft so that the shaft rotates inside the magnetic bearing. Both technologies allow the shaft to rotate without making contact with the bearing surface. Each technology type has advantages and disadvantages. The user should investigate both technologies to determine the best fit for their specific blower application.

Air Bearings

The general principle of operation is that a fluid, typically air, creates a clearance between the bearing surfaces. In blowers, the rotating shaft pressurizes the air trapped between the stationary and moving surfaces. Starting at zero rpm, the shaft rests on the air bearing. When the shaft starts to spin, the air aerodynamically converges in a wedge-like fashion between the rotating and non-rotating surfaces, which causes the air to compress. As the shaft speed increases, it will hit a critical rpm where the air pressure becomes greater than the weight of the rotor assembly, at which point the shaft lifts off of the non-rotating bearing surface and floats within a gap clearance that is typically 5 to 50 microns. Special coatings are used on the contacting surfaces to provide lubricity during starts and stops. There are three types of air bearings: air foil bearings, leaf air bearings, and tilting pad journal air bearings.



Air Foil Air Bearing

Air foil bearings are typically constructed with a single corrugated (bump) foil and a smooth top foil, as shown in Figure 6.41. Both foils are attached to the non-rotating stator along one edge and are wrapped around in the opposite direction that the shaft rotates. When the shaft spins, the air is drawn by radial motion between the shaft and top foil, causing the gas to be compressed. The bump foil acts as a spring to absorb the expansion of the air and corrects any misalignments. The spacing of the foil allows for cooling air to pass through the bearing. To handle the axial loads in the rotating assembly, a thrust bearing is used. This thrust bearing uses the same aerodynamic principle described above to handle the axial load on the shaft.

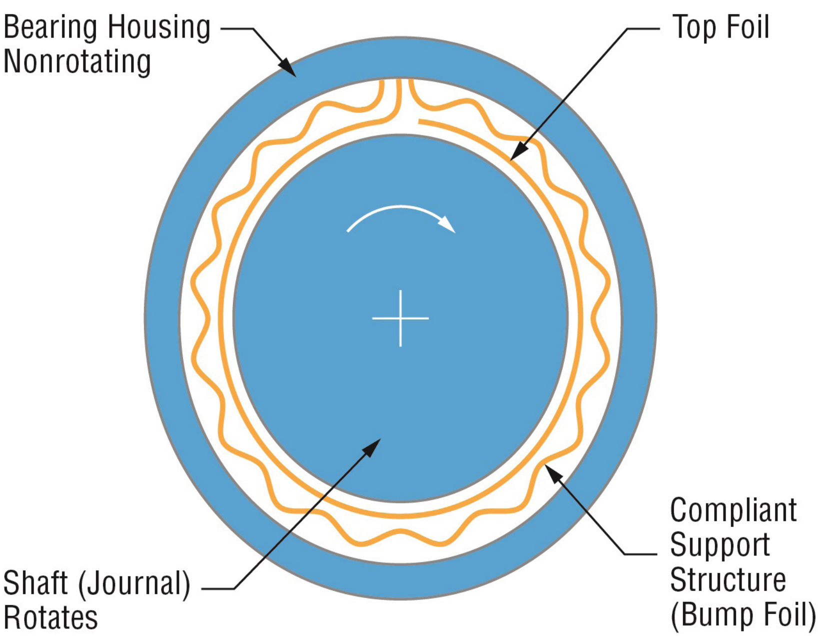


Figure 6.41: Air foil air bearing

Leaf Air Bearing

Leaf bearings are composed of several flat, thin structures (leaves) arranged in an iris formation that rests against the shaft when it is stationary, as illustrated in Figure 6.42. When the shaft starts rotating, a cushion of compressed air is formed, which causes the leaves to expand away from the shaft. As the shaft rotation increases, the pressure becomes critical and creates a clearance between the shaft and leaves, thus allowing the blower to operate.

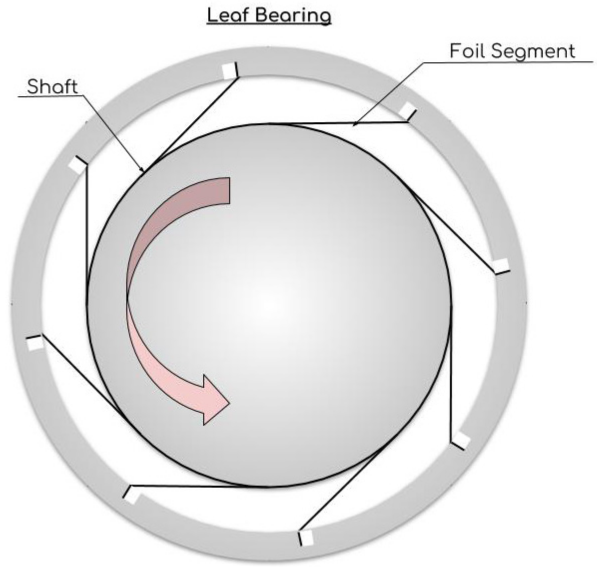


Figure 6.42: Leaf air bearing

Tilting Pad Journal Air Bearing

Tilting pad journal bearings consists of several curved rocker pads in an arrangement that surrounds the shaft, as shown in Figure 6.43. Each rocker pad is designed with a pivot point that rests against the non-rotating part of the bearing. As the shaft starts to rotate, a cushion of air will circulate around the shaft and push against the pads, tilting them slightly. This creates a wedge of compressed air and when the shaft attains critical rpm, the pressure causes the shaft to "lift off." The positioning of the rocker pads around the shaft allows the increased air pressure to be distributed across the surface of the shaft and keeps it centered. The disadvantage of the tilting pad journal bearing is its complex design with multiple parts.

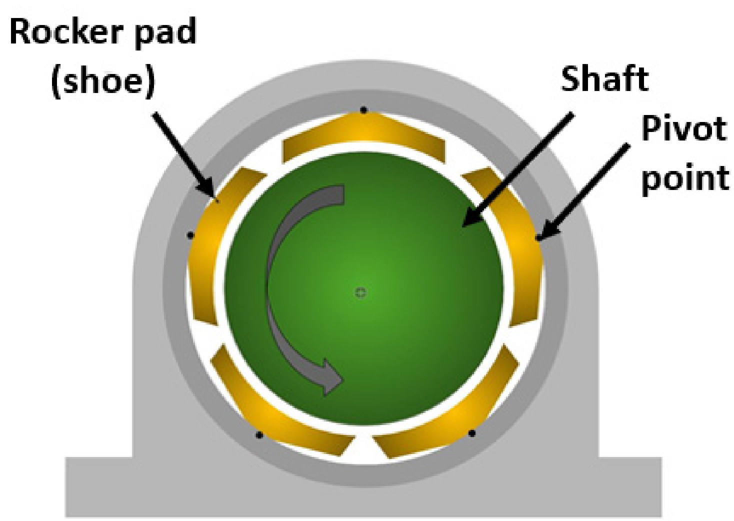


Figure 6.43: Tilting pad journal air bearing

Magnetic Bearings

The second type of bearing used in high-speed blowers is the Active Magnetic Bearing (AMB). The AMB has several sets of electromagnets. When electrical power is provided to the unit, the motor rotor shaft will be levitated in a magnetic field. The magnetic field is generated by two radial and two axial AMBs. The position of the rotor is located by two rotor position sensors. These two sets of AMBs are controlled by a Magnetic Bearing Controller (MBC). The position sensor continuously monitors the shaft position in both the radial and axial directions. As illustrated in Figure 6.44, the position sensors send a signal to the MBC, which adjusts the strength of the magnetic field in each magnet set. The magnetic field centers the motor rotor shaft and keeps it in the correct axial position as the rotor spins. The MBC monitors the position of the shaft/rotor combination on five axes: X, Y, up, down, and Z. This design allows for vibration-free operation, which ensures less stress in the piping and provides pulsation-free air distribution. If the shaft were to move out of its proper position, the MBC will detect this movement and correct the shaft position. If the vibration is determined to operate outside of the acceptable range, the unit will fault out and safely shut down. The MBC system therefore acts as its own vibration sensor.

