Causes, consequences and analyses of Dry Gas Seal damages during operation and pressurized hold.

EagleBurgmann®
Rely on excellence

Reliable gas supply solution for compressors to avoid seal contamination and failures

Model of a Dry Gas Seal (EagleBurgmann DGS with a CobaSeal separation seal)

Centrifugal process gas compressors are needed in the supply chain for oil production and refinement, for example CO2 reinjection, refining processes, petrochemical and chemical operations. For natural gas production and transportation, compressors are required in pipelines and also for the processes that liquefy natural gas.

Backup compressors are usually not needed when compressors are applied even though they are critical for the operation of a plant. This is due to the cost of duplicating this type of equipment. Process gas compressors therefore have to fulfill very high requirements with regards to availability, reliability and safety.

Process gas centrifugal compressors are typically equipped with gas seals to prevent gas from escaping between the stationary compressor body and the rotating shaft. Compressors are normally shut down when high seal leakage occurs, indicating a seal failure. Shutting down on high seal leakage helps to meet safety and environmental requirements and avoid further damage to the equipment. As a consequence, gas seals were designed to fulfill safety and reliability requirements for the industry.

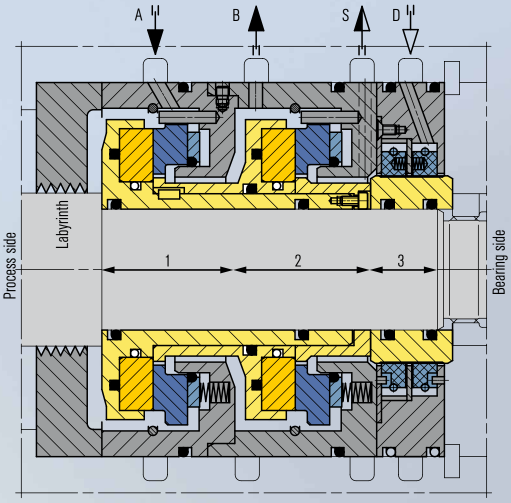
To meet these requirements, the effectiveness of gas seals is determined by the quality of gas supplied to the seal. From experience we have identified the major root cause for high gas leakage to be contamination of the seal.

Contamination of Dry Gas Seals through process gas

The key elements within a Dry Gas Seal are the seal faces and secondary sealing elements. A shaft sleeve, which is fixed to the compressor shaft, holds the rotating seat. The rotating seat is sealed against the shaft sleeve with a secondary sealing element, which is a special O-ring or PTFE filled sealing device. The rotating seat has integrated gas grooves to generate an aerodynamic lift off and provide gas film stiffness during operation.
The non-rotating elements are a combination of the seal housing, which is fixed to the compressor casing, and the non-rotating seal face.
The stationary elements are designed to compensate for axial movements of the compressor rotor in relation to the compressor case. The compressor shaft is exposed to axial movement caused by different loads and case expansion from heat and pressure or vibrations. Compensation for axial movements is achieved by allowing the non-rotating face to move along the balance sleeve (sleeve below the non-rotating face). The non-rotating face is sealed against the balance sleeve with a dynamic sealing element (O-ring or PTFE filled sealing device), which slides on the balance sleeve.

When pressure is applied to the seal or the compressor is rotating, the applied forces will hold the seal faces together and maintain the appropriate gap of 3 to 5 µ. When these conditions are not present, springs are required to hold the seal faces together.

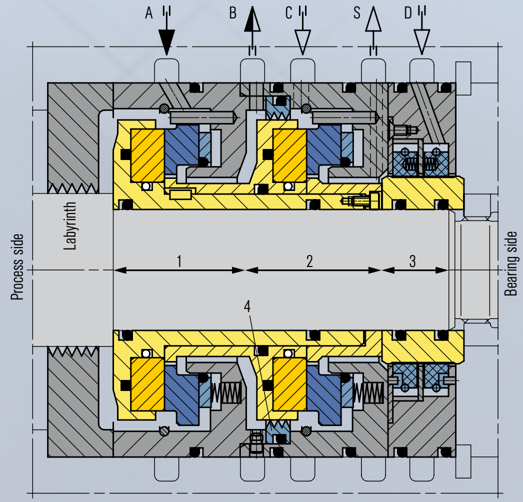
To avoid any wear on the sealing faces, Dry Gas Seals are designed to lift off when operated. This means the rotating seat and stationary face have no contact during operation. The lift off is mainly influenced by two differential pressures over the faces or by circumferential speed.



A Primary seal gas supply
B Primary vent
S Secondary vent
D Separation seal gas supply

1 Primary seal
2 Secondary seal
3 Separation seal

Tandem Dry Gas Seal (EagleBurgmann DGS)



A Primary seal gas supply
B Primary vent
C Secondary seal gas supply
S Secondary vent
D Separation seal gas supply

1 Primary seal
2 Secondary seal
3 Separation seal
4 Intermediate labyrinth

Tandem Dry Gas Seal with intermediate labyrinth (EagleBurgmann DGS)

The seal can lift off at a certain differential pressure, a certain speed or a combination of speed and differential pressure, depending on the specific operating conditions, such as gas type, and detailed seal design.

