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Advances in dry gas seal technology for compressors

Centrifugal process gas compressors, and also certain rotary compressors, require sealing elements between the pressurized gas-containing volume and the bearing assemblies that support the compressor rotor. A variety of different seal types and styles have been available for decades. In the majority of these seals, lubricating oil serves as the fluid that separates rotating from stationary sealing elements. The barrier oil for these “wet” compressor seals is typically introduced at pressures of approximately 30 psi (2 atm) higher than the opposing compressed process gas. Wet seals require a seal oil supply system that generally includes an oil reservoir, two or more oil pumps, filters, coolers, valves and control instrumentation.

Three decades ago, some successful dry gas seal (DGS) applications (FIG. 1) became viable sealing options. Although wet seals will likely remain in contention for some time, a number of considerations have accelerated DGS development.

As of this writing, seven years of uninterrupted compressor service are no longer the exception for services with clean gases. This partially explains why, over the past 20 years, DGSs have displaced many of the different precursor seal styles. Another recent development began in about 2006 at an innovative, UK-based seal manufacturing company.¹ The company has taken on both the design of its own, and the successful refurbishment of many other kinds, of DGS assemblies originally provided by other seal (or compressor) manufacturers.

How DGSs function. Simply put, DGSs operate by creating and maintaining a very thin gas film ($< 5 \mu\text{m}$) between two mating disc-like surfaces, one stationary and one rotating.² The stationary face is spring-loaded. Maintaining this gas film under all operating conditions is essential to reliable seal operation.

The gas film is so thin that the most efficient method of demonstrating its existence is to perform a rigorous running test. For this reason, all DGSs should be dynamically tested at the time of manufacture and also after seal repair (often referred to as seal refurbishment). A basic schematic representation (FIG. 1) shows a dry gas seal and its associated controls. Depending on the nature of the gas and the criticality of service, the design of a gas conditioning and DGS support and monitoring system can be quite sophisticated.

There are many functional similarities between DGSs and their precursor models. The precursor oil-lubricated (wet) seals include many variants of face, bushing and floating ring seals. Yet, there are component features that differ in wet seals, as contrasted with DGSs. For instance, the seal face of the rotating mating ring in a DGS can be divided into a grooved area at the high-pressure side and a dam area at the low-pressure side (FIG. 2). The shallow grooves are often laser-etched, spark-eroded or chemically milled. A typical approximate depth is 0.0003 inch = 8 μ , achieved through highly precise machining operations. T-

shaped, V-shaped (bi-directional) and L-shaped (unidirectional) grooves have been produced, each with advantages and disadvantages. A stationary sliding ring is pressed axially against the mating ring by both spring forces and sealing pressure.

The sealing gap is located between the mating ring and the sliding ring. The needed gas film is achieved by the pumping action of the grooves and the throttling effect of the sealing dam. A suitably designed groove geometry is critical for trouble-free operation of the seal.

Before opting for DGSs in retrofit situations, reliability-focused users ask if an apparently flawed precursor seal really represents the best that the vendor can offer. Use TABLE 1 as a preliminary screening tool³ and follow up with a more thorough review.

More specifically, the claims of competing vendors and for different styles of seals must be checked against actual experience (FIG. 2). In some cases, these checks lead to the purchase of late-generation liquid film (wet) face seals instead of DGSs. In all instances, the areas of safety and reliability must be given full and special consideration.

