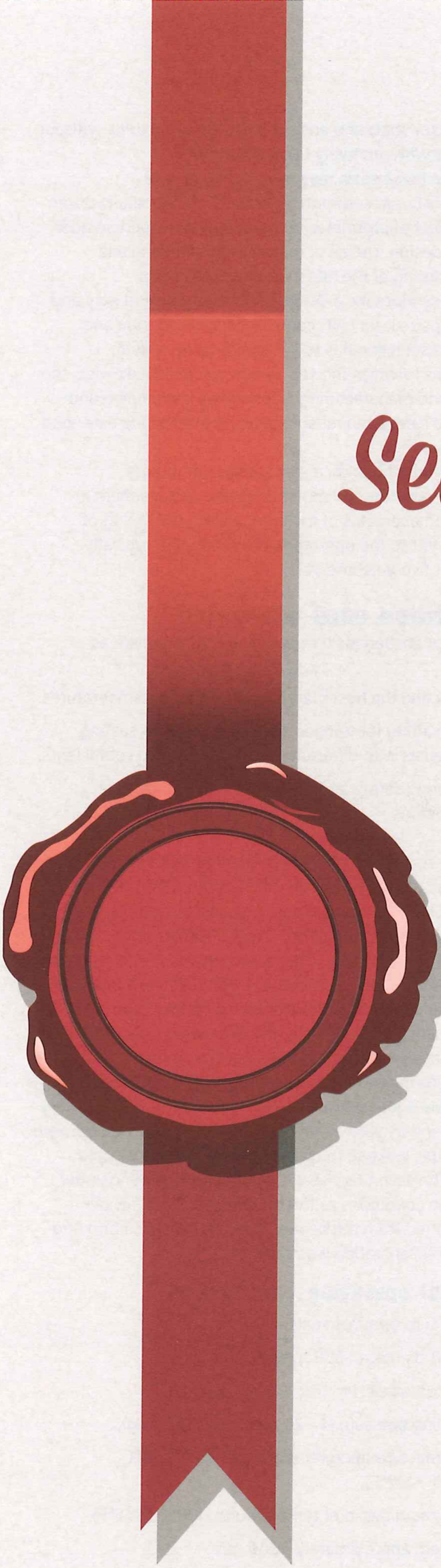

Sealing solutions

Daniel Goebel, Dieter Klusch and Francesco Grillo, EagleBurgmann, recommend the use of dry gas seals for LNG compressors.

With the discoveries of large new natural gas deposits, including shale formations, competition is intensifying for LNG supply contracts, making it imperative that LNG operators achieve the lowest possible delivered costs by optimising reliability and attaining larger economies of scale. Technological progress is supporting the pursuit of these goals; both producers and shippers can rely on a new generation of extremely reliable centrifugal compressors, typically equipped with mechanical dry gas seals (DGS) developed and sized specifically for refrigerant and boil-off compressors used in the LNG sector.

Compressors and seals are an integral part of all processes used to transform natural gas into LNG. Cooling gas below the dew point in the range of -160°C (-256°F) at ambient conditions is typically done stepwise in heat exchangers employing refrigerants (usually methane, ethane and propane).

The cooling media are compressed and then expanded to progressively cool down the natural gas. Compressors circulate the refrigerants. The latest generation of LNG vessels have reliquefaction units on board to decrease LNG losses from liquid returning to a gaseous state during transportation. These reliquefaction units generally use centrifugal geared compressors, combined with the expansion turbine.

At onshore terminals, new, ultra-large capacity processing equipment is being used to increase production rates and reduce the percentage of natural gas diverted to power the liquefaction process. Compressors as large as 120 t have been developed. That, in turn, required the development of a 390 mm (15.35 in.) gas seal to accommodate an increase in maximum compressor shaft sizes from 330 to 350 mm (12.99 to 13.78 in.).

Good shaft sealing technology is critical to compressor efficiency and reliability. Without a highly effective and consistently reliable shaft seal, the compressor would lose efficiency and, in the worst case, suffer unscheduled shutdowns at great economic cost. That makes the choice of seals a key part of the total capital investment decision.