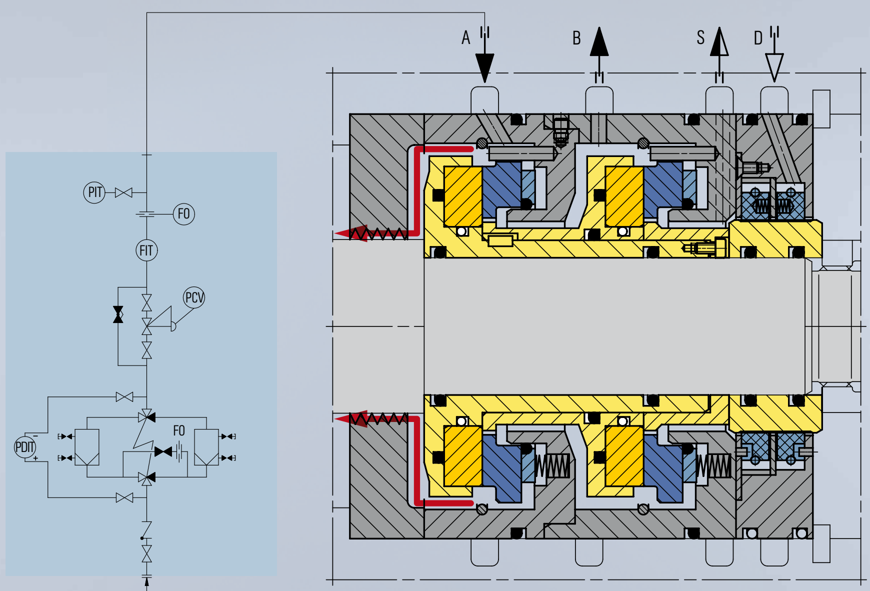
The most common gas seal arrangements used in the industry for compressors are tandem arrangements, or tandem with intermediate labyrinth arrangements, which will be used as basis for this article.

Tandem seals consist of two sets of sealing faces. The set closest to the process gas is known as the primary seal. The second set on the bearing side of the seal is known as the secondary seal.
The secondary seal is a backup seal in case the primary seal fails.

Contamination can enter the seal from the bearing or the process gas side of the seal. This describes the contamination of the primary seal here, as this is the major cause of seal failures or high seal leakage alarms during or after a long period of pressurized standstill of the compressor.

Gas seals are generally very robust and reliable seals. Ensuring the reliability of gas seals requires a supply of clean and dry gas (seal gas) at all times.

Since process gas is a gas, how does it affect the operation of a gas seal? The gas leaking across the faces is low and should not have a detrimental effect on the seal. The quality of gas is the problem and the fact that not all components of a gas will stay in a gaseous phase when the gas temperature or pressure changes.



From discharge or a higher stage of the compressor

Dry Gas Seal with clean gas supply installed

Contamination of the gas seal results when untreated process gas is allowed in and around the primary seal. A clean gas supply is provided to ensure that potential contamination- like particles or fluids - inside the process itself does not enter the seal.

Typically, process gas is taken from the discharge nozzle of the compressor. This gas is routed through a filter and regulated to a suitable pressure or flow to ensure clean seal gas supply to the primary seal. The majority of seal gas flows across the process labyrinth back into the process. A minimum velocity of 5 m/s (16.4 ft/s) - at twice the nominal labyrinth clearance – should be maintained underneath the labyrinth towards the process to ensure no contamination enters the primary seal. An alternative to using process gas would be to use an external source gas source.

The seal gas flows in two directions; a small amount flows between the seal faces as controlled leakage and is then routed to the primary vent together with the secondary seal gas. The majority of the seal gas flows underneath the process side labyrinth back into the process. Different scenarios that contaminate the gas seal are possible.

Contaminated dynamic sealing element

Contaminated seal area behind the stationary face

Damaged seal face

Contamination by particles

Particles present in the process gas can contaminate the primary seal when the seal gas flow across the process side labyrinth is insufficient, or if the provided filtration or conditioning is inadequate for the seal gas to produce the required quality of gas.

In consequence, particles can enter the gas grooves on the rotating face and the sealing gap. If the particles are small enough, they will blow through the seal. Larger particles will get trapped inside the grooves or gap, causing negative effects to the sealing behavior or seal reliability. In addition to the sealing gap, particles can also block the dynamic sealing element.

The dynamic sealing element is an O-ring or elastomer free sealing device between the non-rotating seal face and the balance sleeve. The non-rotating seal face must slide together with the dynamic sealing element on the balance sleeve, axially compensating for axial position or movements of the compressor shaft in relation to the seal housing. The non-rotating face must also move freely to adjust for any movements resulting from the normal seal behavior. If the dynamic sealing element is prevented from moving freely to adjust for axial movements, this will affect the seal gap and lead to high seal leakage if the faces are kept open, or will cause primary seal failure in case the faces stay in contact.

