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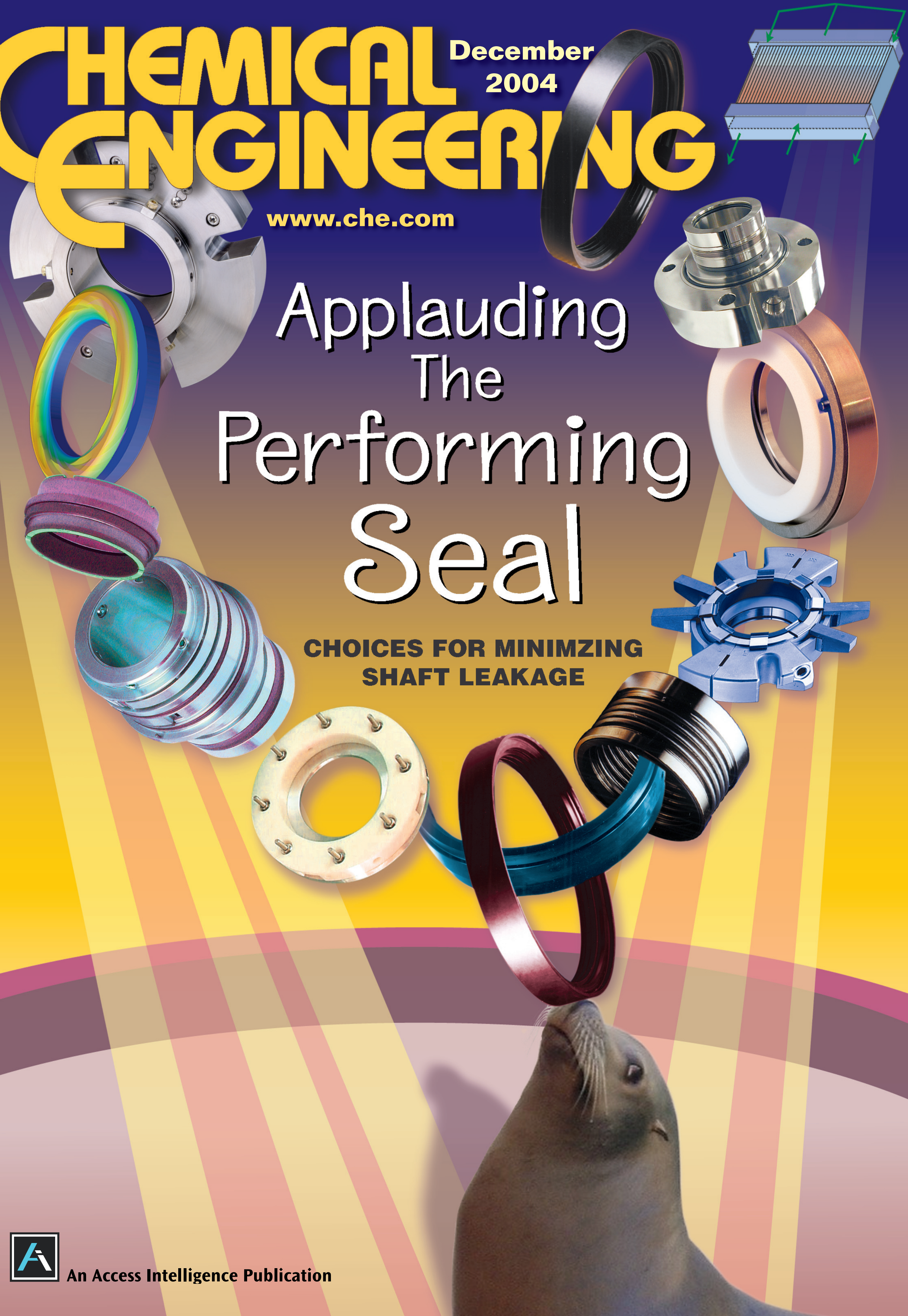
Applauding The Performing Seal

CHOICES FOR MINIMZING SHAFT LEAKAGE



An Access Intelligence Publication

Mechanical Seals

Evaluating What s Right for You

Before choosing the best device to prevent shaft leakage, you should thoroughly review the pros and cons of today's designs

Scott Boyson
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FIGURE 1 (top left). Component seals consist of multiple assemblies that need to be carefully mounted onto the equipment

FIGURE 2 (left). Cartridge seals are preassmbled and are typically installed onto the equipment in three steps or less

FIGURE 3 (top right). Finger springs are non-clogging and are thus ideal for sealing slurry pumps and large equipment

Numerous technological developments have occurred over the past few years to give mechanical seals greater reliability in reducing the escape of liquid and gaseous process fluids from rotating equipment, such as mixers, centrifugal pumps and compressors. Mechanical seals were originally developed as a leak-free alternative to pump packing. Over the years, mechanical seals have undergone continuous improvement.

