DRY GAS SEAL SYSTEM DESIGN STANDARDS FOR CENTRIFUGAL COMPRESSOR APPLICATIONS

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ABSTRACT

Dry gas seals have been applied in process gas centrifugal compressors for more than 20 years. Over 80 percent of centrifugal gas compressors manufactured today are equipped with dry gas seals.

Despite the 20-year trend of increasing dry gas seal applications, an industry accepted standard for gas seal support system design does not exist. The American Petroleum Institute (API) has only recently addressed gas seal system design in its Standard 614 (1999). This paper proposes a set of gas seal system design standards for process gas centrifugal compressors on the basis of safety, reliability, and economics.

This paper presents the philosophy of one centrifugal compressor and dry gas seal original equipment manufacturer (OEM) in regard to gas seal system design standards. These standards are based on over 20 years of experience in the area of gas seal system design, drawing from actual field experience of thousands of compressors. The reader shall recognize, however, that numerous gas seal system design philosophies can be applied to achieve the same system objectives.

INTRODUCTION

Dry Gas Seals

Dry gas seals are available in a variety of configurations, but the "tandem" style seal (Figure 1) is typically applied in process gas service and is the basis for this paper. Other types of gas seals (such as double opposed) are not considered. Tandem seals consist of a primary seal and a secondary seal, contained within a single cartridge. During normal operation, the primary seal absorbs the total pressure drop to the user's vent system, and the secondary seal serves as a backup should the primary seal fail.

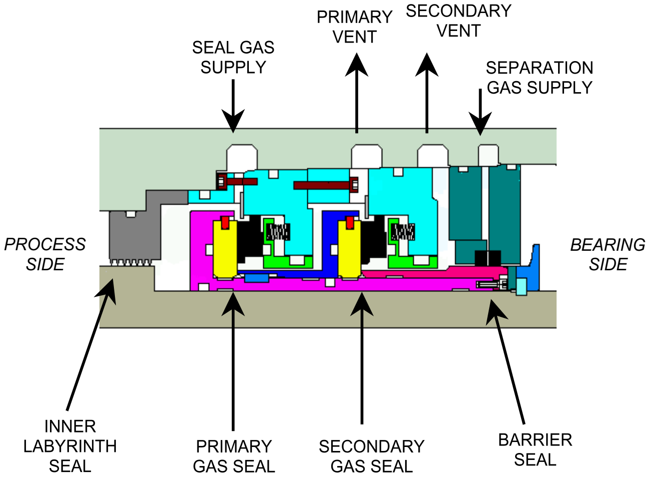

Figure 1. Tandem Gas Seal/Barrier Seal Configuration.

Dry gas seals are basically mechanical face seals, consisting of a mating (rotating) ring and a primary (stationary) ring (Figure 2). During operation, grooves in the mating ring (Figure 3) generate a fluid-dynamic force causing the primary ring to separate from the mating ring, creating a "running gap" between the two rings. Inboard of the dry gas seal is the inner labyrinth seal, which separates the process gas from the gas seal. A sealing gas is injected between the inner labyrinth seal and the gas seal, providing the working fluid for the running gap and the seal between the atmosphere or flare system and the compressor internal process gas.

Barrier Seals

Outboard of the dry gas seal is a barrier seal, which separates the gas seal from the compressor shaft bearings (Figure 1). A separation gas (typically nitrogen or air) is injected into the barrier seals. The primary function of the barrier seal is the prevention of lube oil migration into the gas seal. The barrier seal also serves as the last defense in the event of a catastrophic failure of the primary and secondary gas seal. Traditional labyrinth seals or segmented carbon ring seals are used in most barrier seal applications today. Segmented carbon ring barrier seals offer the advantage of substantially lower separation gas flow requirements due to the larger shaft clearance associated with labyrinth seals. The author has previously presented a more detailed comparison of segmented carbon ring versus labyrinth barrier seals (Stahley, 2001).

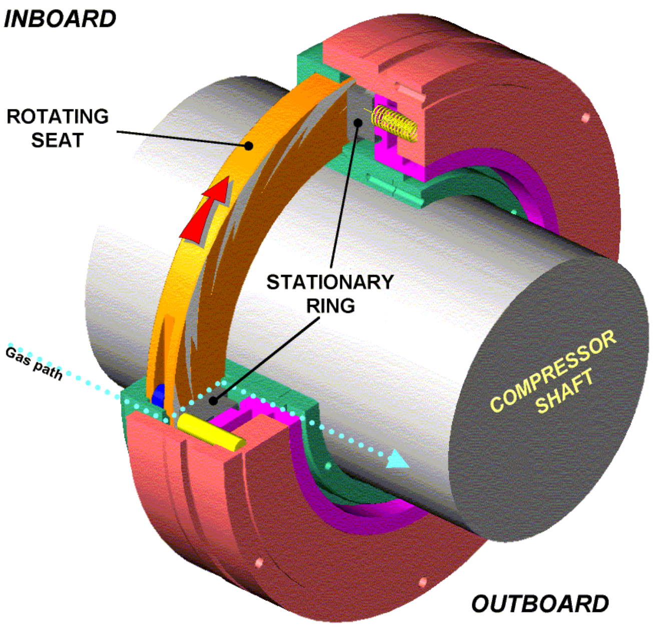

Figure 2. Dry Gas Seal Components.

Figure 3. Grooves in Gas Seal Mating Ring.

Gas Seal Support Systems

The use of dry gas seals requires a support system, which is normally supplied by the centrifugal compressor OEM mounted adjacent to the compressor. The purpose of the gas seal system is as follows:

- To provide clean, dry sealing gas to the faces of the dry gas seals.
- To provide clean, dry separation gas to the barrier seals.
- To monitor the “health” of the dry gas seals and barrier seals.