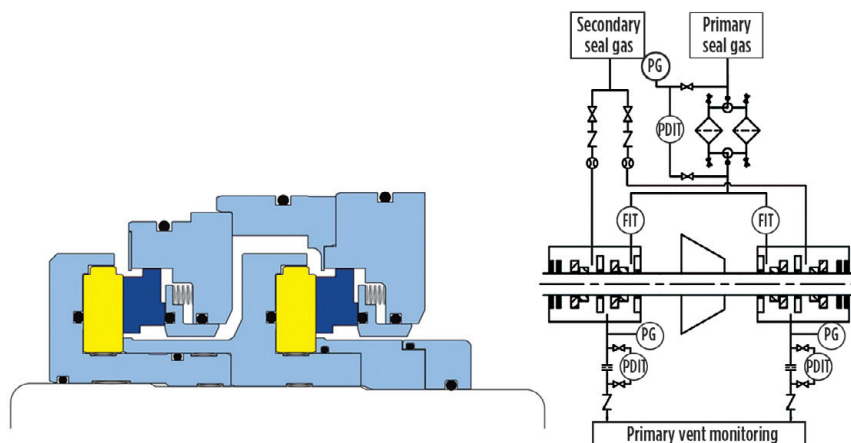


FIG. 1. A typical DGS arrangement with a control system. Source: AESSEAL plc.

Minimizing the risk of sealing problems. Upgrading from the traditional compressor seals to advanced DGSs is entirely feasible. In some cases, gas seals are a good economic choice because the user does not need to purchase an elaborate seal oil console. It may be difficult to justify the cost of installing modern DGSs if the compressor train is a few years old and incorporates older, but technically satisfactory, wet oil seals, or if the compressor train's already existing seal oil console has proven reliable.

Experience shows that preexisting wet oil seals and their support systems are not always reliable and inexpensive to maintain. These are among the reasons why dry gas sealing has come into prominence and why a DGS merits consideration for most process gas compressors.⁴

Giving due consideration implies that specification, review, purchasing and installation of a DGS and its requisite support system cannot be left to chance. An audit of the owner's facility and the particular process unit or gas in which the compressor will be installed is foremost among the steps required to select the right seal configuration. These comprehensive and active review steps often lead to the selection of dual seals, which may be needed to maximize dry gas seal life, long-term performance, and equipment and process safety.

Although less complex and less costly than their wet seal counterparts, DGS support systems merit the attention of reliability-focused buyers. In their re-

spective order of importance, the following factors should be considered in examining DGS support systems for centrifugal compressors:

- **Gas composition.** Understanding the actual gas composition and true operating condition is essential, yet often overlooked. For example, it is necessary to define when and where phase changes start, and that condensed liquids must not be allowed in the sealing gas. A checklist approach is often helpful:
 1. Is clean and dry buffer gas available at all anticipated compressor speeds?
 2. Is the seal protected from bearing oil?
 3. How is the compressor pressurized or depressurized?
 4. How is the machine brought up to operating speed, and how will the seal react?
 5. Are all operating and maintenance personnel fully familiar with the compressor maintenance and operating manual?
 6. Is the full control system included and adequately described in these write-ups?
 7. Are the key elements of the system design understood, and do they include buffer gas conditioning, heating, filtration, regulation (flow vs. pressure) and monitoring?

• Seal safety and reliability.

Positive sealing of the compressor during emergencies must always be assessed. If the "settling-out" gas pressure in the compressor casing exceeds that of the seal gas pressure, advanced face seal assemblies are designed with shutdown pistons. These small pistons are located and dimensioned to exert a force proportional to gas pressure. Their force-action keeps the seal faces closed and prevents gas release.

It's an understatement to note that working with an experienced DGS repair service provider is always helpful. The non-original equipment manufacturer (nOEM) provider's allegiance is primarily with the seal user. Experience-based input may cast light on where DGSs may or may not provide positive gas sealing if the seal faces are damaged or distorted. The backup seal may show reasonable performance under low pressure, but may fail to perform under higher pressure if the primary seal fails. Elastomeric O-rings are used in all DGSs (FIG. 1 shows no fewer than 14 of these O-rings). They are being replaced, and seal faces relapped to perfection, during DGS refurbishment.

