Design Enhancements on Dry Gas Seals for Screw Compressor Applications

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Introduction

The development of compressor gas sealing technology has advanced significantly in recent years. Seal life in excess of 7-8 years is now seen in industry today common. This paper is intended to highlight the considerations when applying Dry Gas Seals (DGS) and advancements in screw compressors today that allow us to push the application envelope.

Due to its proven reliability, DGS are used in nearly every new compressor and are also replacing existing sealing solutions such as labyrinths, oil lubricated mechanical seals and carbon ring seals. Historically, gas seal technology was applied to change from oil seals and other seal technology and was designed to handle the same application range for pressure and speed. With the growing demand in the industry for higher pressures and speeds, the gas seal application range needed to be expanded. In order to cope with these increased requirements on compressor speeds and sealing pressures, modern, advanced materials have been developed for the seal itself. The use of precise design tools, advanced design practices and experienced know-how as well as deep application knowledge are all required in order to insure a reliable sealing solution.

1. Design Challenges

Compact designs with usually small centre distance of the shafts in screw compressors and the relatively large shaft diameters do not leave much radial space for sealing devices. These seal envelopes have approximately one-third of the radial height compared to centrifugal compressors. Figure 1 compares a standard dry gas seal with the available space in a screw compressor.





The main challenge for such designs is that the narrow cross section of seal envelopes requires small seals with comparable small seal face width.

The seal face width of the DGS determines the performance of the seal, including leakage rates and heat dissipation. When applying the CFD tools for seal performance optimisation also the expected amount of seal film stiffness and film dampening capability are optimised to cope with the application data, which are given for most of the applications as follows:

- sealing pressure up to 60 bar
- temperature in the seal area -20°C to 160°C static and 0°C to 160°C dynamic
- tip speed at seal rotor outside diameter up to 80 m/s



Figure 2: Single Seal Cross Section

2. Gas Film and Face Patterns

DGS are balanced (Figure 3). A low pressure differential separates the seal faces in such a way that a low amount of gas passes the seal gap.



Figure 3: Balance Ratio

The main load on the gas film is determined by the balance ratio. The spring force as well as the friction of the dynamic secondary sealing element is neglected in this case.

To stabilize the gas film under dynamic conditions shallow groves are used. For gas seals the axial air bearing technology has been applied. This technology has been discussed by Gümbel and Everding [1925] and by Underwood [1937] and analyzed by Whipple [1951] and Wondswoth [1956]. Figure 2 shows typical face patterns that were considered.



Figure 4: Axial Air Bearing Face Patterns

In the late 1970's the uni-directional spiral grooves were successfully applied to mechanical seals. During the gas seal development the authors company developed bi-directional face patterns in the early 1980's, known throughout the industry as T-Grooves, see Figure 5.



Figure 5: Bi-directional T-Grooves

The bi-directional seal provides a number of key advantages, but not all designs have been successful and many have been limited in pressure or speed capability. Due to its proven application window and being applied in the highest pressure and speed applications successfully, the industry preference today is to use the bi-directional T-Grooves well also providing generally lower leakage rates. T-Groove seal faces are fully interchangeable for all four shaft ends of the screw compressor. This requires less spare parts, allows for fool-proof installation and avoids dramatic failures under reverse running conditions for the compressor.

The proven practical experience of the T-Groove technology is accompanied by a finite differential computer model to calculate and optimize relevant seal performance data such as working gap width, dynamic seal film stiffness and the related dampening capacity. With the calculated pressure distribution in the seal gap, a stress and deformation calculation of the seal faces is performed. For the reader's reference, some calculation results are shown in the following Figures and are specifically conducted for a 60mm shaft size seal, equipped with T-Grooves which fits in the screw compressor cavity.



Figure 6: Working Gap Width [µm] vs. Sealing Pressure



Figure 7: Film Stiffness [kN/mm] vs. Sealing Pressure



Figure 8: Film Dampening Capacity [kNs/mm] vs. Sealing Pressure Naturally all theoretical models are verified with intense testing.

3. Seal Configurations and Applications

3.1 Single Seal GASPAC S



Figure 9: Single Seal

Single DGS are used for applications in non toxic/hazardous and or non flammable gases. The entire pressure differential is sealed across one seal gap. Reverse pressure and vacuum at the process side is permitted under static conditions, only. Under dynamic conditions a positive pressure differential across the seal must be ensured.



3.2 Double Seal GASPAC D

This seal configuration is usually used to seal toxic, explosive inflammable or hazardous gases which are not allowed to migrate to the atmosphere. Wet and dirty or gases which are carrying abrasive particles are usually also sealed with this face to face arrangement. Inert

Figure 10: Double Seal Arrangement

gas is used at connection A to pressurize the seal with a pressure differential to the process side of 3 bar in minimum. The positive pressure differential to the process side ensured that no process gas enters the atmospheric side of the seal.



3.3 Tandem Seal GASPAC T

Figure 11: Tandem Seal

A tandem seal arrangement is used to seal toxic, explosive or flammable gases, where process gas leakage to atmosphere is permitted. This arrangement has become the industries standard for hydrocarbon applications.

In the unlikely case of an inboard seal failure the outboard seal is able to seal the full pressure differential which allows a safe shut down of the compressor.