Today, numerous classifications and design features are available to end users. Each mechanical seal design offers specific strengths that make its use advantageous for certain situations, and tradeoffs that may make its use impractical or ill-advised for particular applications. As the technological sophistication associated with mechanical seal design has increased, users often have a difficult time deciding which seals to use, and where to apply them most appropriately.

Some mechanical seal standards have been written to assist in this matter, but such standards often lag behind the latest technological developments and, in some cases, stifle innovation and add unnecessary cost. Mechanical seal standards take years to develop and cannot keep up with technology. Also, many standards are written around specific design types and older technologies, resulting in the slow adoption of more reliable, lower-cost technology. Ultimately, a full understanding of the options — including the advantages and disadvantages of each — is required to make informed choices.

MECHANICAL SEAL CLASSIFICATIONS AND COMMON USES

Mechanical seals can be classified by design, or by application. Each of the different types listed below is discussed in this article.

Classification by design:

1. Component or cartridge seals
2. Spring-type seals
3. Stationary or rotary seals
4. Balanced or unbalanced seals
5. Pusher or bellows seals
6. Split vs. non-split seals

Classification by application

1. Pump or mixer seals
2. Metallic versus nonmetallic seals
3. High-temperature seals
4. Single versus dual seals (such as tandem, back-back or face-face designs)
5. Wet lubricated seals or gas seals

Classification by design

1. Component or cartridge seals. A component mechanical seal is one that does not come preassembled, but re-

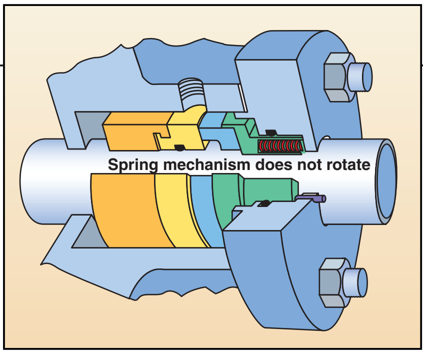

FIGURE 4. Springs mounted in the stationary part of this stationary spring seal assembly automatically compensate for any lack of squareness between the stuffing box face and the shaft

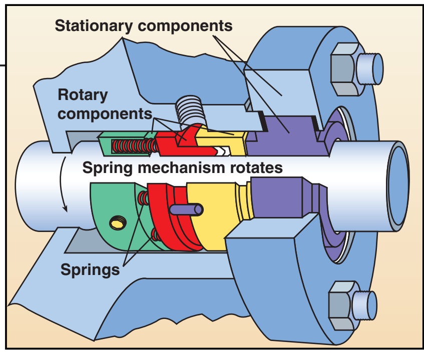

FIGURE 5. Rotary seals do not easily compensate for a stuffing box face that is not perfectly square to the shaft centerline

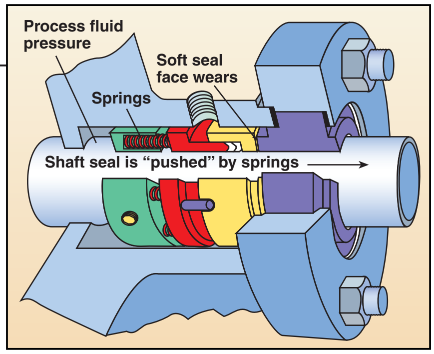

FIGURE 6. Newer pusher seals push the elastomer along a micropolished, non-oxidizing surface rather than than against the shaft, as shown here

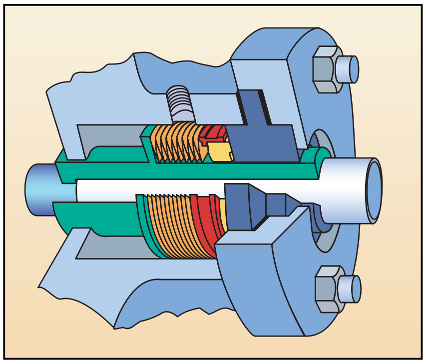

FIGURE 7. Bellows seals compensate for movement by compressing or extending a bellows, which eliminates the need for a dynamic elastomeric element