SEAL GAS SUPPLY

Source

The end user must provide a source of seal gas supply to the compressor OEMs gas seal system. The seal gas source must be available at sufficient pressure to cover the entire operating range of the compressor including transient conditions such as startup, shutdown, or idle, and all static conditions. The seal gas should be at least 50 psi above the required sealing pressure at the customer connection point on the gas seal system in order to allow adequate regulation of the seal gas. If the primary source of seal gas does not meet this requirement, an alternate gas source or gas pressure boosting equipment will be required. It is very common in the industry to source the seal gas directly from the compressor discharge. The author has previously discussed various implications of this approach (Stahley, 2001).

Another concern is the quality and composition of the seal gas. The seal gas should be free of solid particles 10 microns and larger and 99.97 percent liquid free at the customer connection point on the gas seal system. It is also critically important to assess the potential for liquid condensation within the gas seal system or the gas seals themselves. To avoid such condensation, API Standard 614 (1999) requires that the seal gas temperature into the gas seal be at least 20°F above its dew point. This is a good rule of thumb, but may not be sufficient in some cases.

Consider an example of a hydrocarbon gas compressor with a required sealing pressure of 1000 psia. Sealing gas is process (hydrocarbon) gas, supplied to the customer connection point on the gas seal system at 1050 psia. As the sealing gas flows through the gas seal system, through the primary gas seal, and finally to the primary vent, the pressure will drop to nearly atmospheric. A corresponding decrease in gas temperature will result from the Joule-Thomson effect. A phase diagram for the hydrocarbon gas (Figure 4) indicates the dew point for the seal gas at 1050 psia is about 100°F. Following the API Standard 614 (1999) recommendation of 20°F superheat would require the sealing gas to be heated to 120°F at the customer connection point. However, a computer simulation of the seal gas pressure and temperature drops expected throughout the gas seal system reveals that the seal gas will pass through the mixed (gas and liquid) phase even with 20°F superheat (Figure 4). Further computer simulation indicates that, in order to maintain a 20°F margin above the seal gas dew point throughout the entire gas seal system, the seal gas would need to be heated to 200°F (i.e., 100°F superheat) at the customer connection point (Figure 4).

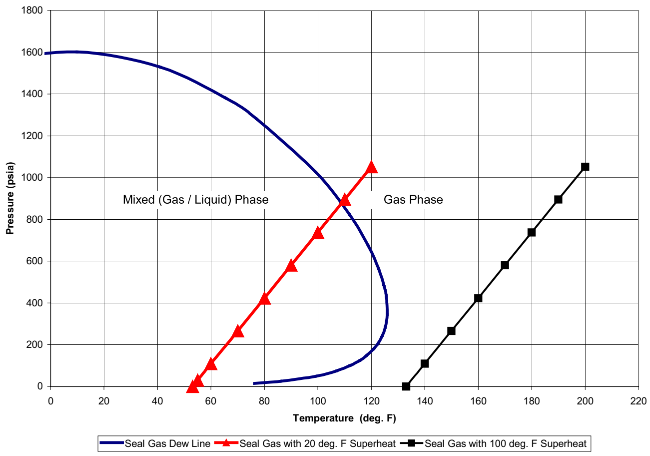

Figure 4. Typical Seal Gas Phase Diagram.

To properly evaluate potential liquid condensation, a computer simulation of the gas seal system, from the customer connection point to the primary seal vent, must be conducted during the system design phase. A 20°F margin above the seal gas dew point should be maintained throughout the entire gas seal system. The computer simulation will determine the level of seal gas superheating required to meet this criterion. Depending on the quality of the seal gas and the result of the system simulation, special liquid separation and filtration equipment, and possibly heating of the sealing gas, may be required. Seal gas lines should be heat traced if ambient temperatures can fall below the dew point of the seal gas.

Filtration

Seal gas filters immediately follow the customer connection point on the gas seal system. These filters should be used as "final" or "last chance" filtration and require compliance with the gas quality requirements explained in the previous section for maximum reliability. Duplex filter assemblies should be employed and provided with a transfer valve allowing filter element replacement while in service. The filter housing should be stainless steel, as required by API Standard 614 (1999).

Since the running gap between the primary and mating rings of most gas seals is about 3 to 5 microns, it is recommended that filter elements be capable of at least 3 micron (absolute) filtration. API Standard 614 (1999) requires the use of coalescing filter elements under certain conditions. It is recommended here that, in anticipation of a possible liquid presence, coalescing filter elements be provided for *all* applications. API Standard 614 (1999) requires some type of automatic liquid drainage of the filter housing when coalescing filters are employed. An alternative, more economical approach is to equip each filter housing with a manual liquid drain valve. The user's operational procedures should include, as part of the compressor operator's daily routine, the inspection of the filter elements and removal of any accumulated liquids as required. If the seal gas quality conforms to the requirements explained previously, liquid accumulation at the filters should be minimal during normal operation.

The duplex seal gas filter assembly should be provided with a differential pressure gauge and a high differential pressure alarm to indicate when the filter element has become fouled and needs to be replaced. The filter manufacturer normally advises a differential pressure at which the filter element should be considered no longer useful and therefore replaced with a new element. The high differential pressure alarm should be set accordingly. A pressure gauge should also be provided upstream of the filter assembly to indicate the seal gas supply pressure (Figure 5).