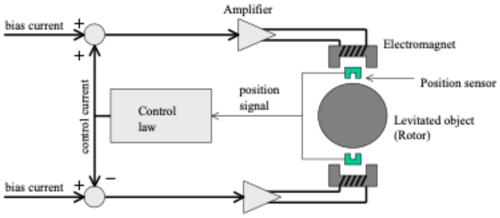


Figure 6.44: Simplified layout of the active magnetic bearing

The advantages of magnetic bearing blowers are extremely low energy consumption and high reliability due to the elimination of mechanical contact and friction between the shaft and the AMB. The AMB allows for limitless starts and stops with zero wear. A backup system is used to provide power to the MBC in the event of a power outage to safely shut down the machine. These blowers also use mechanical roller bearings as touch-down bearings for "worst-case" failures.

Turbo, High-speed Motor Blower Packaging

Direct-drive, high-speed blowers are typically packaged as complete units inside a sound-attenuating enclosure. The components are fitted in a compact arrangement, as illustrated in Figure 6.45. The motor, the VFD electronics, and the needed control equipment are factory-installed and wired into the machine. Due to their small footprint and low vibration, direct-drive blower packages do not require robust concrete mounting pads.

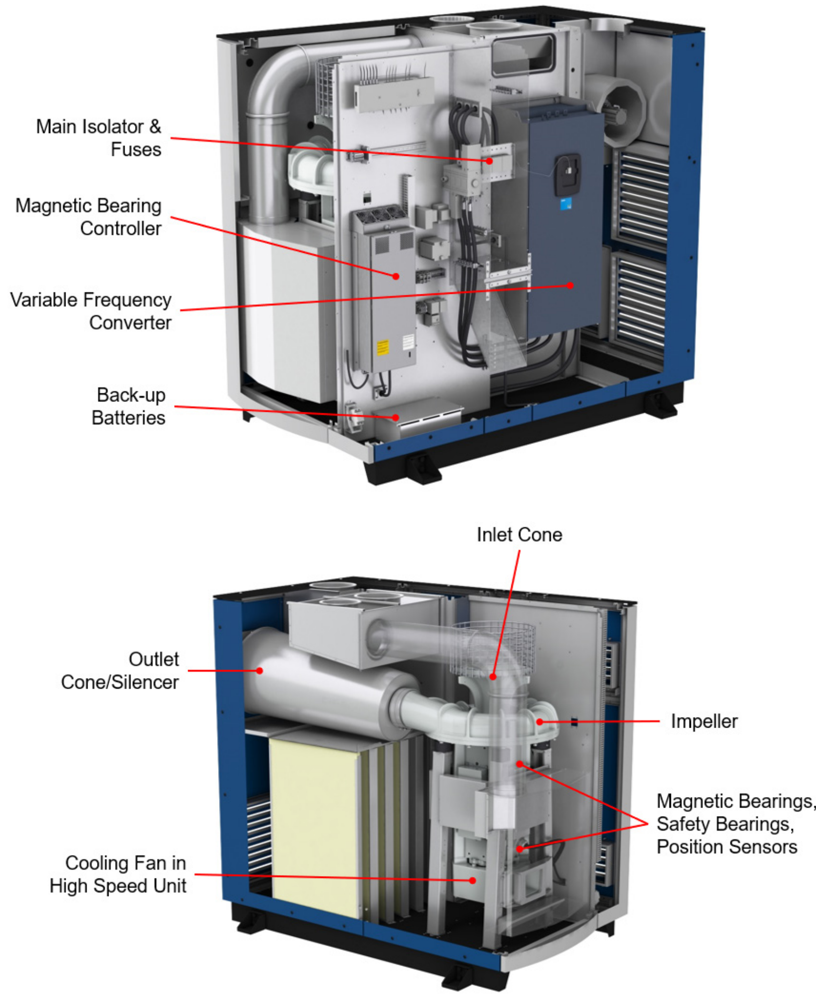
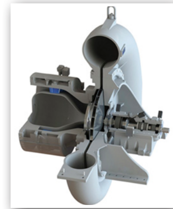


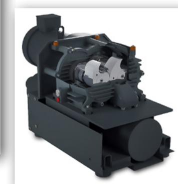
Figure 6.45: Typical direct-drive, high-speed blower packages

Direct-driven blowers can be either water-cooled or air-cooled. In water-cooled designs, an integral water-cooling circuit is used. The integral cooling circuit will require a pump, a heat exchanger, and a fan. In air-cooled packages, cooling air is supplied either by a separately driven electric fan or by using a shaft-mounted cooling fan.

Inlet filters are required to clean the incoming air to prevent particulates from entering the machine and clogging the seals and bearings. Silencers are mounted directly onto the inlet and outlet of the blower package, or even inside the package, to mitigate the noise created by the rapidly moving air in the pipes. Flexible joints are required on the outlet of the blower package to prevent the thermal expansion of the pipe, caused by the heat of compression, from transmitting stresses to the volute.

Centrifugal blowers, unlike positive displacement blowers, will only produce a certain maximum discharge pressure even if the discharge valve is closed. If the piping system is designed to withstand this maximum pressure level, then pressure relief safety valves are not needed. However, if two or more blowers are to be operated in parallel, then each blower must have its own dedicated check valve. This will prevent the air flow of the operating blower from entering the discharge of the offline blower, preventing the offline blower from rotating backwards. Autorotation, over time, could damage the machine. Shutoff valves are typically needed to safely isolate the blower if the unit needs to be taken offline and serviced.





Direct-drive blowers require constant monitoring to assure safe operation. The blower package utilizes instrumentation, such as pressure sensors, temperature sensors, proximity probes, vibration switches, power monitors, and speed indicators. This data is sent to the onboard package controller (that can receive process inputs manually) through analog PID control loops or from signals sent from the SCADA or other plant control systems. The controller adjusts the flow continuously to maintain the required pressure, flow, and process parameters that have been established. The controller also allows the blower to alarm or fault-out due to conditions such as high bearing temperature, excessive vibration, out of tolerance rotor position, or low suction pressure.

As previously discussed, the blower will go into surge if it is operated below the minimum flowrate. To avoid this condition from happening at start-up or shut-down, a blow-off valve is used. The blow-off valve is opened during startup until back pressure is achieved, normally in 30-45 seconds, at which time the valve automatically closes. Once the blower is no longer needed and shuts down, the blow-off valve opens.

Single-Stage Centrifugal Blower Applications

Centrifugal blowers are used in applications that require large volumes of air or gas at pressures of 18 psig or vacuums up to 15" Hg. Although they are capable of operating as exhausters, the majority of single-stage centrifugal blower applications are for pressure service. Centrifugal blowers find extensive use in aerating wastewater for both municipal and industrial wastewater treatment facilities. Aeration feeds the microorganisms in the waste stream with the oxygen they need to digest the organic matter in the wastewater. Industrially, centrifugal blowers supply combustion air in applications like waste-to-power electricity-generating plants. They are used extensively in the non-woven textile industry to produce the non-woven fabrics used as filter media, face masks, and disposable hazmat suits. Due to the fact that they produce oil free pressurized air, centrifugal blowers are commonly used in the food and beverage industry, as well as in the pharmaceutical industry, for applications such as blow-off, dust removal, and drying. Unlike positive displacement blowers, centrifugal blowers see only limited usage in pneumatic conveying applications due to their difficulty in maintaining a constant discharge pressure under varying conveying loads. Due to their usage of air foil or magnetic bearings, high-speed turbo blowers are limited to air applications only, whereas constant-speed centrifugal blowers can operate in applications with air and a variety of other gasses.

Multistage Centrifugal Blower

Operating Principle

The multistage centrifugal (MSC) blower is a dynamic blower that works similarly to a single-stage centrifugal blower by accelerating air molecules into kinetic energy and then converting this kinetic energy into static pressure by slowing the air down. As shown in Figure 6.46, the MSC blower draws air into the center of its first stage via an inducer/volute. The air is accelerated outward, via centrifugal force, towards the periphery of the shrouded impeller, and is then discharged into the diffuser section, which slows the air and builds pressure. The pressurized air is then guided into the eye of next impeller with a single or multiple baffle ring.