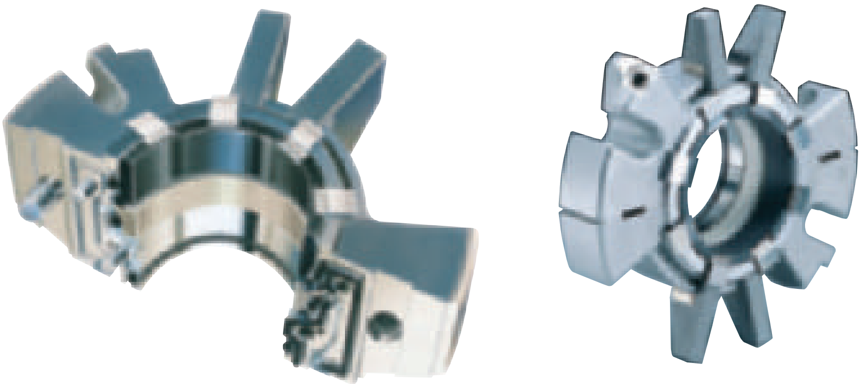

FIGURE 8a and 8b. Split seals have all of their components split into two identical halves, simplifying assembly and disassembly. Use of split seals is increasing in poularity for a large variety of equipment, such as mixers and large pumps

quires assembly of the rotary and stationary parts on the equipment shaft or sleeve. The seal faces must remain clean and intact during handling and installation, and precise measurement is required for proper installation (Figure 1). Too often, component seals fail prematurely as a result of improper installation techniques.

By comparison, a cartridge mechanical seal (Figure 2) is a completely self-contained assembly that is pre-assembled on a seal sleeve and enclosed in a gland. The seal faces remain in contact during handling and installation, thereby limiting potential damage and contamination. And, precise measurements by mechanics during installation are not required. Thanks to this simplified design, the use of cartridge seals can help users to virtually eliminate improper installation as a failure mode.

Most cartridge seals require only a three-step installation procedure:

- Tighten the gland to the stuffing box to seal the stuffing box gasket
- Tighten the set screws to the shaft
- Remove the clips that center the stationary components to the shaft and set the spring compression

However, newer designs incorporate the centering mechanism as an integral part of the seal design. This reduces the installation procedure to just the first two steps.

In general, cartridge seals continue to increase in popularity, thanks to their ongoing technological improvements and ease of installation, while component seal use has been declining worldwide, due to not only the high likelihood of improper installation, but also to the fact that technological improvements associated with component seal designs have been virtually non-existent over the past decade. Component seals are still used in small equipment, where space is limited, and in light-duty applications, such as some positive-displacement pumps and small water pumps.

2. Spring-type seals. The most common spring type in new seal designs involves the use of multiple small coil springs. Compared to large single springs — which are still seen in some older designs — these newer springs offer more-even spring loading. In general, it is beneficial that the spring mechanism is not in contact with the process fluid.

The use of larger single springs can make a mechanical seal susceptible to uneven spring loading on the seal face, which can cause face distortion. Finger springs, which apply spring force through a cantilever effect, are often seen in specialty designs, such as split seal and slurry seals (Figure 3). These springs are non-clogging, have relatively short axial space requirements, and can offer increases in motion capability to compensate for large axial shaft movement common in large equipment.

Bellows springs are available in various elastomers and metals. The elastomeric bellows typically offer a lower-cost option while metal bellows can offer performance advantages and greater reliability in aggressive-chemical and high-temperature applications.

3. Stationary and rotary seals. Stationary seals — seals that incorporate the spring mechanism in the stationary component of the seal — are increasing in popularity. These seals automatically compensate for any lack of squareness of the stuffing box face to the shaft centerline. Thus, when the stuffing box face is not perfectly at a

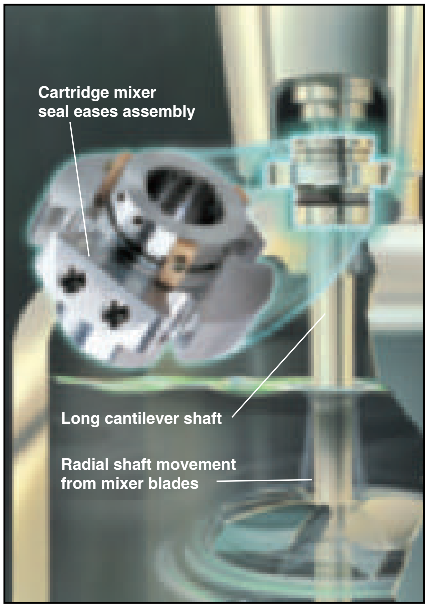

FIGURE 9. Mixers can be difficult to seal effectively, due to large vibration-induced shaft movements they typically experience