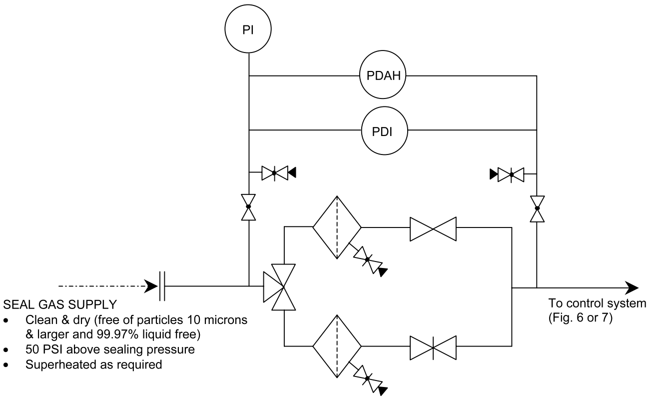

Figure 5. Duplex Gas Seal Filter Arrangement.

Control

There are two basic methods of controlling the supply of sealing gas to the gas seals—differential pressure (ΔP) control and flow control. ΔP systems control the supply of seal gas to the seal by regulating the seal gas pressure to a predetermined value (typically 10 psi) above a referenced sealing pressure. This is accomplished through the use of a differential pressure control valve (Figure 6).

Flow control systems control the supply of seal gas to the seal by regulating the seal gas flow through an orifice upstream of each seal. This can be accomplished with simple needle valves or, when automatic control is desired, through the use of a differential pressure control valve monitoring pressures on either side of the orifices (Figure 7). Automatic control is recommended.

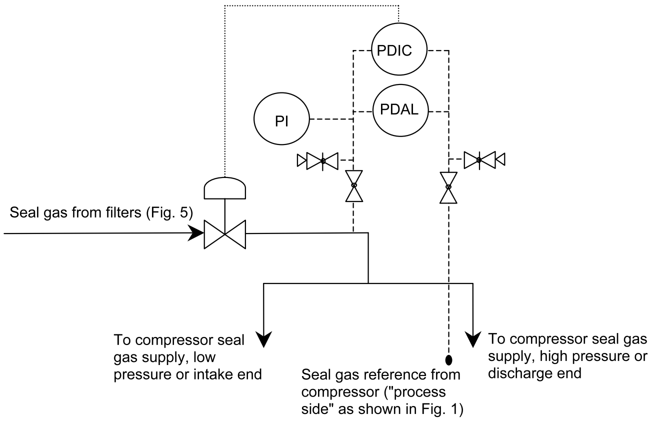

Figure 6. Differential Pressure Control.

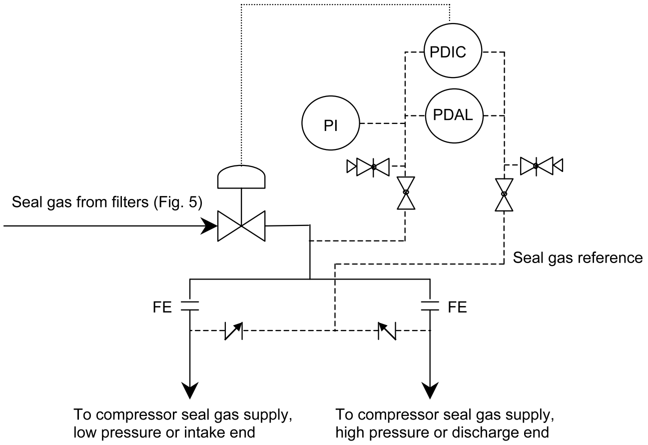

Figure 7. Flow Control.

The primary objective of the seal gas control system is to assure that sealing gas is injected between the inner labyrinth seal and the gas seal at a rate sufficient to prevent reverse flow of unfiltered process gas across the inner labyrinth seal and into the gas seal. A flow rate of 16 ft/s is an industry accepted standard for sealing with labyrinth seals. This is considered the minimum acceptable seal gas velocity for gas seal applications. Therefore, in order to assure a positive flow of seal gas across the inner labyrinth seal, gas seal systems should be designed to provide a minimum gas velocity of 16 ft/s across the inner labyrinth seal at all times. The seal gas velocity across the inner labyrinth seal will vary with labyrinth clearance. In order to maintain the minimum 16 ft/s velocity across the inner labyrinth seal at increased labyrinth clearance, the system should be designed to provide *twice* the seal gas velocity (i.e., 32 ft/s) at design inner labyrinth clearance. This is a conservative approach to system design that allows for increasing labyrinth clearance that may result from normal operating wear of the labyrinth seal.

It is also desirable to minimize seal gas consumption. The majority of the injected seal gas flows across the inner labyrinth seal and back into the compressor, and very little flow is actually required for the gas seal. This "recycled" flow into the compressor is inefficient and uses more energy at a cost to the user. Unnecessarily high seal gas flow can also result in increased initial gas seal system costs, since the high flow can result in larger sized, and thus more expensive, gas seal system components such as filters, valves, piping, etc. This added expense becomes even more significant if special liquid separation and/or filtration equipment is required due to unacceptable seal gas quality.

In order to achieve the minimum seal gas velocity of 32 ft/s across the inner labyrinth seal, and to minimize the amount of seal gas consumed, flow control is recommended over ΔP control systems. Since flow control systems are set to maintain the flow of seal gas supply through an orifice, the supply mass flow rate is constant and will not vary with labyrinth clearance.