EagleBurgmann's design verification and testing, as well as continuous product upgrading and operating range extensions, have resulted in these ultra-large seals being certified for LNG operations by major compressor manufacturers.

Dry gas seals

DGS, also known as gas-lubricated mechanical seals, are an excellent solution for LNG compressors in onshore and offshore applications because of their ability to reduce power dissipation and leakage at shaft ends. They can help to simplify the seal control panel and make it more reliable. In a high performance DGS, the two sliding surfaces run one on top of the other, separated by a film or cushion of gas that guarantees contactless running at speeds up to 20 000 rpm. The narrow, stable sealing gap results in relatively low gas leakage around the compressor shaft and ensures that the seal works without wear and with relatively low power input.

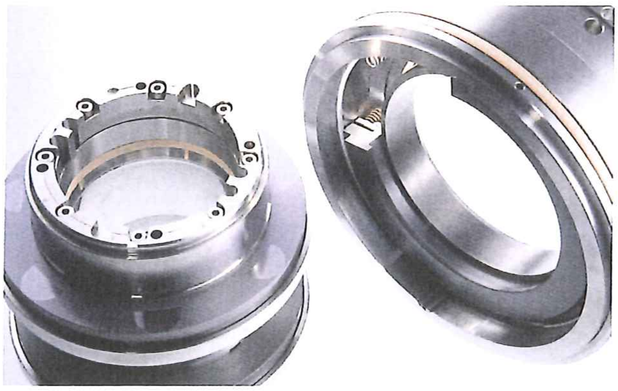

Figure 1. EagleBurgmann DGS.

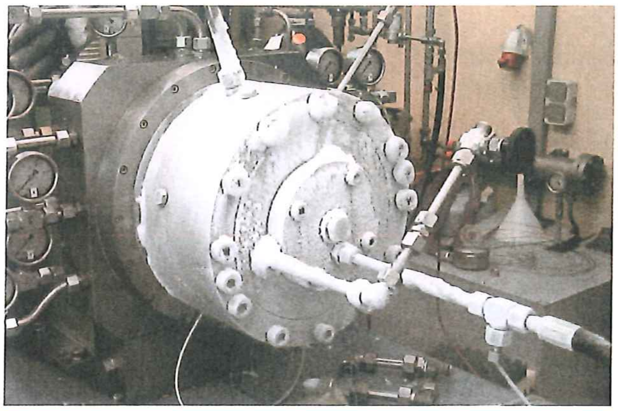

Figure 2. Cryogenic testing in EagleBurgmann's test facilities.

While these seals may have some general characteristics in common regardless of the manufacturer, a great deal of proprietary knowledge and expertise goes into the design, choice of materials, and testing and manufacturing of the latest certified LNG seals.

One cannot take a DGS used in everyday industry and simply upsize it for LNG compressors. The design and materials selection has to anticipate all operating conditions to which the seal will be exposed. Likewise, the testing and manufacturing is extremely demanding and critical to safety and reliable performance during extended operations.

As a rule of thumb, a seal should not require maintenance. It is common practice to replace them at scheduled overhauls of the compressor, the timing of which is left to the operator's discretion, but typically occurs at five-year intervals.

Onshore and offshore

The major challenges for designing LNG seals are as follows:

- Selecting the best materials for very low temperatures.
- Accounting for temperature fluctuation on sealing materials with different thermal expansion coefficients.
- Ensuring safety and reliability in all operating conditions.

LNG seals are typically designed to function reliably in temperatures ranging from -170°C up to 230°C (-274°F to 382°F). DGSs used in onshore liquefaction are normally operated in the range of 40°C (104°F). Their low temperature tolerance is required only for special operating conditions. In LNG terminals, the 390 mm seals installed on the new ultra-large horizontal split barrel type compressors have an outer diameter of up to 550 mm and fit a shaft diameter of 350 mm. For this product, EagleBurgmann employed a safety-critical DGS design using two single seals in tandem arrangement – a primary and secondary with a labyrinth in between – to ensure zero natural gas leakage to the atmosphere where it could ignite. The secondary seal is capable of operating under the same conditions as the primary. To avoid any oil immigration from the bearing into the seal, a carbon ring seal as oil separation was selected.