To avoid the above-mentioned scenarios, a supply of clean gas must be provided to the primary seal whenever the compressor is pressurized or in operation. A reliable clean gas flow will prevent contamination from the process gas from entering the primary seal.

In the next steps, proper filtration must be selected. Typically, filter elements are selected to remove particles as small as 3 µm and sometimes even 1 µm. This ensures the removal of particles that are larger than the seal gap can tolerate, producing a clean quality gas for the primary seal. Seal gas filters have high alarms on differential pressure to identify when filter elements require replacement. The use of dual filter housings means that filter elements can be replaced during compressor operation without interrupting the seal gas flow. Filters supplied with seal gas systems have limitations on the volume and size of the liquids and particles they can manage. Higher levels of contaminants in the seal gas will require additional filtration. This filtration pre-filters the gas and generally contains some type of liquid knock out.

Contamination by liquids

When a compressor is hot during normal operation, the operating temperature ensures the gaseous state is retained for most applications. So the gas remains gaseous when the seal gas flows from the discharge tap through the seal gas system into the primary seal cavity and through the seal - dropping in pressure and temperature from discharge pressure down to atmospheric pressure. Examples of applications where the gas always remains gaseous are pure ethylene or propylene compressors, as these gases condensate at very low temperatures. For other applications, such as wet gas pipeline, when the gas flows through the seal gas system and seal it forms liquids. These liquids are detrimental to the gas seal.

When a gas drops in pressure it will change in temperature. This is known as the Joule-Thompson effect. Control valves and orifices to manage pressure and flow in a seal gas system will change the temperature of the gas. The seal gas also drops in pressure as it flows between the seal faces, changing the temperature of the gas. For most gases this is a lower temperature, which will move the gas conditions and possibly cross the critical temperature line (dew line) and turn it into a vapor (dual phase). Apart from the Joule-Thompson effect, the environment also influences the seal gas temperature. Ambient temperatures can cool exposed supply lines, which will drop the temperature of the gas and change the gas conditions.

Since gases can be made up of different components, they can change the critical temperature (dew point) of a gas. For gas pipelines with methane as the major component, there are also heavier hydrocarbons within the gas which can dramatically change the critical temperature (dew point). Even small differences in the gas composition can make the difference whether a gas remains gaseous or begins to form liquids or vapors.

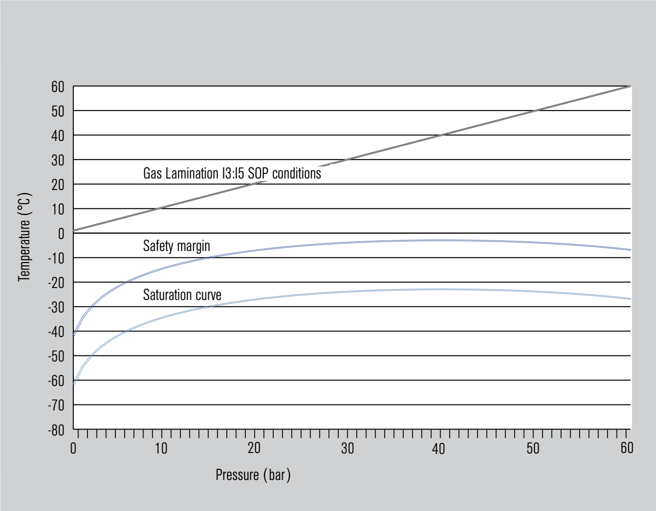
Component	% mol
Methane	89.415
Ethane	7.0
Propane	1.095
N-butane	0.121
I-butane	0.094
N-pentane	0.018
I-pentane	0.025
Hexane+	0.006
Nitrogen	0.80
CO2	1.424

Typical natural gas pipeline gas composition

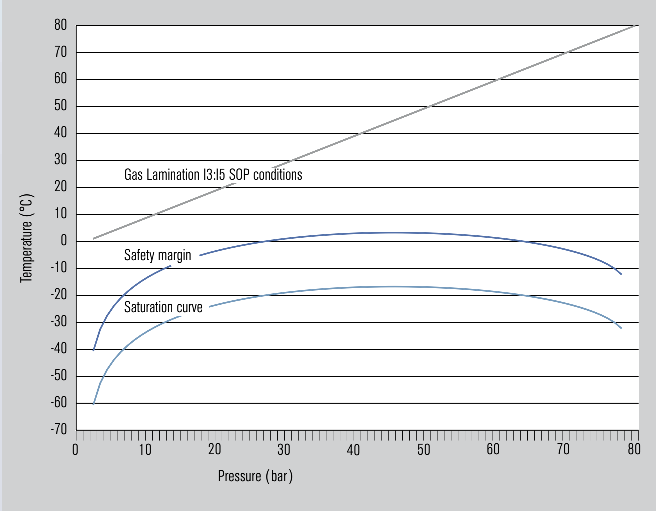
If liquids enter the gap between the rotating seat and stationary face, this creates high shearing forces which generate heat. The generated heat leads to gap instability, causing contact between the rotating seat and stationary face, damaging the seal faces and resulting in a seal failure. If a failure does not occur during operation with the liquid contamination, the seal will fail at the next subsequent start due to increased shear forces.