To demonstrate the advantages of flow control over ΔP control systems, consider the following example. Using a 25 mole weight hydrocarbon mixture, a chart was constructed depicting the sealing gas mass flow, velocity, and differential pressure across the inner labyrinth seal for a range of sealing pressures using both flow control and ΔP control systems (Figure 8). The data for the ΔP control system is based on a seal gas supply pressure of 10 psi over the reference pressure. The data for the flow control system are based on a constant seal gas velocity of 32 ft/s across the inner labyrinth seal.

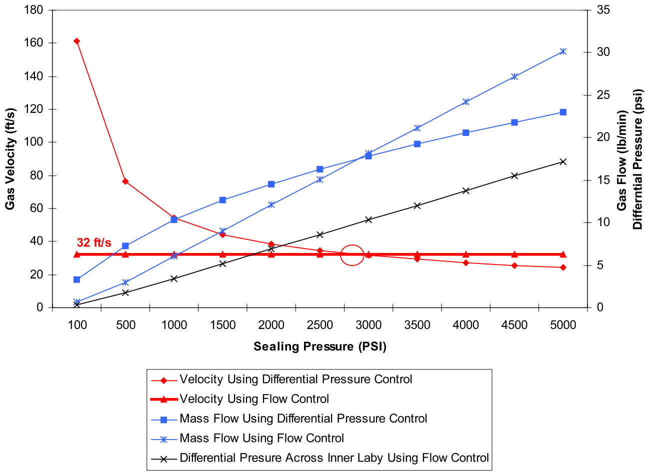

Figure 8. Inner Labyrinth Seal Gas Flow (25 Mole Weight Gas).

As can be seen from the chart (Figure 8), the sealing gas mass flow and velocity across the inner labyrinth seal are equivalent for flow control and ΔP control systems at a sealing pressure of about 2900 psi. At sealing pressures less than 2900 psi, the sealing gas mass flow for ΔP control is much higher than that of flow control at the same sealing pressure. For example, at a sealing pressure of 1000 psi, ΔP control uses about 70 percent more seal gas (mass flow) than flow control. As explained previously, the excess flow consumed by the ΔP control system is inefficient and uneconomical, and the use of flow control is recommended.

At sealing pressures greater than 2900 psi, the amount of sealing gas consumed by the flow control system is actually greater than that of ΔP control at the same sealing pressure. However, the velocity of the sealing gas across the inner labyrinth seal drops below the minimum recommended value of 32 ft/s when using ΔP control at these higher pressures. This increases the possibility of gas seal contamination from unfiltered process gas and therefore is a threat to gas seal reliability. For this reason, the use of flow control is again recommended.

The relationships between sealing gas mass flow and velocity across the inner labyrinth seal for flow control and ΔP control systems demonstrated above hold true for all types of process gases, shaft sizes, and labyrinth clearances. For gases of different mole weights, the sealing pressure at which the two types of control systems have equivalent sealing gas mass flows and velocities simply changes inversely proportional to the change in mole weight. For example, for a 40 mole weight gas, constructing a similar chart (Figure 9) of sealing pressures using the same assumptions as the previous 25 mole weight example, it can be seen that the equivalent pressure is about 1800 psi, as compared with 2900 psi for the 25 mole weight gas. For lower mole weight gases, the equivalent pressure increases. Constructing yet another chart (Figure 10) for a 5 mole weight gas indicates that the equivalent pressure is “off-the-chart” and beyond the sealing pressure capability of today’s gas seal technology.

As can be seen from the three charts of various mole weights and sealing pressures, the differential pressure across the inner labyrinth seal can become quite low when using a flow control system at lower sealing pressures (relative to the equivalent pressure). Low differential pressures across this labyrinth could be susceptible to process upsets, increasing the possibility of gas seal contamination from unfiltered process gas and threatening gas seal reliability. To compensate for this condition, it is recommended that the flow control system be designed to maintain a minimum 3 psi differential pressure across the inner labyrinth seal. This will increase the seal gas consumption and velocity across the inner labyrinth seal accordingly.

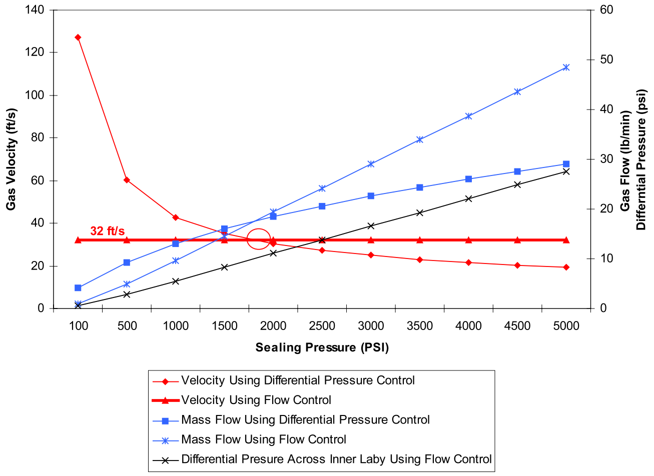

Figure 9. Inner Labyrinth Seal Gas Flow (40 Mole Weight Gas).

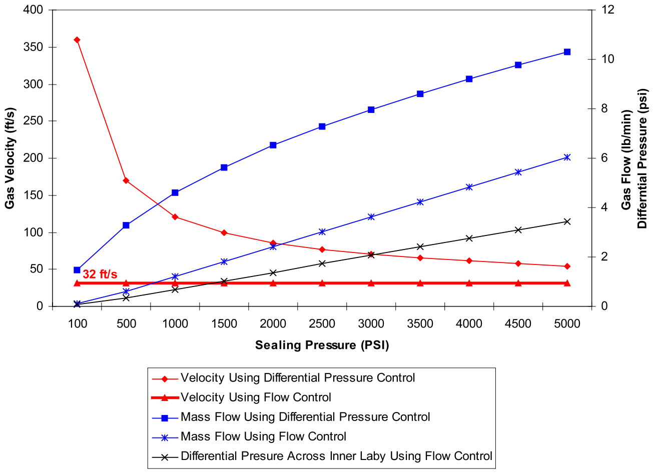

Figure 10. Inner Labyrinth Seal Gas Flow (5 Mole Weight Gas).