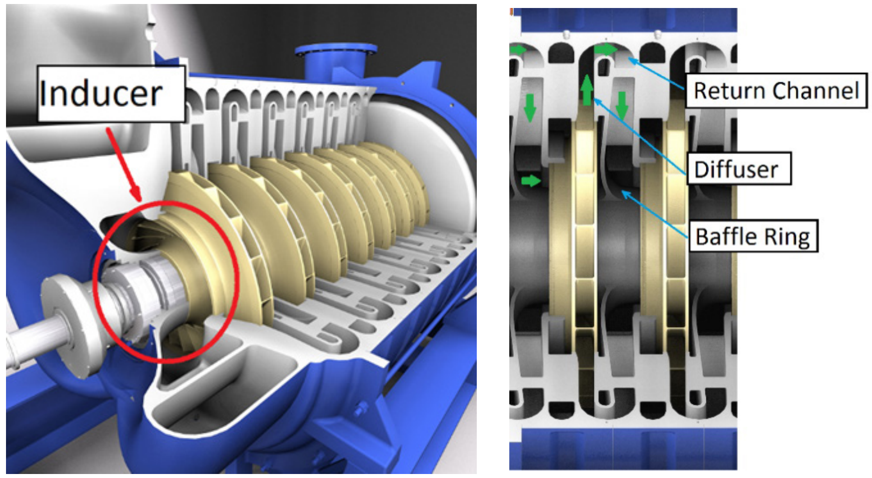


Figure 6.46: Air flow through a multistage centrifugal blower

This process is repeated for as many stages as are designed into the blower, as shown in Figure 6.47. Since the rise in pressure between stages is small, additional stages of compression are needed to achieve higher discharge pressures. The number of stages is determined by the flow and pressure requirements that the blower is designed to deliver. When the air reaches the outlet header of the machine, it is collected into a volute and then fully discharged into the system. This multistage compression process is similar to operating several single-stage units in series.

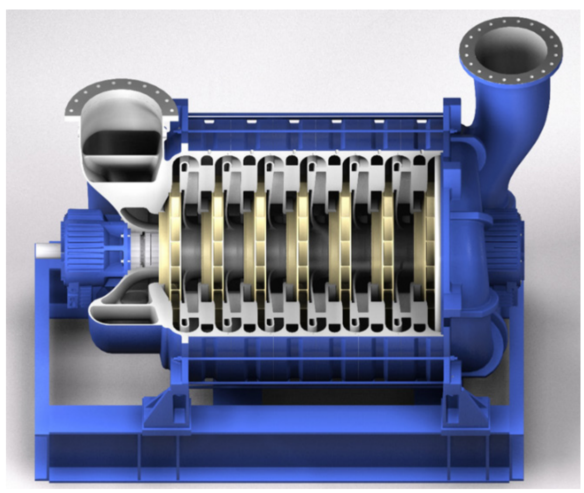


Figure 6.47: Cutaway view of a seven-stage multistage centrifugal blower

MSC blowers are categorized as being either vertically split or horizontally split, which refers to the plane along which the blower casing and bearing housings are joined. Whether they are horizontally split or vertically split depends upon the service for which the blower is designed. Although there are some design differences between the horizontally split and vertically split multistage blowers, which will be discussed later in this section, both categories share a common, basic multistage design.

Performance Range

The flows and pressures of MSC blowers overlap with other blower technologies. Air, along with steam and other non-air gases, can be handled. The most common flow range for vertically split MSC blowers is from 500 cfm to 35,000 cfm, with compression ratios limited to 1.75:1 for very low-flow MSC blowers and upwards of 2.2:1 for very high-flow MSC blowers. At sea level, these compression ratios enable

MSC blowers to operate at vacuums up to 15" Hg and pressures up to 18 psig. MCS blowers can also be operated with negative pressures on the suction side and positive pressures on the discharge at the same time provided the compression ratio is not exceeded. Exceeding the compression ratio limit of a MSC blower can force the blower into an unwanted surge condition. For horizontally split MSC blowers, the flow range is from 5,000 cfm to 100,000 cfm with pressure capability of up to 65 psig and vacuum capacity of up to 15" Hg based on sea level conditions. Note that when classified as blowers, horizontally split MSC blowers are limited to 30 psig discharge pressure. Horizontally split MSC machines that operate above 30 psig are classified as low-pressure compressors.

MSC Blower construction

The typical MSC blower has an inlet head, intermediate sections (stages), and an outlet head, as illustrated in Figure 6.48. The impellers are mounted to the shaft and positioned in each section. The rotating impeller shaft is supported by two outboard antifriction ball bearings (one on each end of the shaft). These bearings carry the radial load of the rotating assembly with the inlet bearing also subject to a thrust load.

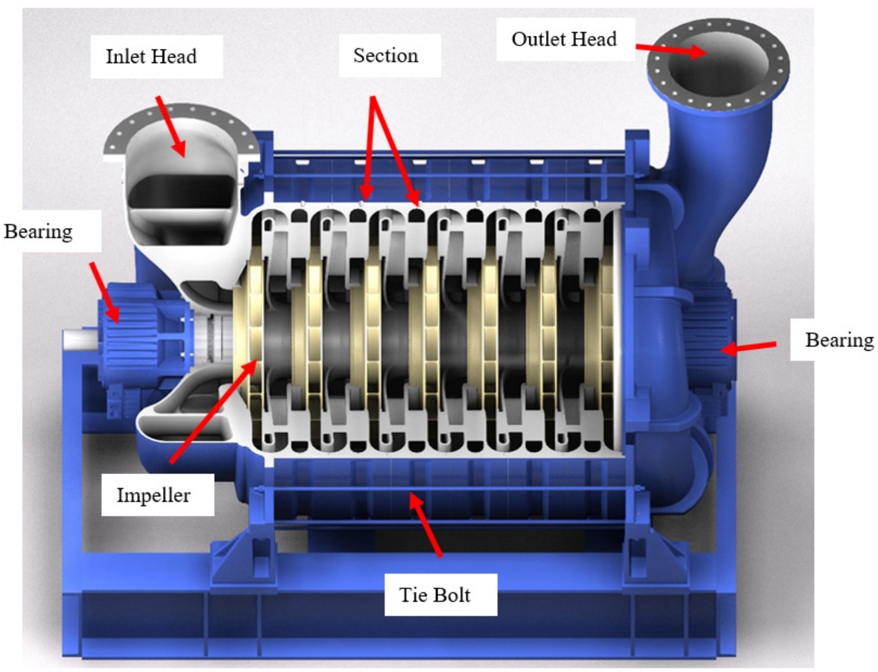


Figure 6.48: Components of a multistage centrifugal blower

In higher-pressure machines where there is greater thrust, the load can be offset by the use of a balance piston. The ball bearings precisely position the impeller assembly so that there is no contact between the rotating and stationary parts within the blower. The bearings are lubricated by an oil slinger in the oil lubrication chamber or are grease-lubricated. Bearings are typically rated for an L-10 life of 10 years or longer as per the Anti Frictional Bearing Manufacturers Association. Shaft seals are typically of the labyrinth or carbon ring design and are located at each end of the shaft. These seals ensure that the MSC blower delivers oil free air by keeping bearing lubrication out of the process air stream. Typical bearing, seal, and balance piston arrangement is illustrated in Figure 6.49.

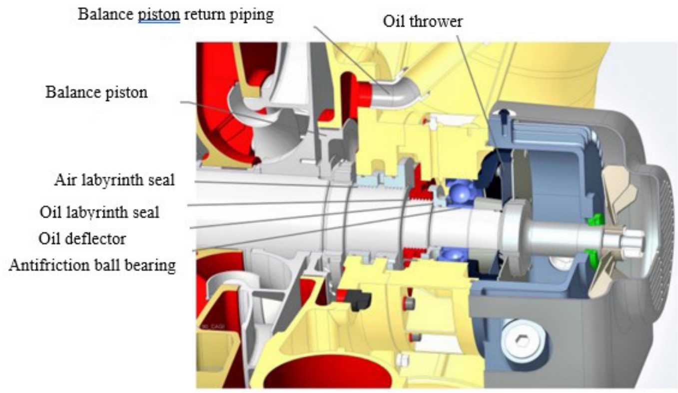
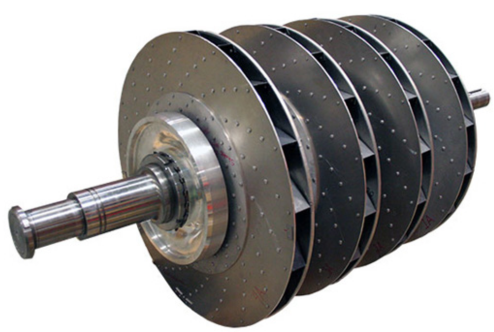


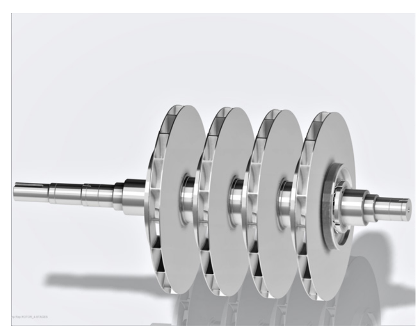
Figure 6.49: Bearing, seal, and balance piston arrangement on non-drive end of MSC blower

The inlet flange centerline is in line with the centerline of the blower shaft, and the outlet is tangential to the blower shaft. The inlet and outlet heads, as well as the sections, are made of machined cast iron. Shafts are typically carbon steel. Impellers can be constructed from cast aluminum or fabricated from aluminum, steel, or stainless steel, as illustrated in Figure 6.50. Where required, corrosion-resistant metals or coatings can be used for impellers and housings, making the units suitable for use with a wide variety of gases and temperatures. It is common for a manufacturer to have multiple impeller designs for each blower frame size. This allows the machine to be modified to produce the airflow and pressure required for a multitude of specific applications.