Many seals fail because of liquids in the gas during normal or transient conditions. This is usually the result of not considering the gas dew point – not completing a dew point analysis - or an inaccurate gas composition is used to complete a dew point analysis. Both of these can result in liquid forming in the seal gas and a system design that does not meet the needs of a dry gas seal.

Several steps must be taken to identify and provide the correct system to prevent liquids in seal gas. The first step is to accurately analyze the gas composition to identify all the components in the respective gases being used for seal gas supply. This includes any changes in the gas composition over time due to upset process conditions, and alternate gases used for seal gas. Most gas composition analyses do not include information on components higher than C5 or C6.



Dew point curve during the project phase (example)



Dew point curve with field gas composition project phase (example)

Process people are not concerned with trace components higher than C5 or C6. Some procedures also dry the gas sample before the analysis is completed. This eliminates components that turn to liquid and affect the operation of the gas seal. Another concern is when the composition of the process gas changes over time. Even minor changes in the gas composition can significantly change the dew point of a gas. It is therefore elemental to provide an accurate and complete gas composition when establishing the phase envelope to ensure a reliable result. Possible changes in gas composition over time must be considered as well.

Taking this information as basis, the second step is to produce the line for the seal gas dew point and to identify at what temperature and pressure the components in the gas will turn to liquids. Pressures and temperatures to the left of the dew line result in a dual phase gas; liquid in the gas. This is the area where the seal gas may not operate in. The third step is to plot the decompression curve with the minimum margin from the dew line (industry standards have identified the safety margin as 20 Kelvin).

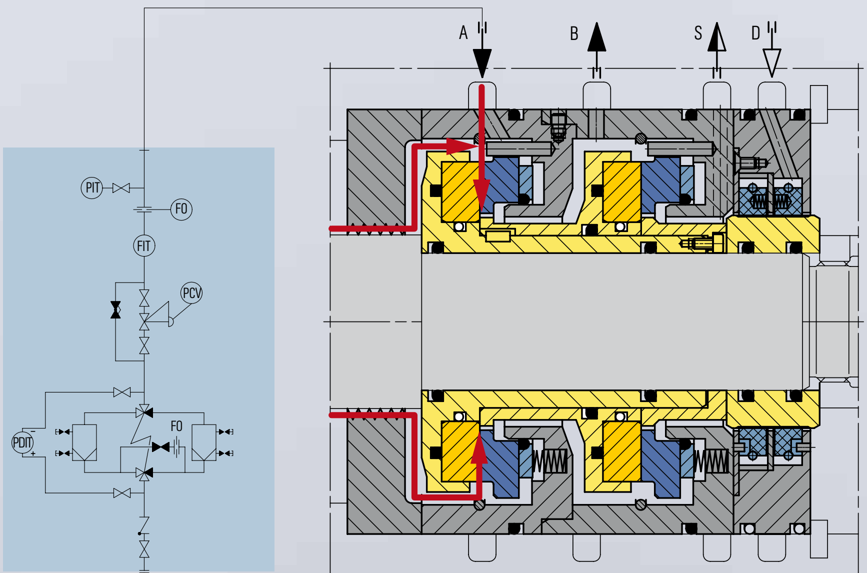
The last step is to collect, analyze and plot all operating conditions; particularly conditions where the gas is at high pressure, such as settle out pressure and when the temperatures of the gas changes. Taking these measures will show what temperature the gas must be for a given pressure to prevent liquids from forming. This is critical to designing the correct seal gas supply system and preventing liquids from forming in a seal gas.

Contamination during pressurized stand still conditions

Due to environmental concerns it is more difficult to vent compressors to the atmosphere. If compressors are stopped after a certain period of time they will be depressurized, sending the gas to flare or atmosphere, resulting in emissions penalties or fines. Some situations can also require a pressurized compressure which ensures a quick response to demand. Having a gas seal fail on a restarted compressor while supporting demands does not result in reliable production, profits or reduced environmental concerns. As identified above, particles in seal gas or primary seal cavity, or liquids that form in a seal gas are root causes for the majority of seal failures. To prevent these failures from occurring it is essential to ensure a clean and quality seal gas for the primary seal. This maintains a reliable seal that will not fail during standstill conditions and prevents failures when restarting or shortly after restarting a compressor.