As demonstrated above, flow control systems have definite advantages over ΔP control systems, and flow control is therefore recommended. The gas seal system should be designed to provide a minimum gas velocity of 32 ft/s and a minimum differential pressure of 3 psi across the inner labyrinth seal at design labyrinth clearance. The application of these criteria will assure a positive flow of sealing gas across the inner labyrinth seal, reduce the risk of gas seal contamination from the process gas, thereby adding to increased gas seal reliability. The use of flow control also has the added advantage of eliminating the need for measurement of the reference (sealing) pressure from a cavity internal to the compressor, which is required when using ΔP control systems. Accurate reference pressure measurement can be difficult in some instances as has been discussed in detail by the author (Stahley, 2001).

The flow control system should include a “high-select” feature for the reference pressure (low pressure, downstream) side of the orifices (Figure 7). The high-select feature includes reference lines on the downstream side of the orifices in the seal gas supply piping to both gas seals. These lines include check valves to prevent cross flow of seal gas from each end of the compressor and are tied together into a single line before connecting to the differential pressure control valve. This allows the system to seal against the "worst case" (highest reference pressure) condition in the event that the seal gas flows required by each gas seal are slightly different. The check valves are drilled through to allow bleeding off the built up pressure. The system should also include a pressure gauge downstream of the control valve to indicate the seal gas supply pressure and instrumentation to initiate an alarm when the differential pressure across the orifices falls below a predetermined value.

PRIMARY GAS SEAL VENT

Sealing gas is injected between the inner labyrinth seal and the gas seal (Figure 1). The vast majority of this injected gas flows across the inner labyrinth seal and into the compressor, or "process" side of the gas seal. A very small amount of the sealing gas passes through the primary seal and out the primary vent, which is normally connected to the user's flare system. The gas seal manufacturer determines the gas seal leakage rate to the primary vent based on the specified service conditions and seal design. Leakage rates are typically between 5 and 15 scfm depending on seal size and service conditions.

The primary vent can be fabricated from carbon steel piping. The vent should be equipped with a valved, low point drain to allow removal of any built up liquids in the primary vent area that could cause damage to the primary seal (Figure 11). If the primary vent is connected to a flare system, a check valve must be included to prevent any potential reverse flow from the flare system into the primary vent area, which could cause damage to the gas seal.

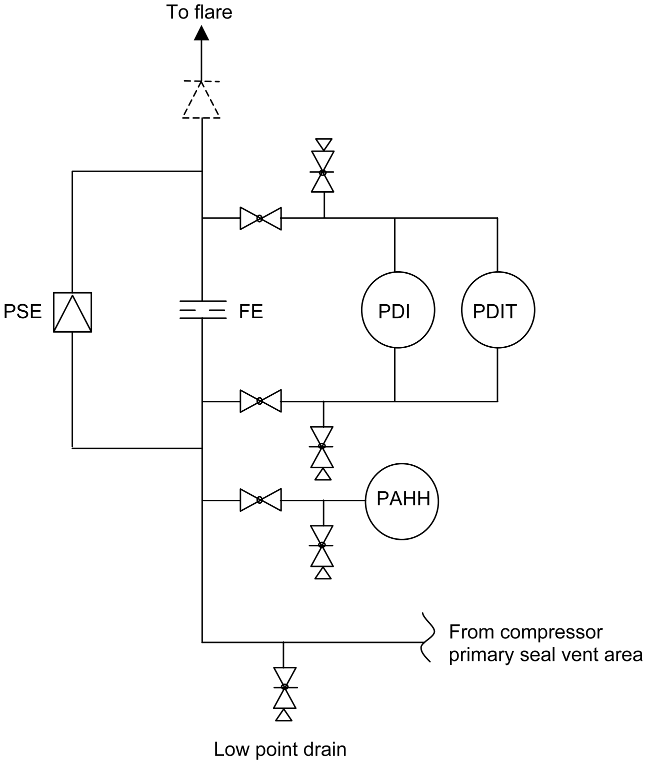

Figure 11. Primary Gas Seal Vent Arrangement.

Primary Gas Seal Health

The suggested method of assessment of the condition of the dry gas seal is by monitoring the gas seal leakage through the primary vent. This is accomplished by measuring the flow or pressure across a restriction orifice in the primary vent piping. An increasing flow or pressure trend is indicative of increasing gas seal leakage and suggests deterioration of the primary seal. The flow restriction orifice ("FE" in Figure 11) should be provided with a differential pressure transmitter to monitor and record seal leakage trends. An alarm should be included to initiate upon increasing pressure or flow above a predetermined limit. The recommended alarm level varies depending on the gas seal manufacturer, but twice the calculated gas seal leakage rate is a conservative approach.

Safety Issues

The primary vent system must be designed to cope with a total failure of the primary seal. It is highly recommended that a shutdown and depressurization of the compressor be initiated upon the failure of the primary seal. The secondary seal is intended to act as a backup in case of primary seal failure, providing the necessary shaft sealing until the compressor can be safely shut down and depressurized. Due to increased safety risks, operation on the secondary seal for extended periods of time is strongly discouraged.