The MSC blower is assembled by adding the proper number of stages onto a single shaft. First, the shaft is installed into the inlet head, then the first impeller is keyed onto the shaft. Next, the housing section is installed over the impeller. The complete assembly, consisting of the shaft-mounted impeller and its surrounding housing section, is referred to as a stage. The remaining stages are added and tightly secured with tie rods to form the MSC housing. Finally, the discharge head volute is installed. To keep the assembly simple and uniform, the external dimensions of the impellers are the same. There are different impeller vane profiles available for a given frame of multistage blower. Within the same MSC blower, the various stages can utilize impellers with up to three different vane designs. The most radial-vaned impellers are closest to the blower inlet head while backward-leaning-vaned impellers are located closest to the blower outlet head to maximize outlet pressure.



Fabricated (Riveted) Impeller



Cast Aluminum Impeller

Figure 6.50: Fabricated and cast impeller assemblies

Multistage Centrifugal Blower Performance Characteristics

MSC blowers are considered constant pressure, variable-volume units, meaning that they provide a relatively constant discharge pressure under variable flow conditions. This characteristic makes the MSC blower ideal for a wide variety of variable flow and constant pressure applications as well as for vacuum service. The performance of a constant-speed MSC blower is defined in its performance curve, as shown in Figure 6.51. As illustrated on the performance curve, pressure remains relatively constant with flow, except for a slight increase in pressure at lower flows, as the units backs up its curve. This slight increase in pressure is referred to as the "rise to surge pressure." As previously described regarding single-stage centrifugal blowers, the MSC blower is subject to surging at flow rates that are below its operational range. At its maximum flow rate, the blower will enter choke condition, where flow remains constant regardless of any further decrease in discharge pressure. As flow reaches the choke condition, pressure decreases. This pressure reduction is due to the friction of the air moving through the blower, which increases as flow increases. This increased friction results in a loss of pressure. This pressure loss can be controlled by using a variable-speed drive on the MSC. By changing the speed of the blower, the differential pressure changes. This reduction in pressure loss makes the variable-driven MSC blower more efficient than a constant-speed blower of similar capacity.

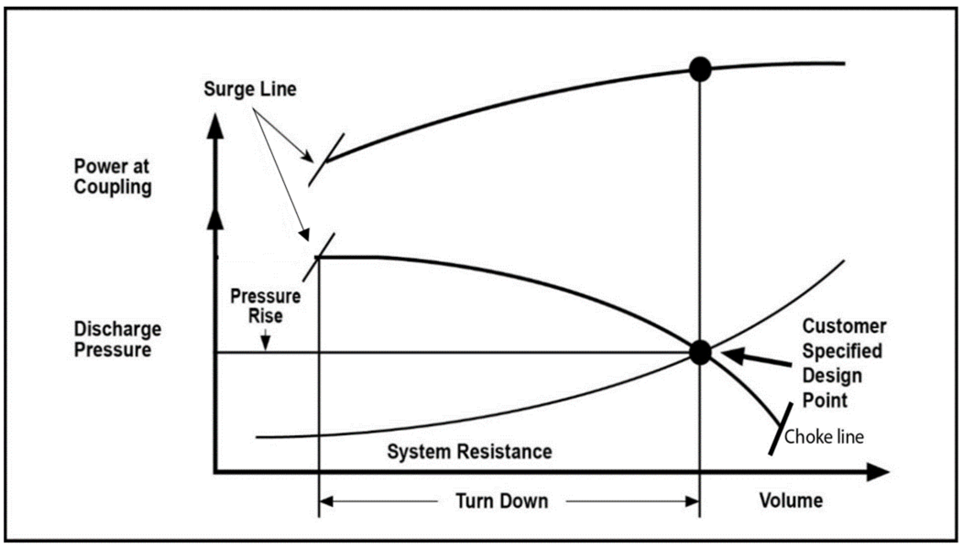


Figure 6.51: Performance curve of a constant-speed, multistage centrifugal blower

All multistage centrifugal blowers develop an internal compression ratio adiabatically, but the final discharge pressure is dictated by the system pressure requirements, isochoric compression. Depending on system resistance, the blower will operate on its performance curve, between surge and choke, to deliver the flow required to maintain a relatively constant system backpressure. System backpressure and MSC flow are inversely related. If system backpressure increases, then the flow will decrease. If system backpressure decreases, then flow will increase. Inlet flow varies to maintain the pressure requirements of the system.

MSC blower horsepower increases as flow increases. Horsepower also varies with changes of inlet gas density due to variations in temperature, inlet pressure, and relative humidity; as illustrated in Figures 6.52 and 6.53.

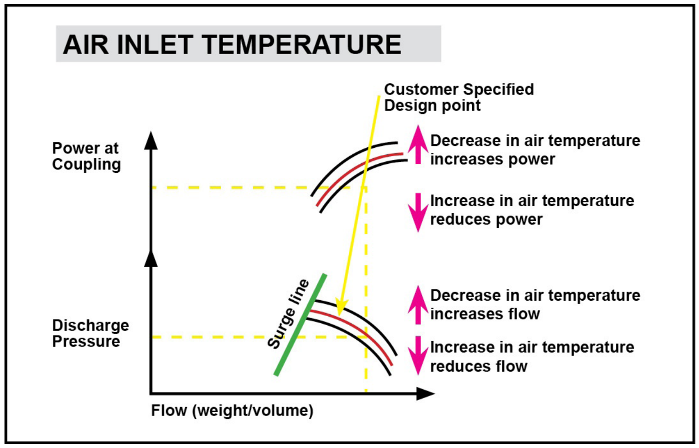


Figure 6.52: Effect of inlet air temperature upon flow and horsepower

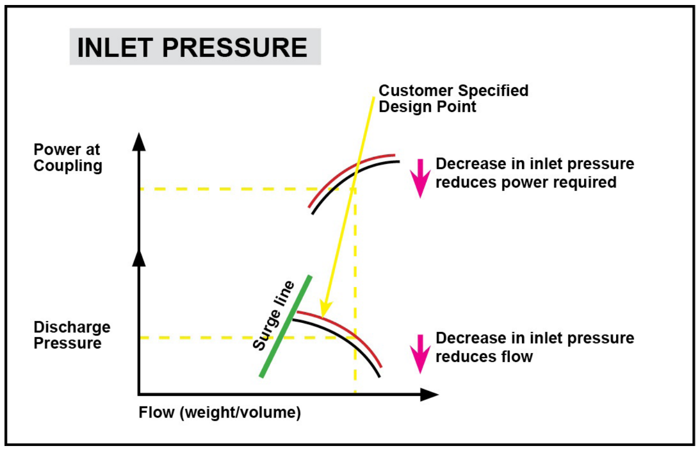


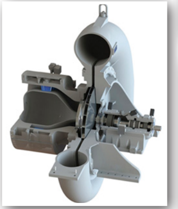
Figure 6.53: Effect of reduced inlet air pressure upon flow and horsepower

A multistage centrifugal blower is defined as a "variable torque" machine for purposes of determining the necessary characteristics for drivers (especially variable-speed motors). This is the opposite of PD blowers, which are classified as "constant torque" devices. Drivers can be sized accurately to the pressure or vacuum requirements for which the blower is designed.

Similar to all air compression devices, MSC blowers develop a temperature rise between inlet and discharge due to the heat of compression and the effects of slip. MSC blowers are air-cooled, and they typically have a discharge temperature limitation of 350˚F for blowers with heat-treated aluminum impellers. Slightly higher discharge temperatures are permitted with the use of steel or stainless-steel impellers. The operating temperature of the blower will not only affect the process that the blower is feeding with gas but the operation of the blower itself. Excessive temperature rise can exceed the thermal limits of the impeller, resulting in excessive thermal expansion that can cause catastrophic impeller-to-housing contact. Excessive blower discharge temperature can also heat the lubricant beyond its operational limit and cause it to breakdown, leading to bearing and seal damage.