During a pressurized stand still condition, seal gas flow, (clean and quality seal gas to the primary seal), is only present when an alternate supply or means of producing seal gas flow is provided. Seal gas flow during normal operation is generated by the discharge pressure, as indicated previously, which is higher than the pressure at the seal. If a higher pressure/flow cannot be provided during a pressurized hold, unconditioned process gas from the compressor flows into the primary seal cavity via the process labyrinth, when the seal gas flow is lost. When the compressor is not or only slowly rotating but still pressurized, leakage still occurs through the gas seal. This means the gas leaking through the seal is unconditioned process gas from the compressor, allowing unconditioned gas to enter the primary seal cavity and contaminating the primary seal.

Process gas flow during pressurized stand still



From discharge or a higher stage of the compressor

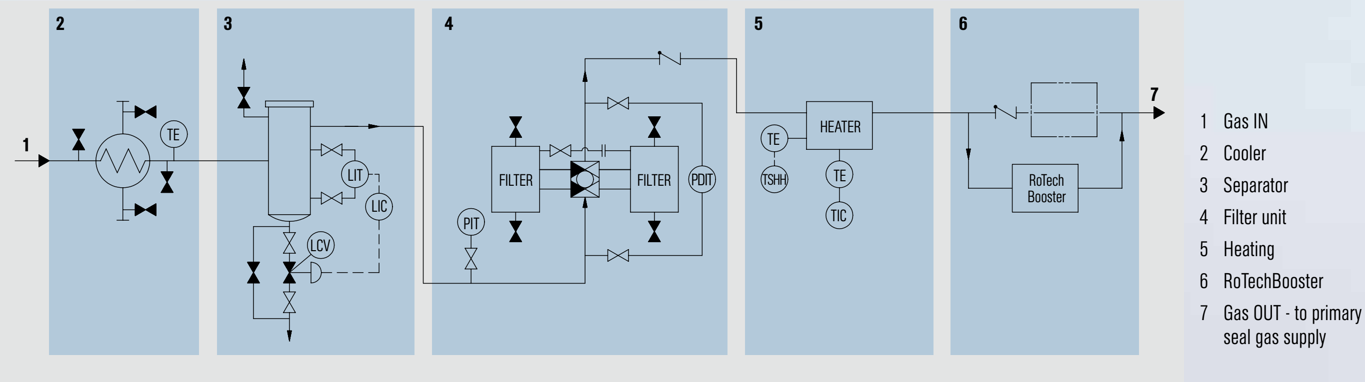


Diagram of a gas conditioning system

As stated in the previous section on contamination by liquid, the ambient temperature must be considered. The reason is that the compressor and seals will be at an ambient temperature during standstill conditions. If unconditioned process gas is exposed to these conditions, the gas drops in temperature and pressure when passing through the seal face liquid forms and contaminates the dry gas seal.

Contaminated seal face

When liquids form between the seal faces while the compressor is not rotating, they may stick together. The flat surfaces of the stationary face and rotating seat are within two light bands of flatness. With such flat surfaces the liquid will create a bond between the stationary face and the rotating seat. This is good on the one hand because it will reduce or even totally eliminate the seal leakage. On the other hand, the downside is that the strength of the bond is so great when rotational force is applied to the seat that it will damage the drive pins and the stationary seat. This causes high seal leakage during the start or restart of a compressor, and identifies a seal failure with the requirement to replace the seal.

Destroyed seal faces after startup with contaminated sliding faces

If the line represents pressure and temperature drops of the seal, then gas passes through or close to the dual phase envelope. There are a few possible solutions for this.

An outside source can be used, but the same analysis must be completed on an accurate composition of this gas. A concern with using an outside source is that gas volume is added to the compressor/process. This increases the pressure in the compressor/process. As the pressure builds in the system, the gas must be vented to maintain the clean flow of gas to the gas seal. Due to stricter environmental regulations this is becoming more difficult to do.

The ideal solution is to circulate the gas within the system. Dirty or wet gas is drawn out of the compressor through a conditioning system to bring it to the quality and temperature required for the gas seal and is pushed into the seal cavity. This ensures the gas seal is provided with a gas that does not allow liquid to form between the seal faces.

Conditioning a seal gas can require filtering the gas using coalescing filters. Or, conditioning can be as complex as cooling the gas to form the liquid, a liquid knockout to remove liquid, a heater to provide minimum dew point margin, heat trace for maintaining temperature, a booster to move the gas, and final filtration to ensure nothing passes through to the seal. Proper analysis of the dew point and operating conditions will define the required conditioning to ensure the right quality of gas is available for the gas seal.

The movement of the gas is one of the most important requirements for providing reliability for a dry gas seal: circulating seal gas from the compressor through the seal cavity. During normal operation there is sufficient differential pressure between compressor discharge and sealing pressure. When sufficient differential pressure is not present, usually during a standstill , a booster is required. Air-driven piston pumps are currently being used for this application, but they have proven unreliable, especially when required to operate for long periods of time or when not sized correctly; a typical limit is 50 cycles / minute for reasonable life.