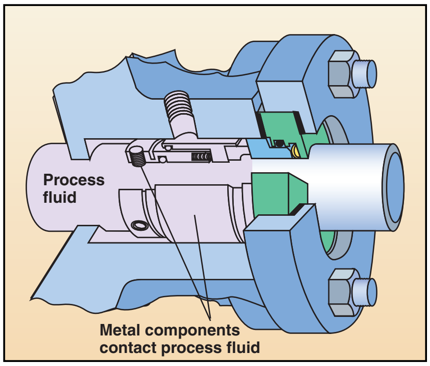

FIGURE 10. Metallic seals require the metal to be compatible to the process fluid

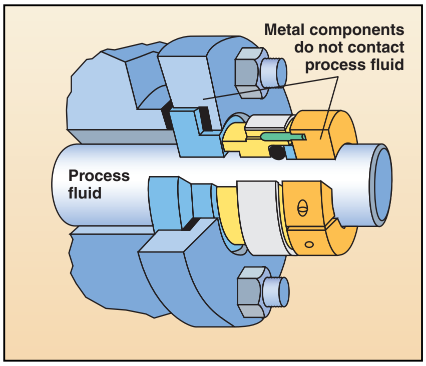

FIGURE 11. Nonmetallic seals are often used on pumps handling such harsh fluids as hydrochloric acid, as an inexpensive alternative to exotic metallurgy seals

right angle to the shaft, stationary springs seals easily compensate for this without compromising seal reliability (Figure 4).

Rotary seals have their springs located in the rotary component of the seal and do not have the ability to compensate very well for any lack of stuffing box squareness. The springs on a rotary seal will try to compress and extend with every shaft revolution. Pump shafts typically rotate at 25 to 60 times per second. At these speeds, rotary seals can't always react fast enough, so reliability is reduced.

Higher speeds, larger equipment with greater tolerances and higher-temperature pumps that can distort due to temperatures all create more problems for rotary seal designs, making it hard for these designs to deliver greater reliability than stationary designs (Figure 5).

4. Balanced or unbalanced seals. Unbalanced mechanical seals are seal arrangements in which the hydraulic pressure of the seal chamber acts on the entire seal face area without any of the force being reduced through the seal design. Unbalanced seals usually have a lower pressure limitation than balanced seals.

Among the common problems associated with unbalanced seals are these:

- If the pressure acting on the face is high enough, seal face lubrication may be compromised
- These seals tend to have higher heat generation than balanced seals because there is excessive closing force applied in an attempt to keep the seal faces together
- More rapid face wear occurs because of the higher closing forces
- Higher power consumption occurs because of the extra drag caused by the higher closing forces

A balanced mechanical seal arrangement reduces the hydraulic forces acting on the seal faces through mechanical seal design. As the seal faces rub together, the amount of heat generated is determined by the amount of pressure applied, the lubricating film between the faces, the rotational speed, and the seal ring materials.

Balanced seals reduce the seal ring area on which the stuffing box pressure acts. With the reduction in area, the overall closing force is diminished. This allows for better lubrication, resulting in reduced heat generation, face wear and power consumption, compared to unbalanced seals.

Balanced seals typically have higher pressure limitations than unbalanced seals. Some standard balanced seals run extremely cool and have pressure limits of 450 psig (30 bar g).

5. Pusher and bellows seals. Pusher seals are those seals that move an elastomeric element such as an O-ring along a surface to compensate for wear (Figure 6). These seals perform reliably in the vast majority of process fluids. While the availability of elastomeric elements made from materials such as ethylene propylene, fluorocarbon and perfluorocarbon compounds offers the user a wide range of chemical compatibility options, seal reliability may still be compromised by the chemical compatibility issues, so close attention to this is required during specification.

Bellows seals compensate for movement by compressing or extending a bellows. Be providing both sealing and movement, the bellows eliminates the need for a dynamic elastomeric element (Figure 7).

Sealing elements are required in other areas of the mechanical seal. However, with bellows seals, these sealing areas are all static and allow for the use of non-elastomeric seals, such as graphite gaskets; thus, they are also less sensitive to elastomeric chemical compatibility issues.

6. Split/Non-split seals. Non-split seals, such as those shown in Figures 1, 2 and 3, require equipment disassembly to install, remove and reinstall the seal. On some equipment, such as mixers and large horizontally split case pumps, this can be quite difficult.

By comparison, split mechanical seals, such as those shown in Figures 8a and 8b, have all of their components split into two equal halves. Split seal designs are now available in many configurations for sealing mixers, high-pressure pumps and dryers.