MSC blowers incorporate many design features that contribute to job versatility and economical operation. MSC blowers provide high volumetric efficiency. There are no contact points other than the bearings and seals, and compared to any other blower technology, MSC blowers are traditionally lower in maintenance and replacement costs. Equipment life cycles of 20 years or more are commonplace. The completely






enclosed construction provides the MSC blower with protection against dust and the elements, making these blowers well suited for indoor and outdoor installations.

Capacity Control

The designed-in capacity of constant-speed multistage centrifugal blowers is determined by impeller speed and impeller profile. As previously discussed, the blower will operate on its performance curve between surge and choke conditions in response to the system backpressure. Controlling the capacity of a constant-speed MSC blower is achieved by throttling the inlet valve. Motorized valves to throttle the inlet can provide precise and low-cost capacity control for both low- and high-horsepower MSC blowers, making it a common choice for capacity control.

By using a variable-speed drive to operate the blower, the speed of the impeller can vary, thus providing efficient capacity control. Figure 6.54 illustrates the efficiency gain realized by controlling the capacity of a MSC blower by using a variable-speed drive (versus capacity control by inlet throttling). Variable-speed drives are limited for use on MSC blowers with low-voltage motors, since variable-speed is cost prohibitive for motors larger than 600 volts.

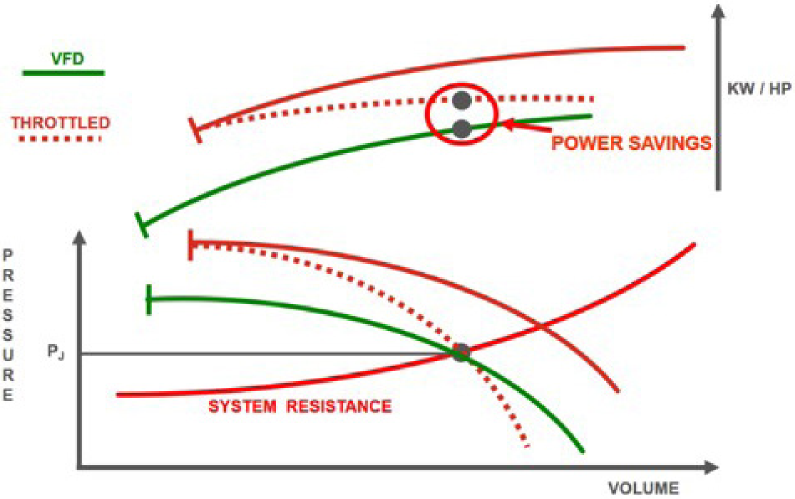


Figure 6.54: Inlet throttling versus variable speed control on a MSC blower

Multistage Centrifugal Blower Packaging

Although MSC blowers are sold to OEMs as bare blower elements for specialized applications, the blowers described in this chapter are commonly provided by manufacturers as fully assembled blower packages. Since MSC blowers are heavily used in several specific applications, such as in wastewater treatment and for industrial combustion air, the MSC blower package is designed to the specific requirements associated with the application for which it is intended.

Figure 6.55 illustrates a typical, basic, fixed-speed blower package. These packages include the common structural steel baseplate, motor pedestal, drive motor and coupling with guard, vibration isolation pads, and required blower and motor instrumentation. Since centrifugal blowers will only produce a certain maximum discharge pressure even if the discharge valve is closed, relief valves are never needed with MSC blowers. Typically, basic blower packages do not include motor starters or variable frequency drives for the drive motor, as these are usually owner-supplied.

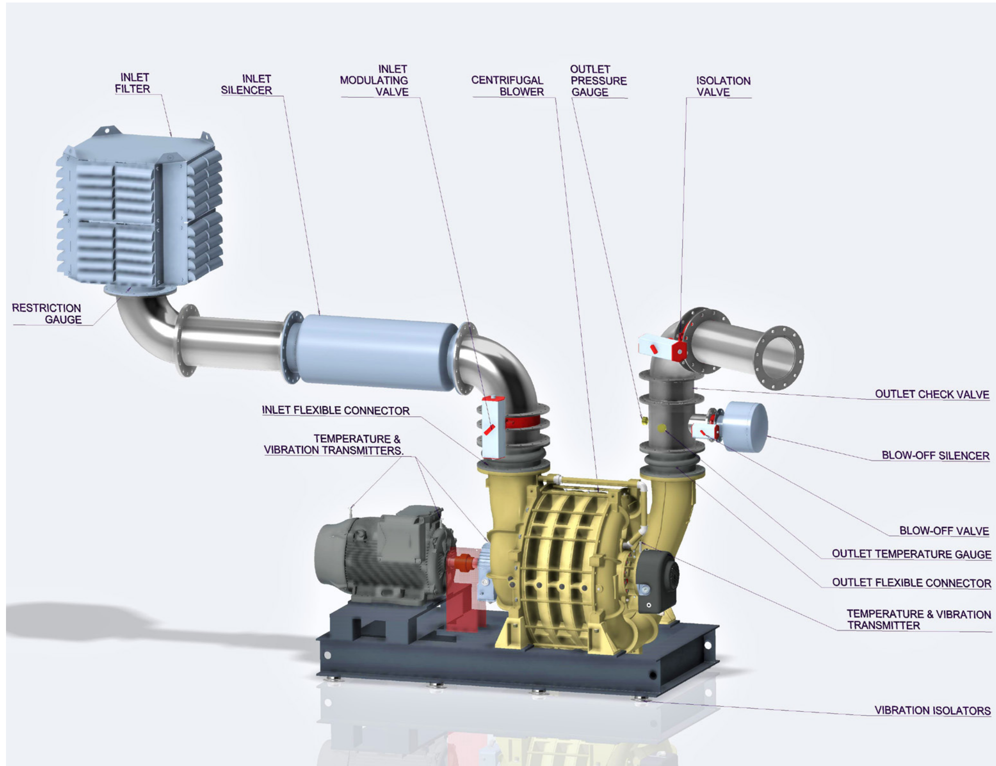


Figure 6.55: Typical MSC blower package with inlet valve modulation

Piping accessories and various options as listed below are often supplied:

- Air intake filters or filter silencers
- Manual, motorized, or pneumatic inlet throttling valve
- Manual discharge isolation valve
- Discharge check valves
- Discharge isolation sleeves or expansion joints
- Inlet isolation sleeves or expansion joints
- Inlet silencer to reduce noise from inlet throttling valve
- Discharge silencer for noise-sensitive areas
- Discharge blow-off assembly with manual, motorized, or pneumatic blow-off valve, blow-off silencer, and bird screen
- Pressure and temperature gauges can be mounted or shipped loose. Pressure and temperature transmitters that feed the machine controller are normally factory-mounted.
- Vibration transmitter probes are common on higher capital cost units

Smaller blower packages may only have a manufacturer-supplied Local Control Panel (LCP) that provides surge protection. As blowers increase in size, protection requirements increase as well, especially the need to precisely deliver the required air flow at the lowest possible cost. For single MSC blower packages, the LCP can provide surge protection plus inlet valve throttling or speed control to achieve flow control and/or optimization to reduce energy consumption. The LCP will ensure the delivery of a metered quantity of gas to the process within the performance limits of the blower. The LCP can manage either inlet throttling or variable-speed blower operation. The LCP is the central point of the unit for smooth operation and protection. On most blower packages, the end user has the option to wire signals from the OEM package instrumentation and valves directly to the Distributed Control System (DCS). From the

DCS, the end user can program the start/stop control loop and flow control loop by themselves. Many LCPs are fitted with modern processors as well as communication protocols that allow these machines to be connected to plant networks for real-time monitoring and control.

Larger blowers are often specified with one or several of following instrumentation and control options:

- Vibration sensors on each blower bearing
- Vibration sensor on motor
- Temperature monitoring of blower bearings
- Temperature monitoring of motor bearings
- Temperature monitoring of motor stator
- Variable-speed driver for motor on lower-horsepower installations
- Motorized inlet valve to provide low-cost capacity control
- Motorized blow-off valve for smooth startup and pressure offloading to prevent surge
- Discharge pressure transmitters
- Inlet gas temperature

For installations having multiple, multistage centrifugal blowers, blower manufacturers often supply a blower Master Control Panel (MCP) that will have ultimate operational control over all of the blowers in the system. The MCP operates from a single-point control signal supplied by the end user.