A pressure sensing device, installed upstream of the flow orifice, should be used to initiate a shutdown and depressurization of the compressor upon increasing pressure above a predetermined limit. Again, the recommended shutdown level varies depending on the gas seal manufacturer, but three times the calculated gas seal leakage rate is a conservative approach.

In the event of a catastrophic failure of the primary seal, the primary vent is subject to a much higher gas flow, causing a backpressure in the piping upstream of the flow restriction orifice. A rupture disc should be installed in the primary vent to relieve the backpressure and evacuate the gas. The rupture disc ("PSE" in Figure 11), installed in parallel to the primary vent flow orifice, should be designed to burst at about 20 psi differential (depending on normal flare system design pressure). It should be noted that the high differential pressure or flow alarm and shutdown limits would be exceeded before the rupture disc will burst.

Before the compressor can be restarted after the gas seal has been repaired or replaced, a new rupture disc must be installed. It must be recognized that it is physically possible to restart the compressor with the damaged rupture disc in place. If this is allowed to occur, the instrumentation installed in the primary vent to initiate an alarm or shutdown will be rendered ineffective. The primary seal gas leakage will flow unobstructed through the void created by the burst rupture disc and a high flow or pressure will not be detected by the instrumentation. The user must be aware of these circumstances and maintenance procedures must be established accordingly.

To avoid this potential safety issue, the rupture disc should be fitted with an electronic continuity detector to indicate the disc has failed, thereby alerting the operator to avoid further startup attempts. Or, the electronic device can be connected into the start control system to prevent startup if the rupture disc has not been replaced. Another, less economical alternative is to use a relief valve in place of the rupture disc. However, the reader is cautioned to note the difficulties in sizing a relief valve for high flow, low differential pressure applications.

SEPARATION GAS SUPPLY TO THE BARRIER SEAL

Source

The end user must provide a source of separation gas supply to the compressor OEMs gas seal system (Figure 12). The separation gas is required for the barrier seals, which are intended to prohibit lube oil migration into the gas seal. The separation gas is fed to the barrier seals through stainless steel tubing. The separation gas must be available at sufficient pressure as defined by the barrier seal manufacturer with enough margin to account for buildup of pressure drop through the gas seal system components. It is very common to use instrument air as the separation gas medium. This requires careful attention to safety considerations, which will be discussed later. *It is highly preferable to use nitrogen as the separation gas medium.*

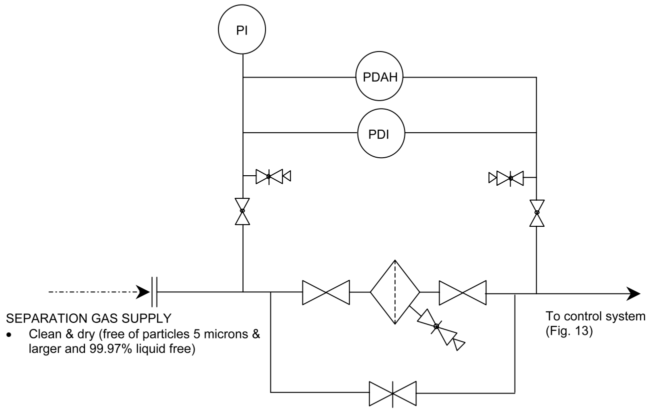

Figure 12. Barrier Seal Filter Arrangement.

Compared with the main seal gas supply, the quality and composition of the separation gas is of lesser concern. Barrier seal tolerances are not as small as gas seal tolerances, and therefore the gas quality requirements are less stringent. However, the typical sources of separation gas (nitrogen or instrument air) are generally very clean in comparison to seal gas sources. Therefore, the separation gas "requirement" at the customer connection point on the gas seal system is that it be free of solid particles 5 microns and larger and 99.97 percent liquid free.

Filtration

A separation gas filter immediately follows the customer connection point on the gas seal system. This is again intended as "final" or "last chance" filtration assuming compliance with the gas quality requirements explained in the previous section. API Standard 614 (1999) requires a duplex filter arrangement, but a single filter element with stainless steel housing has been proven to be adequate for this service. The filter should include a bypass line allowing filter element replacement while in service.

Since, as mentioned previously, the typical sources of separation gas are generally very clean, it is recommended that filter element be capable of 5 micron (absolute) filtration. Coalescing filter elements and manual drain valves should be provided for all applications.

The separation gas filter assembly should be provided with a differential pressure gauge and a high differential pressure alarm to indicate when the filter element has become fouled and should be replaced. A pressure gauge should also be provided upstream of the filter assembly to indicate the separation gas supply pressure (Figure 12).

Control

The supply of separation gas to the barrier seals should be controlled using a differential pressure (ΔP) control system. Approximately equal parts of the separation gas will flow through the barrier seal into the compressor bearing chamber (outboard side), and into the secondary seal vent area (inboard side). The ΔP system controls the supply of separation gas to the barrier seals by regulating the separation gas pressure to a predetermined value above the secondary vent pressure. This is accomplished with a differential pressure regulator.

The barrier seal manufacturer determines the required separation gas pressure to the barrier seal. Typical pressure requirements are 3 to 5 psi differential for labyrinth barrier seals and 5 to 10 psi differential above the secondary vent area pressure for carbon ring barrier seals. The separation gas supply tubing should include a gauge to indicate the differential pressure between the gas supply and the secondary vent. It is important to note that the reliability and length of service of the barrier seal can be greatly influenced by the absolute value of the separation gas pressure. The design of the system must take into consideration the maximum pressure that can be accepted by the barrier seal without creating abnormal wear of the seal itself. The barrier seal manufacturer must provide the maximum pressure versus seal life characteristic.