The alarm and shutdown devices of the seal oil system must be of reasonable range and sensitivity to provide reliable alarm and shutdown characteristics. DGS systems often rely on pressure switches of very low range and high sensitivity. These switches might have a tendency to mal-

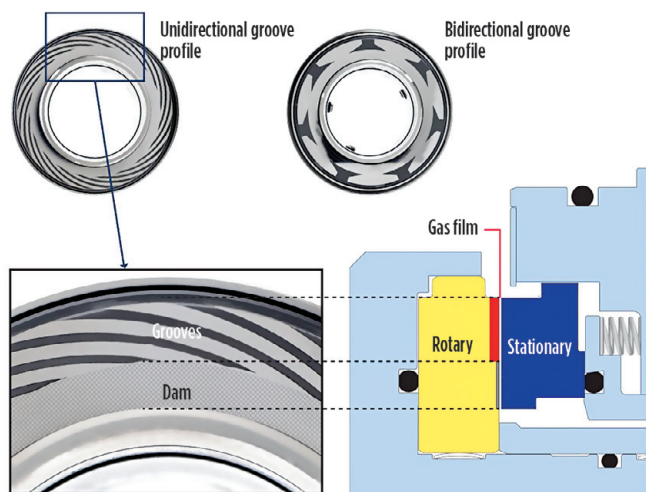


FIG. 2. Mating ring vane-like grooves (top left spiral groove and top right swallow tail), with detailed view of mating ring surface features (bottom left), with corresponding view of seal face assembly (bottom right).³

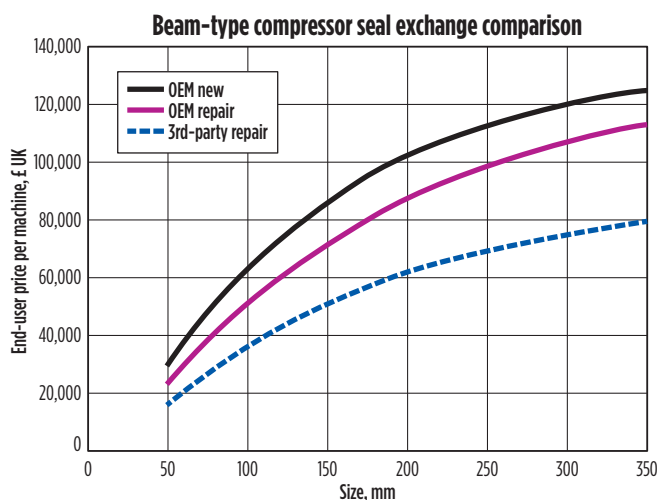


FIG. 3. An experience-based estimate contrasts the likely cost of three different DGS exchange strategies. Similar cost comparisons should precede any "buy new" vs. "refurbish" decisions.

function or give a false sense of security. It is important to ensure that the system will provide a sufficiently high degree of alarm and shutdown performance.

Some seal configurations excel at on-line monitoring. The favored seal must allow easy onstream verification of sound working condition. Seal systems that are hampered by small-diameter orifices that are prone to plugging should be avoided, as should sensitive pressure switches that often become inoperable. DGS failures are not as easy to detect as wet seal failures.

In all instances, the well-versed user must undergo a rigorous cost-justification analysis. FIG. 3 represents an experience-based approximation as an example.

Combining OEM and repair expertise.

Compressor end users face considerable expense when a machine is taken out of service for a routine overhaul. At this point, they may elect to refit new seals supplied by the original DGS manufacturer.

Given that there is usually no discount, this “go-new” choice could be an expensive option. Some savings can be achieved by having the seals repaired by the original DGS manufacturer, where the associated repair costs often reach 80% of the price of new seals.

In extreme cases, when the original DGS manufacturer has full order books and 100% test utilization, it may elect to price the repair at an even greater cost than a new unit. The original manufacturer may justify this approach as a means of improving new seal production efficiency with batch-size economics.

A more cost-effective option may allow a competent third-party DGS repair specialist to refurbish the seals. Using a typical two-seals-per-machine, beam-type compressor as an example, FIG. 3 shows the cost comparison between the three options outlined.

Regardless of hydrocarbon gas prices, it will be prudent to consider gas leakage rates to justify a conversion to gas-lubricated seals. Along these lines, one researcher⁴ suggests studying the failure statistics of oil-type seals and comparing these statistics with existing estimates. Present failure rate estimates for gas seals are in the vicinity of 0.175 failures/yr, meaning that a problem can be expected every six years or so.