Horizontally Split MSC Blowers

Horizontally split MSC blowers are normally used in specific applications where the horizontally split casing provides certain capabilities that allow it to be used on critical duty for gas or air applications where the ultimate in reliability and in-place maintainability is desired. Accordingly, the horizontally split MSC design is capable of meeting the exacting specifications of the American Petroleum Institute (API). This makes the horizontally split MSC the blower of choice for the oil and gas industry. The horizontally split casing also allows for quick inspection and maintenance of the bearings, seals, and impeller by simply removing the top half of the bearing housing and casing, as illustrated in Figure 6.56. This can be accomplished without removing the blower from the installation. This quick disassembly advantage is a major reason rotating equipment engineers specify horizontally split MSCs for critical duty applications.

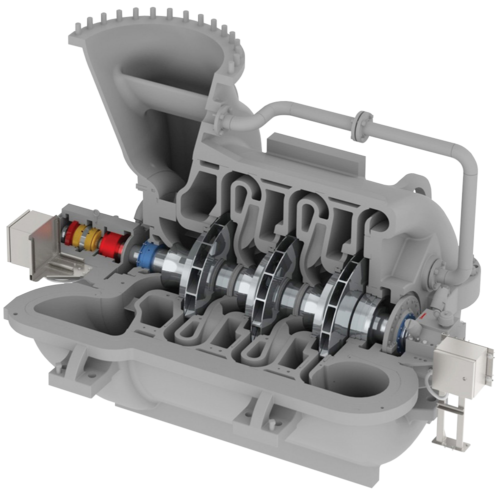


Figure 6.56: Typical bare shaft horizontally split multistage centrifugal blower

Horizontally Split MSC Design Characteristics

Although horizontally split MSC blowers follow the same operating principle and characteristics of the vertically split designs, horizontally split designs differ significantly in housing construction, bearing design, and impeller design. Horizontally split MSC blower housings are made of two castings that bolt together versus the separate stage-sections that are sandwiched together in vertically split designs. The housings are manufactured from a wide range of materials to meet specific process applications. They can be cast from iron, ductile iron, steel, or stainless steel. Fabricated casings can offer a greater range of material options. Housings can be designed to handle elevated pressures and temperatures in closed loop process gas applications.

Unlike the vertically split MSC designs that utilize ball bearings on both ends of the impeller shaft, the horizontally split MSC utilizes hydrodynamic bearings for both the radial and thrust loads. The radial bearings can be either sleeve or tilting pad type. The thrust bearing can be tapered-land type or "Kingsbury" type double-acting tilt pad. These bearings were previously illustrated in Figure 6.37. These hydrodynamic bearings require that a thin film of oil be maintained between the rotor shaft surface and the bearing surface. Accordingly, a pressurized lubrication system continuously pumps oil into the bearing journals to maintain this film of oil as the blower operates. Maintaining clean oil at the right temperature allows the bearings to have a theoretically infinite life compared to roller antifriction bearings that have a finite life. This long-lived bearing life is a key characteristic of horizontally split MSC blowers that make them the superior choice for critical applications.

The impellers on horizontally split MSC blowers are typically the closed, backward-leaning-blade type, as illustrated in Figure 6.57. Unlike impellers in vertically split MSC blowers, which are all of the same diameter, impellers in a horizontally split blower reduce in diameter as the impellers get closer to the discharge. Impeller size reduction, coupled with higher rotation speeds, allow the horizontally split MSC blower to attain higher flows and pressures than the vertically split design. Horizontally split MSC machines are often classified as low-pressure compressors, as their operating pressure can approach 65 psig. Impeller material can vary from standard high strength carbon steel to stainless steel grades and even more corrosion-resistant, high-strength options. In some designs, the impeller front cover at the impeller inducer section is the seal face to the casing inter-stage labyrinth seal. As illustrated in Figure 6.58, the seal has a long horizontal sealing area and creates a barrier that prohibits air leakage from the high-pressure side of the impeller to the lower-pressure inlet side. This extra sealing length allows axial movement in the rotor without allowing the impellers to contact the casing. This design is more forgiving than an open impeller design that has very tight clearance to the casing. This forgiveness is another reason that the horizontally split design is more commonly specified for critical applications than is the vertically split design.

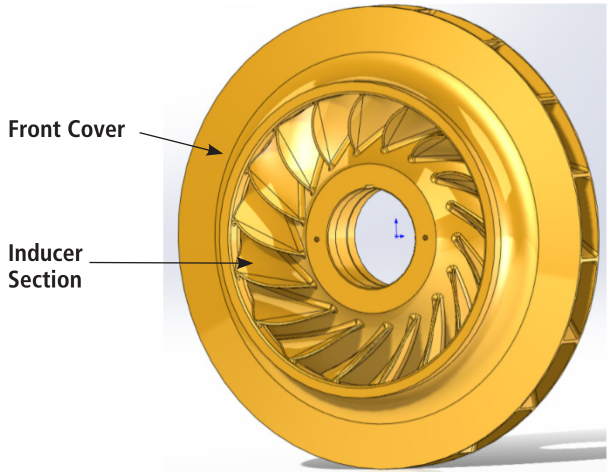


Figure 6.57: Closed centrifugal impeller with backwoard-leaning blades

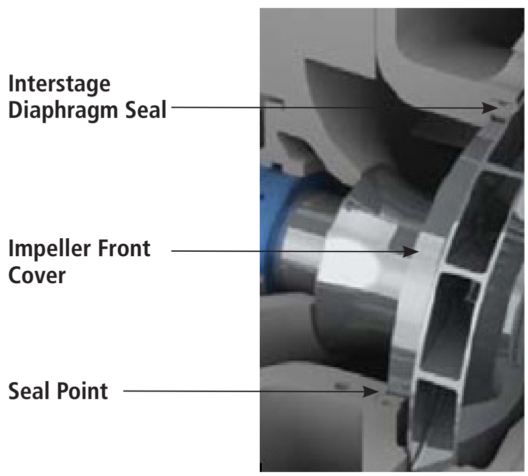


Figure 6.58: Extended horizontal sealing area provided by closed impellers

Horizontally split MSC blowers can be designed with simple labyrinth seals, or they can be fitted with special seals to handle steam and other non-air gases as required by the application.

Unlike vertically split MSC blowers, most horizontally split MSC blowers can be fitted with inlet guide vanes at the inlet to the first stage impeller as a means for achieving capacity control. Other forms of capacity control are variable speed and inlet valve throttling. Figures 6.59 and 6.60 show the performance curves for various capacity control methods available for horizontally split MSC blowers.

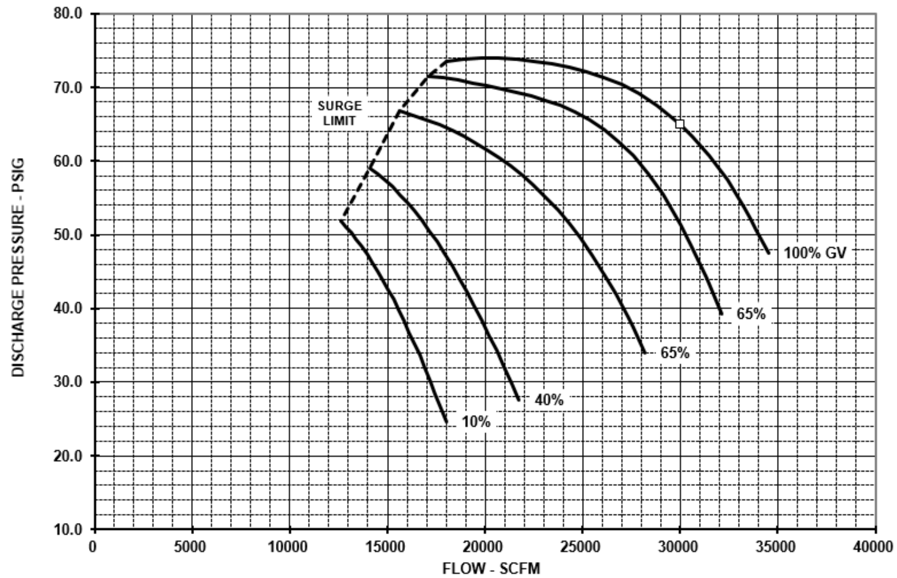


Figure 6.59: Horizontally split MSC blower performance curve with inlet guide vane