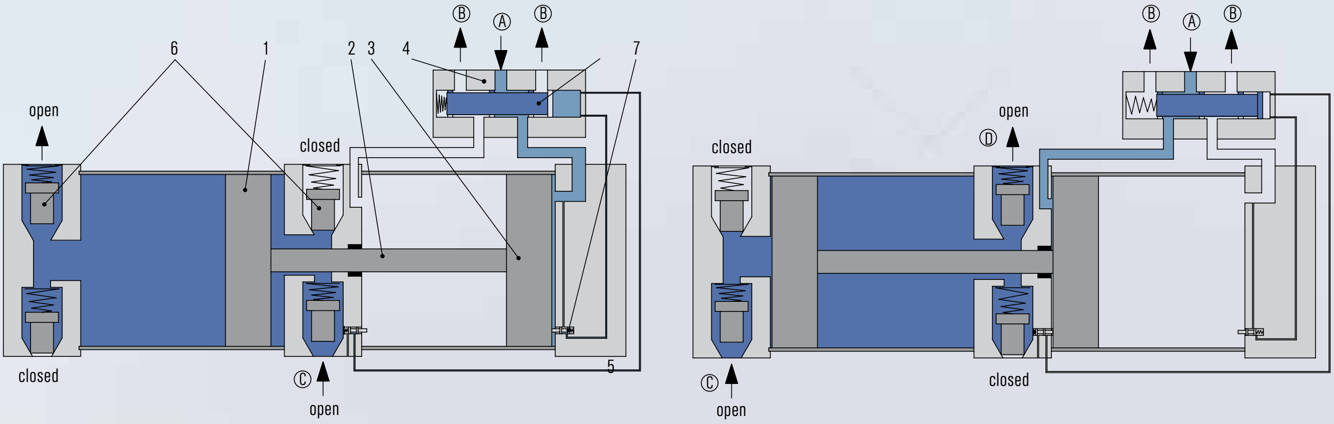
The air driven boosters are positive displacement piston type boosters, and the one used as an example will provide 1:1.78 pressure ratios. They incorporate many moving parts in the booster to operate the unit. There are poppet valves, shuttle valves, check valves, piston rod and pistons that all have seals and wearing parts. These require maintenance and affect the reliability of the unit.

The principle operation of the booster uses air as the drive media. It is supplied through a shuttle valve to apply pressure on one or the other end of the piston. The position of the shuttle valve spool is controlled by pressure and determines which end of the piston is applied with pressure.

The position of the spool is controlled by a pilot system and spring and poppet valves. The poppet valves control pressurization and depressurization of the pilot system. The spool movement is also assisted by a spring to move the spool when the pilot system is unpressurized. When the piston pushes against the poppet valve on right hand end of the cylinder, the pilot system is pressurized and the shuttle valve spool is moved to the left, allowing air pressure to enter the drive cylinder and move the piston to the left.

When the piston hits the poppet valve on the left hand side, the pressure is vented from the pilot system and the spring assists in moving the spool to the right. This will vent the pressure in the cylinder on the right and pressurize the cylinder on the left. As the piston moves back and forth, check valves on the process end open and close to draw pressure in from the suction on one side of the piston and push process gas out on the other side of the piston. This produces the seal gas flow.

These systems are complex not only for the booster itself but also for the system required to ensure it operates the controls for the drive gas, over pressure protection and monitors the wear of seals. With the many wear parts and additional equipment to operate the unit, it becomes a very costly system and has many reliability concerns.



Operation principle piston type booster

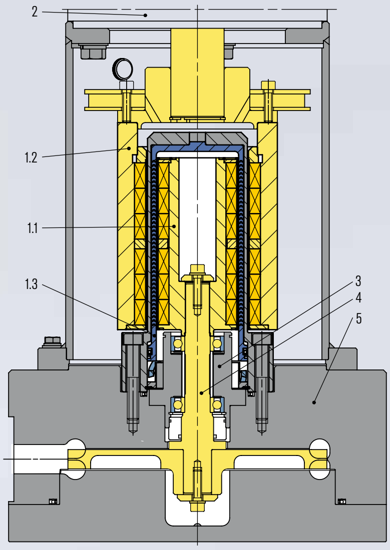
Item	Description	Item	Description
1	Process piston	A	Drive gas IN
2	Piston rod	B	Drive gas OUT
3	Drive piston	C	Process gas IN
4	Shuttle valve	D	Process gas OUT
5	Spool		
6	Check valve		
7	Poppet valve		

Dirt and debris in the shuttle valve, poor quality or excessive cycling of poppet valves, ice buildup in the shuttle valve spool, poor quality air and many other issues have prevented these types of boosters from operating reliably. Due to these reliability issues, air driven boosters have not performed well and are not the best option for long periods of continuous operation.

To ensure reliable operation of gas seals and compressors during standstill conditions, a reliable device to circulate the seal gas must be used. As rotating equipment is generally much more reliable than reciprocating equipment, the best booster design will be a centrifugal type.