Classification by application

1. Pump or mixer seals. Centrifugal pumps typically incorporate an impeller that is either overhung but still

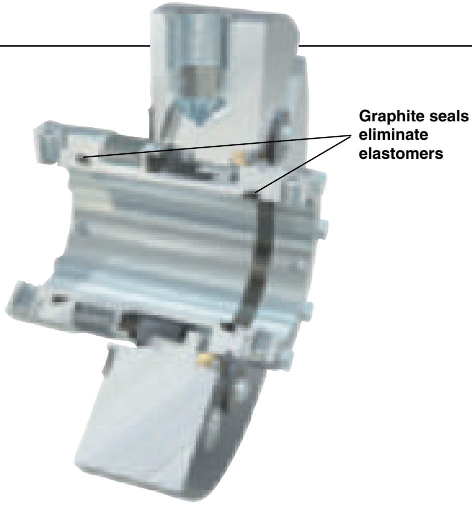

FIGURE 12. With no elastomers, this metallic bellows seal can handle a wide range of temperature extremes, sealing effectively to temperatures above 500°F (260°C) and below 45°F(45°C)

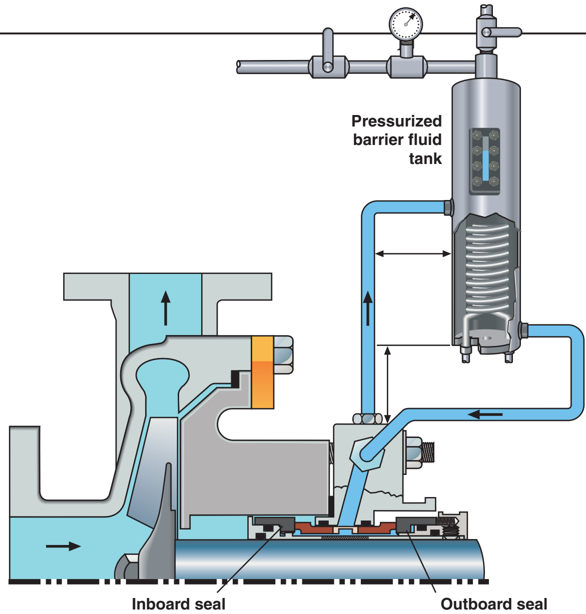

FIGURE 13. Dual seals have two sets of seal faces for added reliability and safety

relatively close to two sets of bearings, or is mounted between the bearings. In both cases, the mechanical seal is mounted relatively close to the two sets of bearings. Shaft movement in the radial direction is relatively limited, requiring less than 0.016 in. (0.5 mm) of runout capability in the seal to compensate for the shaft movement. However, in large mixers, the seal is mounted much further away from the bearings. Large mixer blades can induce vibration resulting in large amounts of shaft movement, requiring the seal to compensate for as much as 0.125 in (3 mm) of shaft runout or more (Figure 9). Also, large mixers also typically require the mechanical seal to compensate for shaft axial movement or growth due to thermal expansion. Designs are available that easily allow for increased axial and radial shaft motion without affecting spring force.

Mixer shafts typically enter into the top of the vessel; therefore the mechanical seals used in these applications are not lubricated by the process fluid, but run dry. A dual seal is commonly used to supply external lubrication although dry-gas and dry-running seals are also being used. If shaft runout is large enough to threaten seal reliability, then an integral bushing or bearing can be incorporated into the seal design. Split mixer seals are gaining in popularity as they enable users to eliminate mixer disassembly to change out the seal.

2. Metallic versus nonmetallic seals. A metallic seal in described as such not because it is made of metal. It is described in this way because it has some metal parts that are in contact with the process fluid. If any metal parts are in contact with the process fluid, then the device is called a metallic seal (Figure 10).

Similarly, a nonmetallic seal is described as such not because is has no metallic parts. Rather, nonmetallic seals have no metal parts in contact with the process fluid (Figure 11) Only the nonmetallic seal faces, O-rings and gaskets contact the fluid process fluid.

Nonmetallic seals can offer advantages over metallic seals in fluids where common metallurgy may be attacked by such common fluids as seawater, brine and strong acids. Nonmetallic seals may also offer a low-cost alternative to specialty metallurgies, such as those based on titanium. However, most nonmetallic seals have lower pressure and temperature limits when compared to metallic seals, thus limiting their use.

3. High-temperature seals. Temperature limits on mechanical seals are based on any elastomers that are used. High-temperature perfluorelastomers are typically suggested for reliable use at process temperature limits below 500°F (260°C). At low temperatures (beyond –45°F or -45°C), elastomer flexibility is not adequate to ensure dynamic sealing. Applications encountering these temperature extremes require seals that have no elastomers in contact with the fluid. For such cases, metallic bellows seals that use non-elastomeric sealing elements such as graphite work reliably well (Figure 12).