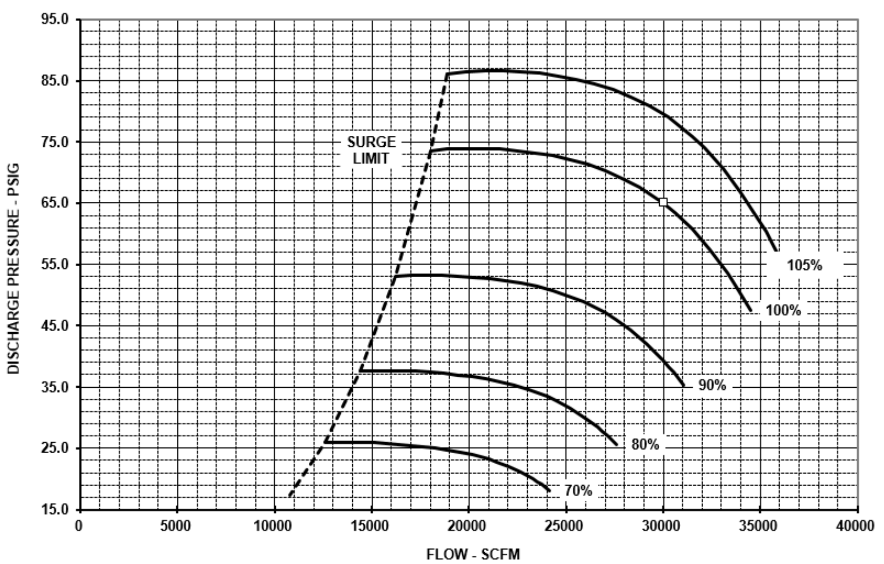


Figure 6.60: Horizontally split MSC blower performance curve with variable speed

Horizontally Split MSC Blower Packaging

Similar to vertically split MSC blowers, horizontally split blowers are commonly provided as fully assembled blower packages. Many packages are required to meet advanced process industry specifications, such as API, so the horizontally split MSC packages are often more complicated than vertically split industrial packages. Horizontally split MSC blowers can be driven by an electric motor, an engine with a speed increasing gearbox, or directly via steam or gas turbine. Figure 6.61 shows a horizontally split MSC blower package driven by a steam turbine with a separate lubrication oil module.

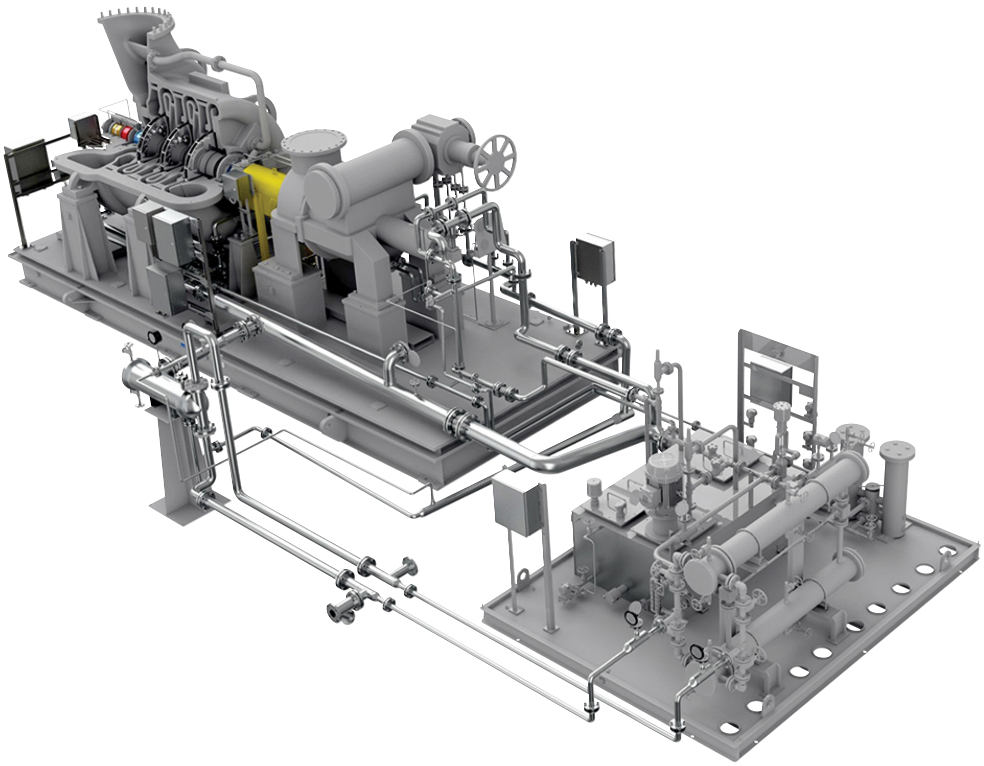


Figure 6.61: Horizontally split MSC blower package with steam turbine drive

MSC Blower Applications

Multistage centrifugal blowers are used heavily in the wastewater treatment industry, in both municipal and industrial treatment facilities. MSC blowers supply oil free air throughout the wastewater treatment process; from early-stage grit removal to aeration of the wastewater stream to aid in the digestion of its organic material, to backwashing filters, and to supplying combustion air for the incineration of the sewage sludge in large furnaces. Industrially, MSC blowers supply combustion air for the glass melting furnaces used in the manufacturing of fiberglass and glass containers. In some instances, these blowers are replacing air compressors in air-knife and blow-off applications due to their greater efficiency compared to using regulated, high-pressure compressed air. As exhausters, MSC blowers are used to extract landfill gas from landfills and coalbed methane from underground coal deposits. Horizontally split MSC blowers find extensive use in the oil, gas, and petrochemical industries due to their ability to meet the exacting API specification often required for equipment in these industries. The sulfur recovery process, used to convert hydrogen sulfide gas into elemental sulfur, is a key application in the petrochemical industry, where horizontally split MSC blowers are used to supply air for thermal incineration.

Regenerative or Side Channel Blower

Operating Principle

Regenerative blowers are dynamic blowers often found in relatively small airflow blower applications with flows up to 1700 cfm. Broadly speaking, these regenerative blowers follow the same dynamic operating principles that apply to centrifugal blowers — using an increase in air velocity to create a pressure difference. Because there is no lubricant injected into the compression chamber of the side channel blower, the air leaving their discharge port has an oil content no greater than the oil content of the intake air.

This velocity energy is created by a series of fins on the impeller, rotating at a relatively high speed inside the blower housing, as illustrated in Figure 6.62. The impeller is located within a housing composed of a blower cover and blower housing, as shown in Figure 6.63. The blower cover and housing each have a curved side channel machined into them to accept the impeller. On the impeller, there are two fins aligned next to each other, one front facing, one rear facing. With this fin orientation, two streams of air are sent into a spiral motion at the same time. As the impeller rotates within the two side channels, each fin sweeps two separate volumes of intake air at a time and aerodynamically directs them into the 180-degree curved side channels. During this process, the air velocity is increased. The side channels direct the air back towards the impeller, where another passing fin "picks up" the air and repeats the spiral process, increasing the air velocity with each iteration. As the air passes around the side channels from intake to discharge, the repeating spiral motion process continues to increase the velocity energy of the air until it leaves the blower housing.

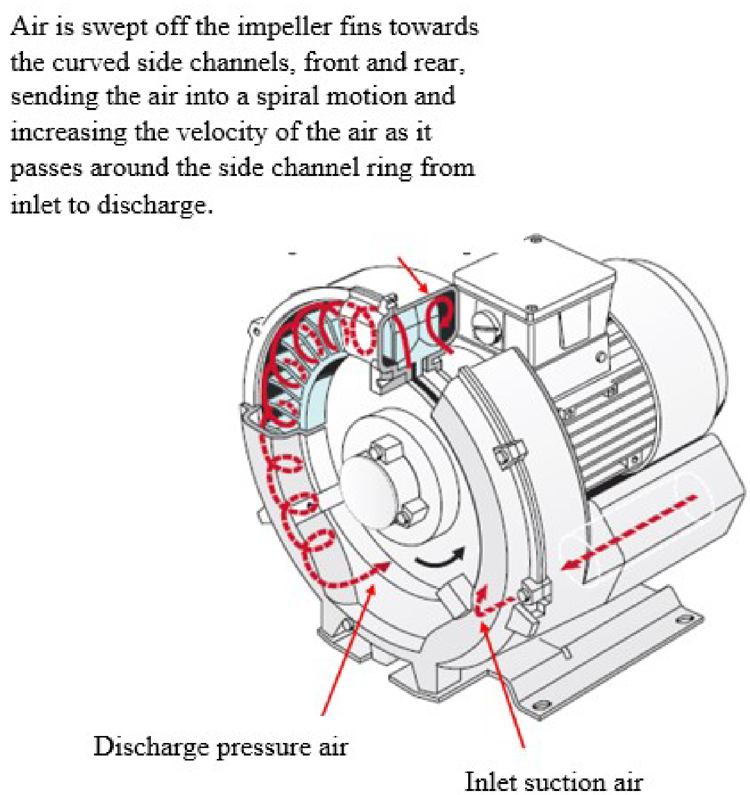


Figure 6.62: Regenerative blower

When the air leaves the blower, it enters the diffuser, where a tremendous reduction in speed occurs. This speed reduction transforms kinetic energy into pressure. The velocity of the air determines how much pressure or vacuum is generated. Throttling the inlet and/or discharge port permits the air volume to remain inside the blower for a longer period of time, allowing for more spiral "regeneration" cycles to occur, which increase the velocity energy. The regeneration process gives this dynamic blower its name — "regenerative" blower.