4. Dry gas seal environment

4.1 Seal gas supply filtration

A clean dry gas is necessary for optimum seal life and increased reliability. The quality of the seal gas injected to the process side of the seal must be filtered to a minimum particle size of 3 µm absolute. Designed flow through the filtration systems must not exceed the filter design capacity and is optimised by reducing the flow to that required to prevent process gas from flowing into the seal across the process side labyrinth. By reducing the flow velocity and volume to only what is required to protect the seals you allow the coalescent action to be optimized. This value is dependent upon filter design and the process side labyrinth clearance and is evaluated in the detailed design phase.

In our standard system design, dual coalescent filters are used to manage filtration of aerosols and particles to 1 μ m absolute or better. However, the limitation of coalescing filters is that the design is capable of removing in the range of 0.1% of entrained liquids by volume

in the gas stream. Due to the wet nature of many types of applications, it is highly recommended that a specially designed pre-filter capable of liquid knockout up to 10% of entrained liquids by volume be included (refer to Figure 12)



Figure 12: Filter System with Drypac

If reciprocating compressor oils are in the supply gas stream, a carbon filtration system may be necessary to remove the oil and manage the condition of the supply gas.

4.2 Dew point of the gas

The seal supply gas must be maintained at a temperature of 20° C above its dew point as it enters the seal cavity. The seal cavity must also be above the dew point of the gas, as the gas temperature will quickly equalize with the seal temperature due to heat transfer of the supply flow to the steel compressor casing.

Specific applications like hydrogen recycle machines, cracked gas machines or gas reinjection machines often have suction temperatures at or below the dew point of the gas, therefore increasing the likelihood of saturated gas and liquids dropping out in the seal. Heat tracing or even coolers and heaters are required in order to insure the recommended margin of temperature above the dew point. The dew point should be checked against: ambient, suction, bearing oil and interstage supply gas temperatures. Heat tracing the supply lines may be sufficient, but heat tracing only attempts to maintain the current temperature and thus should be used right from discharge all the way to suction in order to maintain discharge temperature. If the gas is allowed to cool in order to knock liquids out and reduce the dew point of the gas, then a gas heater is recommended to insure the gas temperature is heated back up providing at least the stated 20° C differential. Changing or further reducing the dew point of the gas with the use of coolers may be required and should be designed in conjunction with a demister or liquid knock out filter and a heater to establish the required dryness and temperature differential of the supply gas.

4.3 Filtered gas at all times, booster unit

During a start up, shutdown, or lower downstream pressure demands than normal there can be times when the compressor has abnormally low differential pressure from suction to discharge, resulting in low seal gas flow rates. This allows possible contamination of the seal cavity with unfiltered gas.



Figure 13: Ampliflow Booster System

An Ampliflow unit is designed to boost the seal gas supply flow and pressure and is automated to operate whenever the required differential pressure is not adequate to supply the necessary flows to the seals. Supply flow should be designed for a minimum of 5 m/s velocity flow through the process side labyrinth or carbon ring seal. If an alternate source of clean process compatible gas is available at a sufficient pressure above normal suction pressure, then it can be used in place of an external booster system. In Figure13 a booster system is shown that is used for commissioning new units in relatively clean services. Similar units are designed directly into the gas seal supply line for applications in dirty wet services to insure flow to the seal at all times even after commissioning.

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4.4 Pressure differential control valves for flow control

There are numerous ways in which to provide filtered gas to the dry gas seals. One key design consideration is to provide a flow of 18 ft/s velocity across the process side labyrinth. Calculating this velocity at 2 times the nominal design clearance allows a sufficient flow plus a safety margin. Empirical data from testing has concluded that this velocity is sufficient, including safety margin, to prevent back flush through the process seal into the seal cavity. This design criterion minimizes the flow in order not to over tax the design capability of the filtration system or create efficiency losses due to recompression of the gas being recycled through the seal supply line and back through the compressor.

Flow control is the most reliable and effective way to achieve the above criteria for high pressure applications. The simplest and least influenced method from outside factors is a regulator taking a signal across a pre-calculated sized orifice. This can be increased to 36 ft/s (approximately 10 m/s) to provide additional margin to cover an upset where the process side labyrinth or carbon seal become worn to twice its normal clearance.

Due to the critical nature of these types of applications and often slight differences in pressures with balance piston line flow, it is also recommended that the pressure and the supply flow or differential pressure across an orifice be independently monitored to each seal.

5. Conclusion

This paper is based on the authors' company experience in applying Compressor Gas Seals to high pressure, high speed, dirty and wet gas services. With the existing reliable technology the following application range is available:

- Pressures from zero pressure differential up to 450 bar across one seal face
- Speeds up to 250 m/s at the outside diameter of the rotating face and speeds over 65,000 rpm.
- Temperatures from –135°C up to 230°C
- Shaft diameters from 25 mm up to 360 mm

The authors' company has developed solutions and system enhancements to take care of each of the stated system issues as well as the standard gas seal control system. For any high pressure, high speed, dirty or wet application, we recommend discussing the details of your specific application with a Compressor Seal Specialist to insure all requirements for a long reliable seal life are in place.