4. Single versus dual seals. A single seal has one set of seal faces. One seal face rotates while the other remains stationary. Pressed against each other by a spring mechanism and hydraulic force, the seal faces contact each other and are lubricated by the process fluid. The downside is that in any single seal, there is always a process fluid-to-atmosphere interface at the seal faces. At this interface, fluid vaporization, crystallization and oxidation may occur, compromising seal reliability.

By comparison, a dual seal has two sets of seal faces and incorporates either a barrier fluid or a buffer fluid (Figure 13). This fluid acts as a barrier between the process fluid and the atmosphere. By elimination of this interface, seal reliability can be increased. In addition, seal leakage will be to the buffer fluid rather than to the atmosphere, ensuring greater safety for applications involving hazardous fluids.

Dual seals are used where they offer greater reliability than single seals and greater safety. Dual seals can also provide a backup or spare seal capability to minimize emergency shutdown and maintenance activity, by acting as an installed spare seal.

Meanwhile, a dual seal can easily act as two independent seals mounted on one shaft. This can be useful in batch processes where one seal can seal the fluid while the other idles on the buffer fluid. The inboard set of faces does the hard work and when it begins to leak, the outboard set of seal faces takes over, allowing for extended runtimes. This approach not only allows for im-

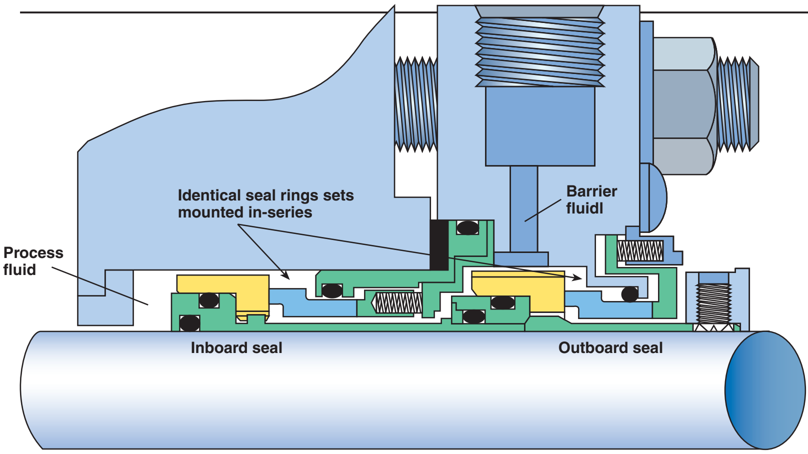

FIGURE 14. Tandem seals offer an ideal configuration, as they act like two seals mounted on one shaft

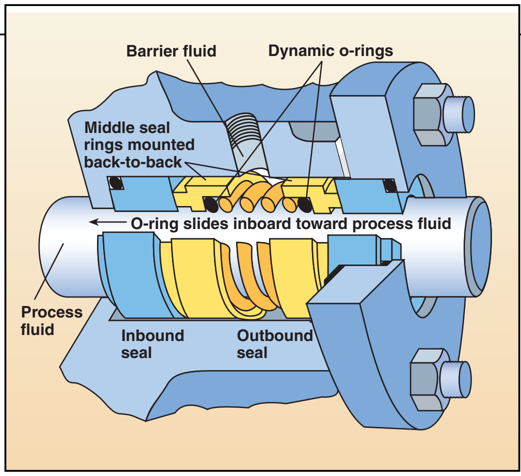

FIGURE 15. Back-to back seals are not ideal in particulate or slurry service, since solids can accumulate at the inside diameter of the inboard seal

proved process operation, but it also allows the maintenance engineers to shift from reactive to planned maintenance to manage seal changeouts.

Dual seal classifications:

a. Tandem seals. A tandem design is sometimes referred to as an inline design. It uses two sets of seal faces that are mounted as in series on a shaft (Figure 14). Many of today's high-performance pump seals use this arrangement as it offers the best compromise of pressure capability and particulate handling. However, tandem seals are typically larger in size and are more difficult to fit in very small equipment.

b. Back-to-back seals. Back-to-back seals use seal faces that are opposed to each other (Figure 15). The spring mechanism is located in the center of the seal, and pushes one face inboard and the other outboard. The barrier fluid is typically located on the outer diameter of both sets of seal faces.