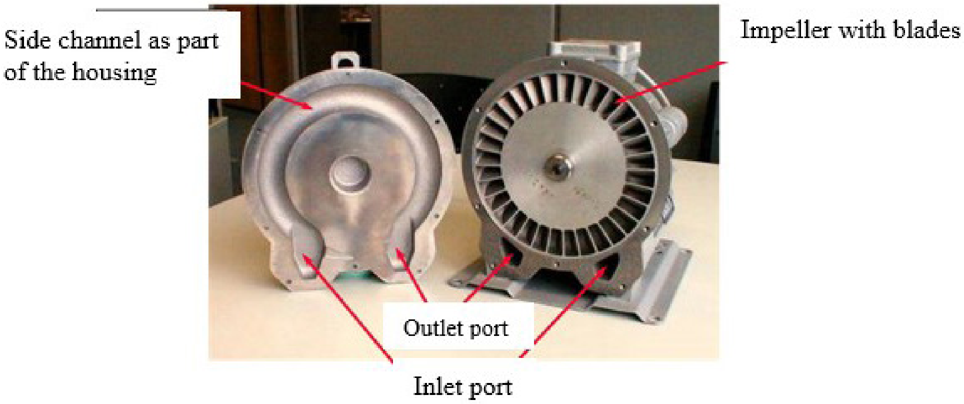


Figure 6.63: Regenerative blower side channel

Side Channel Blower Performance

Regenerative blowers have a maximum capacity range of approximately 1700 cfm and have a pressure capacity of up to 15 psig and a vacuum capacity of up to 16" Hg. The performance of a regenerative blower is determined by the size, number, and profile angle of the blades on the impeller, and by the impeller's speed. The larger the diameter of the impeller, the more air flow volume the blower will provide. The faster the impeller rotates, the greater the capacity of the blower. As illustrated in Figure 6.64, the impeller diameter size is 340 mm. An impeller this size would be coupled with a motor ranging from 2 hp to 7 hp and would typically generate up to 225 cfm.

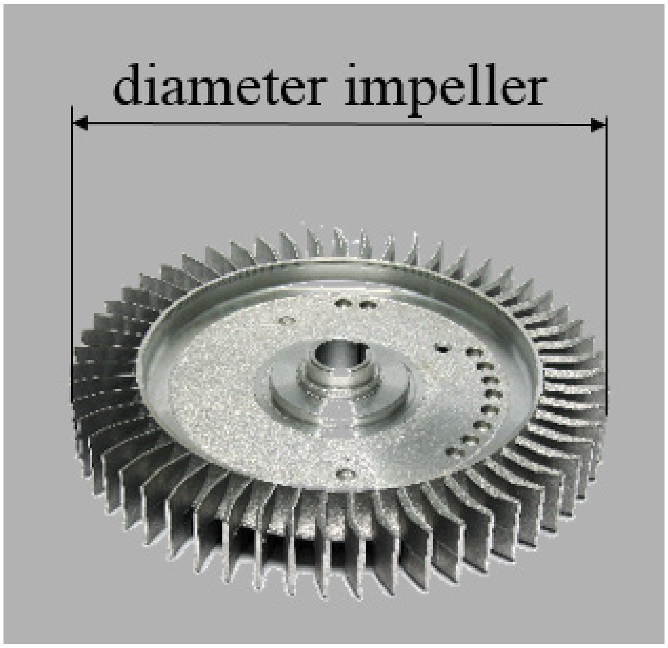


Figure 6.64: 340 mm diameter regenerative blower impeller

Capacity Control

The capacity of a constant-speed side channel blower can be controlled by the use of a three-way valve that diverts excess capacity back to the inlet to maintain a constant pressure. Alternatively, since capacity is proportional to impeller speed, the blower can be driven by a variable-speed motor to allow for capacity ranges between 100% and 43% from the same blower.

Side Channel Blower Construction and Packaging

Side channel blowers are supplied from the manufacturer as a complete blower package. As illustrated in Figure 6.65, the construction of the side channel blower package is a rather simple design with the impeller mounted directly onto the drive motor shaft. The impeller is sandwiched between the blower housing and the blower cover, and the entire assembly is mounted atop a base. The standard material of construction for all components in the side channel blower is high-strength aluminum alloy. On larger blowers, the impeller, housing, and cover are manufactured from cast iron. The internals of the side channel blower can be anodized for added corrosion resistance, but stainless steel and other metallurgy options are rare. Discharge silencers are normally included with the complete blower package.

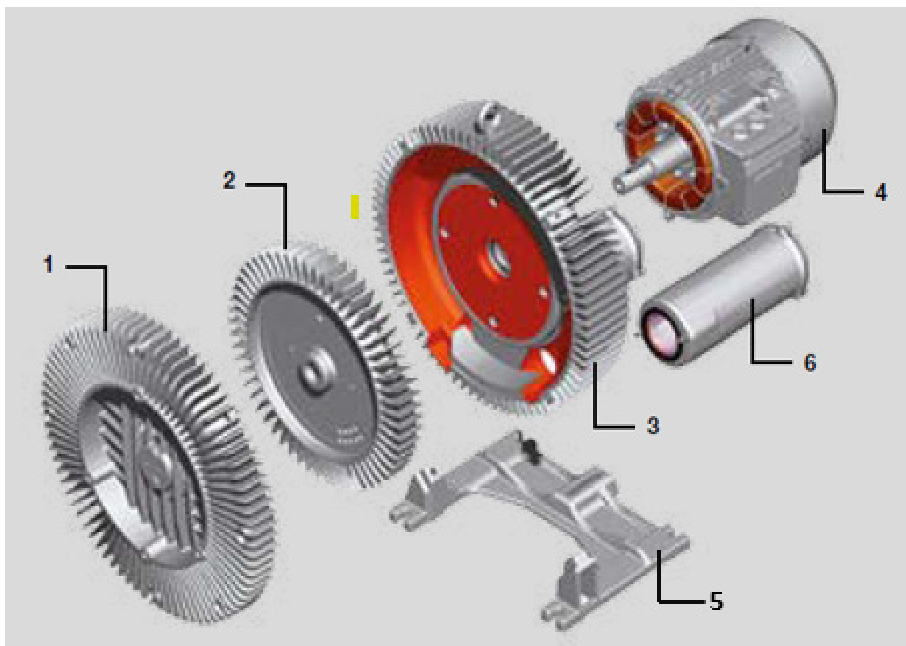
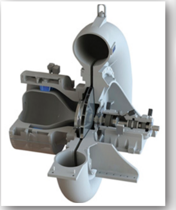


Figure 6.65: Side channel blower construction
1. Blower cover
2. Impeller
3. Blower housing
4. Motor
5. Base
6. Silencer






Side Channel Blower Applications

Side channel blowers are used in a wide variety of applications where large volumes of oil free air at low pressures or vacuum are required. Typical applications include aeration of sewage in the wastewater treatment industry, fluidizing of Portland cement, and aeration of ponds and lagoons. Pick-and-place vacuum lifting, vacuum packaging, pneumatic conveying, and air-drying are very common uses of the side channel blower in industrial applications. Other vacuum uses include chip, dust, or smoke removal. Probably the two most recognizable uses of side channel blowers are in the dental industry, for vacuum creation, and as the vacuum source for central vacuum systems. Larger central vacuum systems often have multiple pumps for higher flows, either tank-mounted or stack-mounted.