At least one DGS manufacturer recommends basing maintenance intervals

for DGSs on limits imposed by an elastomer's aging process. This manufacturer suggests the following maintenance routine after 60 months of operation:

- Replace all elastomers, springs, seal faces and seats
- Carry out a static and dynamic test run on a test rig.

Making technically sound choices.

Consider DGSs only in conjunction with a clean gas supply. If the process gas can cause fouling deposits to develop, it is important to ask critical questions of any manufacturers offering DGSs for use with that kind of gas.

If extensive micro-filtration is needed, it is necessary to factor in the cost of maintaining a DGS support system. Look for seals that will survive a reasonable amount of compressor surging. Consider DGSs that incorporate features ensuring startup and acceleration to full operating speed without allowing the two faces to make contact. If these seals are not available from the desired supplier, then look beyond the usual sources.

Recall again that at least one innovative manufacturer offers modern DGSs for OEMs, as well as aftermarket applications. Also, this manufacturer has the capability to repair and test DGSs made by others.¹

In the past six or seven years, a considerable number of users and sites have been added to the reference list published in 2009. Today, in 2015, reliability engi-

neers are urged to investigate the extent to which any compressor seal manufacturer can meet the owner-purchaser's reliability requirements. The logical follow-up would be to consider using their DGSs.

Making economically sound choices.

Most compressor OEMs have service and re-rate divisions that will upgrade, repair, refurbish and modify any machine. Also, third-party independent repairers are often formed, owned or staffed by former employees of compressor OEMs. This means that either the OEM or an independent non-OEM will service, overhaul, repair and even re-rate entire compressors, regardless of origin.

While compressor users tend to accept as standard practice all of these repair options, the same is not true for DGSs. For reasons nobody can explain, DGSs tend to be sent back to seal OEMs. This is actually a paradox, because an entire compressor train is far more complex than a gas seal. Moreover, a highly qualified DGS manufacturer may be eminently more qualified to perform DGS refurbishments.

However, DGS production for new compressors has been ramped up over the past two decades, as has the well-planned implementation of dry seal retrofit options. As with all industries where demand for new products outstrips the capacity to support existing products, both pricing structure and lead time for component repairs have come under scrutiny.

TABLE 1. Turbocompressor seal selection guidelines³

Application seal type	Service	Inlet pressure, ¹ kPa (psia)
Air compressor labyrinth	Atmospheric air	Any
Gas compressor labyrinth	Non-corrosive Non-hazardous Non-fouling Low-value	Any
Gas compressor ² labyrinth with injection and/or ejection using gas being compressed as motive gas	Non-corrosive or corrosive Non-hazardous or hazardous Non-fouling or fouling	69 to 172 ³ (10 to 20)
Gas compressor gas seal, ⁴ tandem preferred	Non-corrosive Non-hazardous or hazardous Non-fouling	≥ 25,000 ≥ 3,600
Gas compressor oil seal, double	Corrosive ⁵	Any ⁶
Gas seal ⁶	Non-hazardous or hazardous Fouling	

¹ Operating seal pressure range

² Where some gas loss or air induction is tolerable

³ Pressure ranges shown for labyrinth seals are conservative; manufacturers extend this range upward, resulting in a debit due to power losses

⁴ Within state-of-the-art

⁵ H₂S is the most common corrosive component in process gas compressors

⁶ Dry-running gas seals often have pressure limitations below those of oil seals

In other words, a primary emphasis on the manufacture of *new* DGSs has resulted in service issues related to product engineering and repair support for DGSs that have been in use for several years.

A major UK seal manufacturer anticipated this issue even as it began to develop. In the 2000–2004 time frame, this manufacturer began to design and establish facilities that were specifically aimed at the repair and testing of dry gas compressor seals (FIG. 4). As of late 2015, this manufacturer has repaired hundreds of DGS units; it is also engaging in a thorough review and updating of seal gas control panels when such efforts are appropriate.

Unlike some OEM repair facilities that do a shortened test on repaired DGS units, this seal manufacturer-rebuilder fully tests all DGS units, both new and refurbished, as outlined in API 617 (FIG. 5). Only full testing harmonizes with today's emphasis on asset reliability.