It is vitally important to the reliability of the barrier seals and gas seals that lube oil is only supplied to the compressor bearings when proper separation gas pressure exists. This can be assured with the following controls (Figure 13):

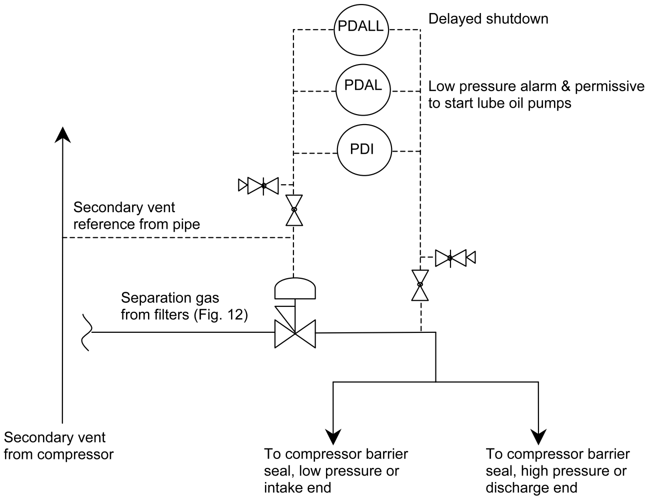

Figure 13. Separation Gas Supply.

- An alarm is required if the differential pressure between the separation gas supply and the secondary vent falls below a predetermined level.
- If proper separation gas pressure is lost during operation (rotation) of the compressor, a delayed shutdown is recommended. If low separation gas differential pressure is detected, a shutdown should be initiated after about 30 minutes. This will give operators time to attempt to reestablish proper separation gas supply and minimize the effects of oil migration to the gas seals. When compressor shaft rotation has come to a complete stop, lube oil flow to the bearings must be halted. If this is not possible due to turning gear requirements or for concern of heat soak into the bearings, an emergency nitrogen supply must be supplied to provide the required sealing during these conditions.
- If proper separation gas pressure is lost while the compressor is static (not rotating), lube oil flow to the bearings must be immediately halted.
- Proper separation gas pressure must be confirmed before proceeding to provide lube oil flow to the bearings. A "permissive-start" of the lube oil pumps is required.

SECONDARY GAS SEAL VENT

Reviewing overall seal operation, sealing gas is injected between the inner labyrinth seal and the gas seal. A very small amount of the sealing gas passes through the primary seal and out the primary vent. An even smaller amount (typically less than 0.1 scfm) of sealing gas passes through the secondary seal and out the secondary vent. The majority of the flow through the secondary vent is separation gas that has passed through the barrier seal (Figure 1).

The secondary vent can be fabricated from carbon steel piping. The vent system should be equipped with a valved drain at its lowest point to allow removal of any potential lube oil carryover from the bearings. The secondary vent should be vented to atmosphere. If the secondary vent is connected to a flare system, a check valve must be installed to prevent any potential backflow into the vent, which could cause damage to the secondary gas seal and/or barrier seal. The system design must also consider the possible increased flow to the compressor bearing housing and/or coupling guard area to avoid interfering with the normal venting of these areas from too high a pressure supplied to the barrier seal.

Secondary Gas Seal Health

It is difficult to monitor the health of the secondary seal. Unlike the primary seal vent, a flow or pressure measurement of the secondary vent is of little value for assessing the health of the secondary seal. Since the vast majority of the gas flow through the secondary vent is injected separation gas, measurement of this flow is not representative of secondary seal performance.

As explained by the author (Stahley, 2001), the biggest threat to the reliability of the secondary seal is contamination from bearing lube oil. Therefore, an evaluation of lube oil migration into the secondary seal cavity may provide the best means for monitoring the condition of the secondary seal as well as the effectiveness of the barrier seal. This can be accomplished by routine inspection of the low point drain installed in the secondary vent piping. The presence of increasing amounts of lube oil in the secondary vent drain over a period of time is indicative of deteriorating barrier seal performance. Progressive lube oil contamination will lead to degradation of the secondary seal. Conversely, if primary vent pressure or flow is normal, and the secondary vent drains are dry, it is usually safe to conclude that the secondary seal and barrier seal are in an acceptable operating condition.

Safety Issues

It is highly recommended that a nitrogen source be employed for separation gas. If a nitrogen source is not readily available, the user should consider the use of special nitrogen generation equipment to avoid the complications arising from the use of air as the separation gas medium. A safety issue arises when air is used as the separation gas for the barrier seal. Under this condition, it is possible to create an explosive mixture in the seal system secondary vent when air mixes with combustible process gas. Combustion can occur within the secondary vent if a certain gas to air mixture exists (i.e., within the explosive levels) and a source of ignition is introduced. The worst case scenario is a catastrophic failure of the primary seal, while the secondary seal remains intact. Under this condition, the secondary vent would be exposed to higher levels of sealing gas leakage, up to the maximum primary seal leakage rate advised by the gas seal manufacturer.

The explosive levels for a given gas will vary depending upon its components and the expected amount of gas seal leakage to the secondary vent (advised by the gas seal manufacturer), so the potential for explosive mixtures must be evaluated on a job-by-job basis. According to the Gas Processors Suppliers Association (1987), in general, a hydrocarbon gas and air mixture is potentially explosive if between the range of about 1 percent to 15 percent hydrocarbon gas by volume. If analysis determines the existence of an explosive mixture, the issue must be addressed through the design of the separation air system. The system can be designed to create a "lean" or "rich" environment in the secondary vent.