Typical operating parameters

- 390 mm terminal seals.
- Shaft diameter: 350 mm (13.78 in.).
- Sealed gases: N_2, CH_4, C_2H_6, C_3H_8.
- Sealing pressure: 4 - 24 barg (58 - 348 psig).
- Normal operating temperature: 30°C - 50°C (86°F - 122°F).
- Minimum gas inlet temperature: -100°C (-148°F).
- Speed: approximately 3000 rpm.

Typical seal design data

- Pressure: 50 barg (725 psig).
- Temperature: -110°C - 230°C (-166°F - 446°F).

The smaller compressor/expander plants installed on board LNG vessels typically employ geared-type compressors. The seals used in the compressor stages are subjected to moderate temperatures and do not require special materials, but must be capable of withstanding other operating stresses such as vibration and rough seas. Furthermore, the overhang design of the compressor requires the DGSs to be as short as possible, so a design employing a single seal plus an oil separation seal is used. Expander stage seals present the bigger challenge in sealing gases at extreme low temperatures. The seals used on the expansion turbines are exposed to extreme cold – down to -135°C (-211°F) in regular operation. Nitrogen is usually the process gas used in the secondary cooling cycle. For these DGSs, EagleBurgmann selected special metal materials and elastomer-free secondary sealing elements. The DGSs for LNG reliquefaction compressors/expanders were designed for the conditions described below.

Compressor stages – LNG vessels

Typical operating conditions

- Shaft diameter: approximately 50 - 70 mm (1.97 in. - 2.76 in.).
- Sealed gases: N_2.
- Sealing pressure: 10 - 52 barg (145 - 754 psig).
- Normal operating temperature: 40°C - 50°C (104°F - 122°F).
- Speed: approximately 20 000 rpm.

Typical seal design data

- Pressure: 50 barg (725 psig).
- Temperature: -29°C - 125°C (-20°F - 257°F).

Expander stage – LNG vessels

Typical operating conditions

- Shaft diameter: approximately 50 - 70 mm (1.97 in. - 2.76 in.).
- Sealed gases: N_2.
- Sealing pressure: 10 - 52 barg (145 - 754 psig).
- Normal operating temperature: -135°C (-211°F).
- Speed: approximately 20 000 rpm.

Typical seal design data

- Pressure: 52 barg (754 psig).
- Temperature: -196°C - 230°C (-320°F - 446°F).

Materials selection criteria for low temperature operations

EagleBurgmann's LNG selection criteria for low temperatures for all metal parts and secondary sealing elements ensures a reliable, long-term operation and good material properties in temperatures as low as -196°C (-320°F). All secondary sealing elements are made of polytetrafluoroethylene (PTFE) with special filler material to withstand low temperatures.

For the primary sealing elements, the rotating seat and stationary face employ the company's standard solution used since 1992: silicon carbide against silicon carbide. These faces are especially large in a 390 mm seal, so compensating for temperature deformation is important.

Figure 1 shows the seal core. The rotating seat is turning together with the compressor shaft while the ceramic stationary face is fixed by torque pins to the metal housing.

The balance sleeve is shrink-fitted to the housing. EagleBurgmann uses tungsten carbide for both the balance sleeve and supporting ring for the sealing element, preferring it for low temperature coefficient and because, when polished, tungsten carbide gives a high quality, smooth surface.

Figure 3. An EagleBurgmann 390 mm seal during preparation for shipment.

Figure 4. Typical LNG vessel with reliquefaction unit.

The stationary face must be sealed reliably against the balance sleeve to avoid any leakage bypass and its face must move axially to compensate for any shaft movements. During extreme temperature fluctuation, the gap will vary dramatically. If it is too large, good sealing function is not ensured, and if it gets too small, or even disappears, it loses axial flexibility. This required special attention to cope with the temperature extremes and the -135°C (-211°F) standard operating temperatures for expander seals. This specific design of the polymer cup seals ensures minimum sliding forces combined with wear-free operation.