Many booster designs require shaft seals, resulting in additional leakage of gas. If a magnetic coupled or canned booster is used, this eliminates any additional gas leakage; no gas to manage or leaking to atmosphere. One of the most important parts in a centrifugal design is the impeller. The impeller design must handle a wide range of operating pressures and varying gas. If the correct impeller is not used, changing gas conditions can result in a booster failure.

Selecting a rotating, clean gas booster provides the ability to use a standard reliable electrical motor. The use of a variable speed drive provides the capability to manage the varying gas density and wider range of operating pressures with lower power consumption. This allows for minimal capital to install and operate the booster. The integration of an air-driven device, which is the standard for piston type solutions, uses large volumes of air to drive the units. This requires installation of other equipment just to support an air driven booster.



Operation principle rotating type booster

Item	Description
1.1	Inner rotor
1.2	Outer rotor
1.3	Can
2	Motor
3	Bearing cartridge
4	Impeller
5	Pressure housing

The equipment used for circulating seal gas is used not only for standby conditions but anytime there is insufficient pressure across the compressor to deliver adequate seal gas flow. When the correct circulation unit is provided, the compressor can be placed in a pressurized hold for a nearly unlimited period of time. Continued supply of clean dry gas to the gas seals will ensure the ideal conditions for the gas seal and guarantee a trouble-free start or restart of your compressor.

Piston type boosters are primarily designed to generate pressure increase, allowing installation in line with pressure reduction elements such as pressure control valves, flow control valves or orifices. Although these units generate more than sufficient pressure boost, they are limited in the flow produced. They therefore do not always achieve the flow necessary to achieve minimum velocity across the process labyrinth. To achieve the required velocity across the process labyrinth,

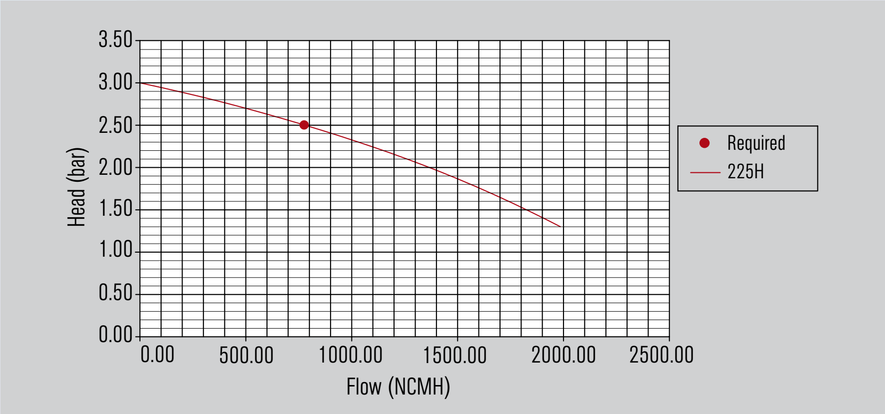
EagleBurgmann RoTechBooster

two or even more of these units are needed; more air volume is required to drive them. Using this type of booster requires accepting lower velocities or higher air consumption with multiple units.

To provide an idea of the requirements for a piston booster, an example for a pipeline application with the below conditions will be used:

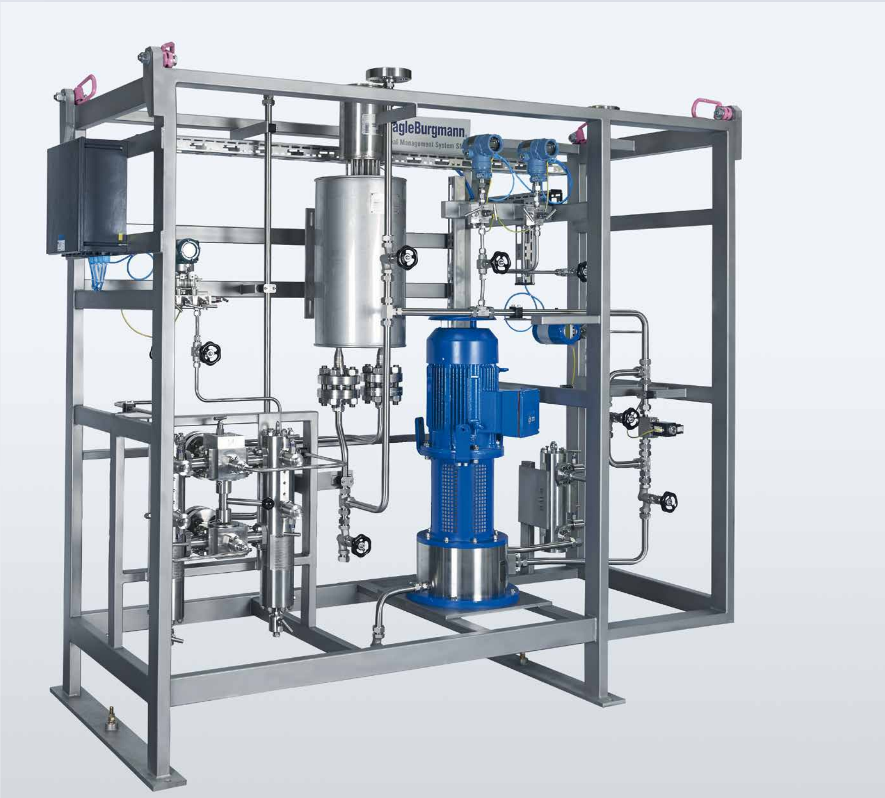
Shaft size: 150 mm (5.9")
Pressure: 70 barg (1,015 PSIG)
Temperature: 23 °C (73.4 °F)
Required flow for 5 m/s (16.4 ft/s) at twice the labyrinth clearance: 389 Nm^3/h (229 SCFM)
Output of piston booster at 90 cycles/min.: 332 Nm3/h (196 SCFM)
Drive air required for one unit: 62.6 Nm^3/h (36.8 SCFM)