A downside of this design is that since the inboard is pushed toward the process fluid, it can get stuck or hang up and lose sealability. In addition, the inboard seal faces are inside the design, which can be problematic when sealing fluids that contain particulates. The back-to-back design is still widely used in top- mounted mixers and reactors, as it is an ideal configuration for sealing high pressure, clean fluids and vapors.

c. Face-to-face seals. This design involves seal faces that are pushed toward each other. These seals typically do not have a pumping ring to circulate the barrier fluid and must rely on convective flow (Figure 16).

All double seal types should incorporate a double balance feature for the inboard seal. This allows the seal to operate reliability regardless of whether the barrier/buffer fluid is at higher or lower pressures compared to the process pressure. This is critical to maintain reliability and safe operation during operating pressure transient conditions.

5. Wet lubricated seals or gas seals. Wet lubricated seals operate in the mixed lubrication regime. The process fluid between the faces carries some of the load on the seal faces. At the same time, the seal faces are also in contact and thus generate heat and wear. Wet lubricated seals require lubrication from the process liquid, or a pressurized barrier fluid or an unpressurized buffer fluid. A wet dual seal with a pressurized barrier lubrication system requires a barrier liquid that is compatible with the process fluid. Small amounts of leakage and heat generation at the contacting sealing interfaces must be tolerated.

A dual seal with a buffer fluid system is typically used on vaporizing fluids. The seal buffer tank can then be connected to a central vapor-recovery system.

A typical gas seal design uses hydrodynamic lift-off to separate the rotary and stationary seal faces. Spiral grooves in the rotary seal face collect the gas. As the seal rotates, gas is compressed toward the end of the groove, creating an opening pressure. This pressure exerts an opening force that is greater than the closing force separating the seal faces. This slight separation allows the gas, typically inexpensive and inert nitrogen, to flow across the seal faces. Thus, the seal faces ride on a pressurized, gaseous fluid film.

Unlike the case with wet lubricated seals, gas seal use is not limited by the tribological characteristics of the sealed fluid, because of the inert nitrogen gas that separates the seal faces. Heat generation is non-existent, so that potential mode of failure is not relevant here. Vaporizing and non-lubricating fluids are easily sealed. Process upsets are tolerated due to the stiff gas sealing film and reliable conventional sealing capabilities offered by these designs. Expensive vapor recovery systems used with buffer fluid systems are not required.

Advances in gas seal design have focused on enhancing the reliability and practicality of using such designs (Figure 17). Because the gas is directed right into the sealing interface, numerous opportunities are created for the seal design engineer. Gas seals using newer technology are able to combine both hydrostatic and hydrodynamic opening forces. This allows for a stiffer, self-regulating gas film (Figure 18). In addition, closing forces can be hydrostatically controlled during operation allowing for better sealing control during equipment operation.

Older style gas seals typically use remotely mounted gas control panels, which are mounted on a platform near the pump to adjust gas pressure as required. As pump and mixer applications have variable operating pressures, the gas pressure must often be set at a pressure greater than maximum operating pressure, resulting in greater nitrogen flows at normal equipment pressures.

By comparison, newer designs elimi-

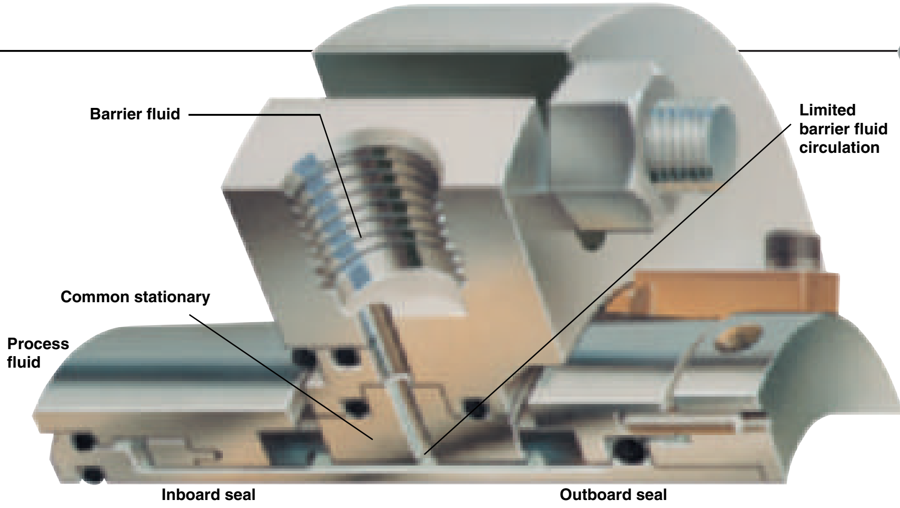

FIGURE 16. **Face-to-face seals are often limited due to their lack of barrier pumping capability**