Optimising seal performance

Proper tapering of the seal face is another critical part of designing a DGS for extreme temperatures. It begins with predicting the seal face deformation. The EagleBurgmann solution is to size the seal face taper at room temperature for optimal geometry under ordinary operating conditions, applying the company's validated calculation codes and experience to get the optimum result for extreme heat or cold temperatures, then fine-tuning the result through extensive testing.

The rotating seat of a DGS compressor seal is grooved to ensure that the gas separation film forms and stabilises during dynamic operation, including compressor start-ups and coast down. These proven 3D grooves ensure optimal pressurisation within the sealing gap (between rotating seat and stationary face). The company's engineers simulated operating conditions to generate an optimum operational sealing gap below 5 μm and ensure reliability of the gap under all operating conditions.

Controlled testing of every seal type

Every LNG seal type is subjected to rigorous cryogenic testing under simulated operating conditions at the test centre. Liquid nitrogen is used to cool down the seals to -170°C (-274°F) prior to the dynamic test. The master tests for each seal also simulate particular operational issues of LNG compressors that represent major challenges for dry gas seals, such as the impact of rotor deformation that might occur in variable or low-speed operations or compressor coast down from shaft misalignment, simulated by reproducing a forced plant shutdown more than 120 times.

Turning requirement

Some equipment used in LNG applications is calling for turning conditions in order to heat up or cool down the gas turbine or compressor shaft to avoid deformations. As DGSs are more effective in lifted off condition extreme low speeds, in the range of 5 - 40 rpm, this might lead to contact operation of the seal. To ensure that many turning cycles over the compressor service time can be covered, the industry asks for up to 1000 hours proven reliable operation even in turning (contact) conditions. EagleBurgmann completed this challenge and its seals have proven reliable even after 2000 hours in contact at 7 rpm.

All intermediate tests, as well as the final dynamic test run, showed that the seal performed as designed for.

Furthermore, all intermediate and final measurements of the sliding faces indicated that all sliding parts (seats and seal faces) were in good working condition. The sliding faces of both seats (inboard and outboard) showed no wear at the end of the testing process; only smooth polished areas were visible.

The hardness of a diamond coating (EagleBurgmann DiamondFaces) on top of proven seal face materials lead to no wear. Therefore, cleaning procedures were not required after the turning took place. In addition, by having 'wear-free' seal faces, the aerodynamic seal performance and axial movability remained unscathed. The reliability and robustness of DiamondFaces in combination with proven seal materials meets specific LNG industry needs.

Manufacturing considerations

Very large seals are the most challenging to manufacture because the geometrical tolerances must be the same as for smaller seals. Geometrical tolerances such as the flatness imposed on seal faces have little to do with the size of the seal.

Field experience

EagleBurgmann has a long history in low temperature sealing solutions. It delivered the first seals for on-board reliquefaction and small scale LNG plants 13 years ago.

In 2005, the company developed 390 mm cryogenic seals for onshore LNG operations for one of the world's leading compressor manufacturers. As a result of that success, that OEM commissioned the company to develop a version of the same 390 mm design for a high temperature environment – a furnace gas recompression train in a new cogeneration plant at a major steel mill in Wuhan, China. The 390 mm seal underwent further testing up to a +250°C (+482°F) bulk seal temperature. With the design robustness and sophisticated gap control solutions, no significant design modifications for high heat were necessary. These seals have been in continuous service since the cogeneration plant started up in 2009.

The feedback from the compressor OEM has been very positive, a testament to the versatility of the original design to adapt to all temperature extremes and fluctuations. The result is a new generation of dry gas seals built to a high standard of safety and efficiency on which LNG operators can rely. **LNG**

Bibliography

- Meher-Homji, C. B.; Matthews, T.; Pelagotti, A.; and Weyermann, H. P., 36th Turbomachinery Symposium: Gas turbines and turbo compressors for LNG service, 2007.
- Shukri, T., 'LNG technology selection', *Hydrocarbon Engineering*, February 2004, pp. 71 - 74.