Of course, properly engineered DGSs contribute greatly to overall machine reliability. Advanced seal designs reduce overall maintenance requirements; they also save power and gas consumption, and, therefore, contribute to sizeable operating cost savings in gas transmission services.

DGS technology advances through global repair services. One of the premier global DGS repair services has upgraded its customary repair and inspection facilities to unparalleled standards of excellence. Since the repair and testing program was aimed at any type, configu-

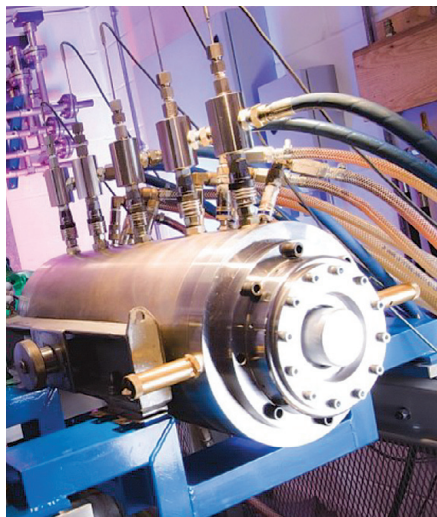


FIG. 4. One of two dynamic test rigs at a DGS manufacturer-rebuilder's factory location. Source: AESSEAL plc.

ration or specification of DGS, the new facility had to be devised with the utmost versatility in mind. It ensures that the repair of large-diameter and high-speed seals is accommodated.

In 2005, a new electrical substation dedicated to reliably supply power to the company's DGS test facility (FIG. 4) was commissioned to supply two DGS test rig motors, as well as the other services necessary to conduct dynamic tests on these seals (FIG. 5). Each of the two test rigs contains a state-of-the-art inverter drive enabling precise speed control of the 106-kW-rated motors, up to a maximum speed of 7,000 rpm. Each motor provides input to a planetary gearbox with three output modules that can be interchanged to provide output speeds up to 45,000 rpm. The power and speed capacity of each test cell allows for the dynamic testing of large-diameter, high-speed seals under full operational conditions.

Testing is feasible with either 350-bar (5,000-psi) air or 230-bar (3,300-psi) nitrogen. Air is supplied by a 45-kW multistage reciprocating compressor that delivers 130 m³/hr at a 350-bar capability. Irrespective of the type of gas used for the test, it is passed through a coalescing filtration system that removes particles above 2 µ in size. To test a wider range of DGS operating conditions, it is also necessary to provide additional heating or cooling. Cooling of the gas and test equipment is achieved with a 76-kW capacity chiller, whereas additional heating can be introduced with a 60-kW heat exchanger.

Control of test activities is achieved through specially designed test panels and software. The test panels control all gas flow in and out of the test cell, and are designed to enable any part of the seals under test to be individually pressurized or vented, as appropriate. Test speed and temperature are controlled from an integrated software program, which also controls the data logging or capture of speed, pressure, gas consumption and temperature taken from critical locations around the seal and test cell.

The DGS repair process. The ability to test DGSs to high standards is only one aspect of a full repair service. A leading company has drawn upon many years of experience in the conventional seal industry and transferred the same service-based culture into a first-class DGS repair program.

The first element of the repair process is usually an initial price quotation that can also be based upon electronically transferred images or historical repair knowledge of the seal's condition. This allows the service provider to quickly respond to customer demands for reasonable estimates of cost and time-to-repair; the estimate sometimes leaves the office before a defective seal arrives at the DGS service facility.

Once a seal arrives, it is disassembled, mapped for damage assessment, and then documented in a concise examination report that provides the full scope of work needed to restore the seal to original as-designed condition. Firm price and delivery are rapidly offered together with details of the dynamic test protocol, one normally conducted in accordance with API 617.

At this stage of the repair, initial design work is already conducted. This design work typically covers equipment and fixtures, such as spin test and balance mandrels, needed later in the repair process. Since the facility is geared toward different seal and compressor designs, fixtures must be purposefully designed for a particular repair. They will later be needed to verify the integrity of rotating face materials and, if required, to effect dynamic balancing to ISO Standard 1940.