Based on the size and operating condition for the above example, the required seal gas flow for each seal is more than one piston booster can provide. To meet the recommended flow for two seals, three boosters should be used for the application. This would require almost 132.5 Nm^3/h (78 SCFM) of air to provide the required flow for the boosters cycling at 70 cycles a minute. Other boosters producing high pressure ratios will consume even more air.



Performance of EagleBurgmann RoTechBooster Type 225H

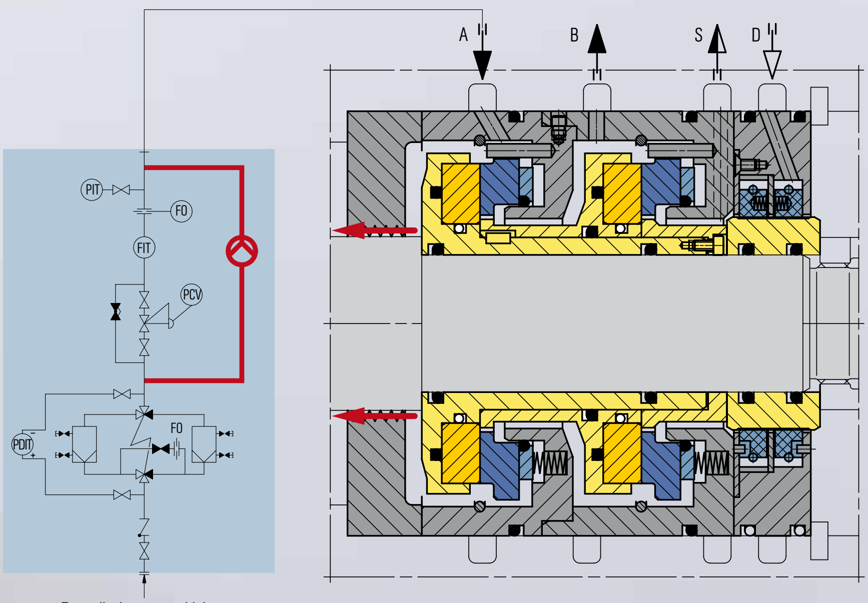
Power consumption: 6.7 kW
Running torque: 25.6 Nm
Estimated temperature rise: 20.2 °C (68.3 °F)
Estimated outlet temperature: 43.2 °C (109.8 °F)
Check bearing loads: OK



EagleBurgmann gas conditioning system with integrated RoTechBooster.

To cover the required seal gas volume, only one RoTechBooster is required!

RoTechBooster designs use 5 to 20 horsepower electric motors; as long as power is available the booster has the available resources to operate. To minimize required horsepower a RoTechBooster is installed parallel to the pressure reduction elements. The impeller design generates high flows to ensure the required velocity across the process side labyrinth. This minimizes the head required to generate flow through a system therefore minimizing the horsepower requirements. With a variable frequency drive, the speed is adjusted to manage flow and head requirements, efficiently delivering seal gas to the primary seal and maintaining sufficient velocity across the process labyrinth.



Gas supply system with a RoTechBooster installed

Conclusion

Contamination is the leading cause for dry gas seal failure. As identified in this article, if process gas or inadequately conditioned seal gas is provided to a dry gas seal, it will affect the reliability of the seal. To prevent this from occurring requires an accurate gas analysis, correct conditioning components and seal gas flow whenever pressure is present in the compressor. When a compressor is in pressurized standby, using an alternative gas requires venting of gas pressure and leads to environmental concerns. Incorporating a booster in the system eliminates venting of process gas and prevents contaminated process gas from entering the primary seal. A reliable booster, like an EagleBurgmann RoTechBooster, delivers the recommended seal gas flow until the compressor is restarted to prevent failures in standby situations during or shortly after compressor restarts.

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