In a lean system, a quantity of air is injected into the secondary vent to ensure that the gas to air mixture is below the lower explosive level (LEL) of the gas (i.e., the ratio of gas to air is too low to allow combustion). This is accomplished by bypassing separation air from the supply piping directly into the secondary vent piping (Figure 14). It is also possible to include bypass ports within the secondary seal housing itself to bypass separation air directly from the barrier seal into the secondary vent cavity in the compressor. In a lean system, the secondary vent can be routed to atmosphere. A conservative design approach is to bypass enough separation air to create an environment of no more than 50 percent of the LEL under worst case (primary seal failure) conditions.

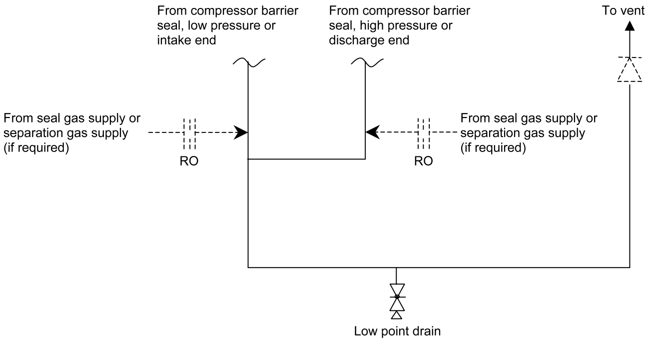

Figure 14. Secondary Gas Seal Vent Arrangement.

In a rich system, a quantity of process gas is injected into the secondary vent such that the gas to air mixture is above the upper explosive level (UEL) of the gas (i.e., the ratio of gas to air is too high to allow combustion). This is accomplished by bypassing process gas from the seal gas supply piping directly into the secondary vent piping (Figure 14). A conservative design approach is to inject enough process gas to create an environment at least 5 percent more gas by volume above the UEL under worst case conditions.

A rich system increases the amount of process gas to be vented, and environmental issues will probably require that the secondary vent be connected to the user's flare system. Connecting the secondary seal vent to a flare system when using an air separation system presents further safety issues and is not recommended. A flare system upset could possibly create a reverse flow in the secondary vent, forcing process gas into the compressor bearing cavity, and hence into the lube oil system. This could create an explosive environment. It must also be recognized that an increase in separation air flow, such as could be expected if the barrier seal were to malfunction, could alter the gas composition in the secondary vent, resulting in an explosive mixture (below the UEL).

It is ultimately the user's decision if the system is designed to run rich (above the UEL of the gas) or lean (below the LEL of the gas). A rich system will greatly reduce the overall separation air consumption, but will increase process gas consumption and increase the amount of hydrocarbon gas routed to the secondary vent, creating a potentially dangerous environment. A lean system increases the overall separation air consumption, but will decrease process gas consumption and the amount of hydrocarbon gas routed to the secondary vent. These factors must be evaluated by the end user based on the specific project conditions before the system design can be finalized. The use of nitrogen for separation gas is again highly recommended.

SUMMARY

The author has addressed the four main components of gas seal systems in detail and proposed design standards for each:

- Supply of sealing gas to the dry gas seals
- Primary seal vent system
- Separation gas supply to the barrier seals
- Secondary seal vent system

The gas seal system design standards proposed herein are summarized in a single diagram for easy reference (Figure 15). Also provided is a tabulation of recommended gas seal system alarm, shutdown, and permissive-start conditions (Table 1).

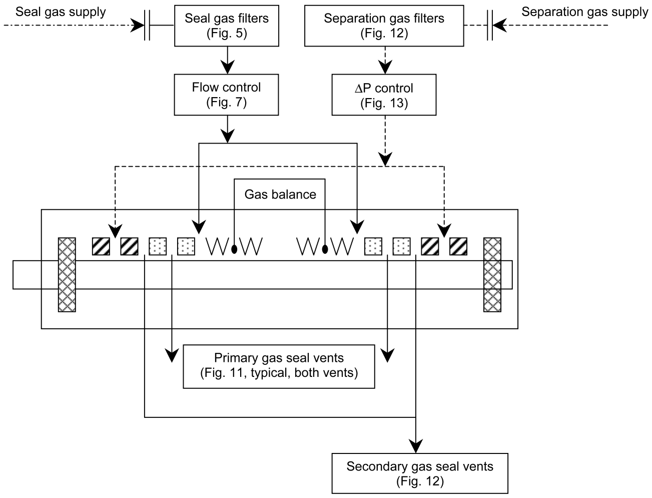

Figure 15. Gas Seal Support System.

Table 1. Alarm and Shutdown Conditions.

Parameter	**Alarm Condition**	**Shutdown Condition**	**Permissive Start**
Seal gas filter differential pressure	High	NA	
Seal gas supply flow	Low	NA	
Primary vent pressure or flow	High	High	
Separation gas filter differential pressure	High	NA	
Separation gas supply differential pressure	Low	Low (delayed)	Required

CONCLUSION

The purpose of this paper was to put forth to the community of process gas centrifugal compressor users a design standard for dry gas seal support systems. The design suggestions and recommendations presented are based on the experience of one manufacturer of both centrifugal compressors and dry gas seals. These recommended design practices will provide the user with an effective, reliable, safe, and economical dry gas seal support system.

The gas seal system design recommendations proposed in this paper are applicable to the industry's most common arrangement of a beam-style compressor with tandem dry gas seals. These system standards are "typical" and may need to be modified for different types of compressor and/or gas seal arrangements, but the basic design philosophies are applicable to most applications. Each project should be evaluated on a case-by-case basis to assure an appropriate gas seal system is applied.

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