A complete material assessment is performed, whereby all materials of construction are fully certified. Providing both rapid repair response and all requisite documentation is facilitated by close links to top suppliers of raw materials. The company has made it a practice to order materials beyond those needed for a particular repair. The resulting buildup of DGS parts stock advances the speed of responding to numerous repair requests.

Replacement and rebuilding steps.

Replacement of damaged faces is an important facet of the repair process. Premium-grade corrosion-resistant tungsten carbide, reaction-bonded and sintered silicon carbide, and silicon nitride seat replacements are offered. Stationary faces can be supplied in blister-resistant carbons and diamond-like carbon-coated silicon carbide, where additional polytetrafluoroethylene (PTFE) coatings can also be applied to seal faces.

Steel components can be repaired and recoated as required, and, where replacement parts are necessary, full code

requirements can be met. In all repairs offered by competent DGS refurbishers, replacing consumable items is standard. Such replacement includes all springs and fasteners, as well as secondary seals, where all O-rings fitted to DGS repairs are explosive decompression-resistant grades. Whenever polymer upgrading is feasible, the original selections are replaced with spring-energized PTFE-equivalent sealing devices.

Since most DGSs are supplied with external barrier devices, these components can also be repaired. Labyrinth components and both contacting and non-contacting segmented seals are often supplied as part of the repair program.

Once all of the replacement parts have been produced, reassembly and testing can proceed. A full spin test is conducted at 23% over the maximum speed rating of the seal, subjecting the component itself to twice its normal rotational stress. Whenever applicable, full dynamic balancing is performed on all rotating assemblies.

All stationary assemblies are subjected to pressure tests that exercise the face assembly and serve to identify seal hangup. Only then are the various assemblies finally fitted into the test equipment (FIG. 4).

Customers are invited to observe DGS testing at the company's main facility. Even if unable to attend, they can still view the test progress in real time via a WebEx Internet link. A second remote surveillance option involves a 3G mobile phone link, whereby the test is filmed with a 3G camera. This option is available in the form of live video streaming to any mobile phone with suitable 3G features.

Irrespective of whether customers choose to witness the tests, each test is fully recorded, and a CD of the full test event is produced for each individual seal. The CD is normally supplied with the information pack that is placed inside the shipping cartons for the repaired seals.

Although tests are normally conducted in accordance with API 617, at least one experienced DGS refurbisher often accepts and carries out additional customer testing requirements. Dynamically testing each seal typically takes three or four hours, which includes second-by-second data logging (FIG. 5).

The company provides an information packet for each repaired seal: the data



FIG. 5. A typical graph relating to the logged data taken during a comprehensive DGS dynamic test, where pressure and speed are varied to suit future operating conditions. Source: AESSEAL plc.

packet normally includes the pre-repair inspection report, a post-test condition inspection report, full details of the dynamic test itself, a full set of tabulated dynamic test results, a graph of the data-logging results, and a full set of installation details. It includes a spin test certificate, a balance test certificate, a dynamic test certificate and full certificates of conformity for any materials used.

The repaired seal is shipped in a heavy-duty airfreight case, which incorporates carrying handles and a locking mechanism. In addition to the actual seal repairs, an assembly tool replacement service is offered. This is particularly useful when seal assemblies are produced at locations remote from the compressor factory, but the compressors were shipped without the best available DGS assembly tools.

Nevertheless, the success of a seal design and manufacturing company that can provide seals of its own design, as well as the successful refurbishment of many other kinds of DGS assemblies, deserves to be considered here. One company's DGS repair service continues to grow.⁴ To date, it has received and completed repairs on hundreds of these seals, with a multimillion-dollar value covering several OEM product ranges.

Compressor owner-operators now have unprecedented and solidly verifiable options.² They can decide to continue working with the OEM, or they can trust the demonstrated capabilities of a firm with expertise in seal design

that is firmly anchored in a modern and accessible testing facility. The customer can now investigate the full extent of this company's commitment to timely repairs and superbly executed testing of any compressor DGS in use today. **HP**

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