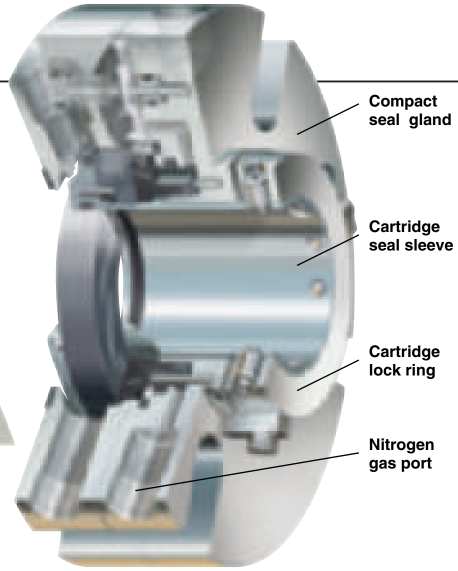

FIGURE 17. **Gas seal usage is increasing as newer designs enhance reliability and user friendliness**

nate the remote gas panel arrangement by using an in-gland control system that regulates the gas supply pressure with respect to process pressure.

Sealing mixers, agitators, reactors and other slowly rotating shafts present particularly challenging design issues for gas seals. Typically, such equipment has long, unsupported shafts, that result in large amounts of movement. And they often operate at circumferential speeds that are too low for hydrodynamic lift-off. However, as the sealing device location for such equipment is typically at the top of the vessel, they can benefit greatly from gas sealing as a gas seal will naturally operate in a dry environment.

As emission regulations tighten on agitator vessels, dry running single seals and braided packing are no longer a viable option for many fluids. The other sealing option for this equipment has been the use of conventional dual wet lubricated seals and dual split seals. While these sealing arrangements can provide longterm operating reliability, they both rely on a pressurized barrier fluid arrangement when mounted at the top of a vessel. Barrier fluid leakage will eventually migrate and mix with the process fluid. This may not be an acceptable or desirable alternative in many high-purity processes.

Meanwhile, mixer shafts with large radial runout can create unstable operation in gas seal designs that rely solely on hydrodynamic lift-off grooves. By combination of a hydrostatic pressure with the hydrodynamic lift-off, a dual compensation system is created, minimizing unstable operation.

Mixer shafts operate at speeds below those typically required for hydrodynamic lift-off and separation of the seal faces. Special lift-off grooves developed for the specific application are typically required. These special designs require a minimum circumferential speed to be reached for lift-off to occur. At speeds below this, contact occurs, causing wear and possible process contamination from wear debris. In addition, gas consumption can be high on some designs due to high gas differential pressure requirements.

Some seals use a combination of hydrostatic and hydrodynamic pressures to achieve lift-off. Stable lift-off can easily be achieved from zero rpm to speeds as high as 5,000 rpm. Special lift-off grooves are not required.

The split dry gas seal is ideal for sealing critical equipment that is difficult to disassemble. As mentioned above, nonsplit seals require equipment disassembly. As many mixers and reactors are large, their disassembly can be time consuming and expensive. This, coupled with the fact that they do not have back-up spares, make them critical to a plant's operating efficiency.

The split dry gas seal ideally will have a lift-off speed of zero rpm due to its use of both hydrostatic and hydrodynamic lift-off. This minimizes wear and allows for both very-low-speed and very-high-speed operation. The seal faces should be resiliently mounted (discussed below) for maximum reliability.

Seal features

Once a set classifications has been identified for the equipment or process fluid, it is important to identify specific features that are desirable in a mechanical seal. Some features to consider are discussed below.

Resilient mounting. Older seal designs mount seal faces directly into metal housings. However, even with modest increases in temperature, the metal housing expands at much greater rates then the seal material, causing the face to lose its flatness. Research and experience has shown that this distortion has a negative impact on reliability and leakage control. Single piece, monolithic seal faces are used to prevent the thermal distortion that results from differential rates of thermal expansion.

Today, most seals are resiliently mounted to minimize the impact of transient axial and radial loads. Resilient (or cushioned) mounting reduces the negative impact of equipment vibration. Such designs not only reduce transmission of vibration to the seal face but also reduce the impact of high torque that can occur during startup, especially with viscous fluids. Seal face distortion from axial sealing pressures are also minimized with cushioning.

Double-balanced capabilities. Dual seals use a barrier fluid that is set at a higher pressure when compared to stuffing box pressure. They can also use a buffer fluid that is set a lower pressure. But often during the life of the seal, pressures fluctuate, requiring the seal to operate in a "reverse" pressure mode. Double-balanced dual seals perform reliably during pressure reversals, unlike single-balanced dual seals that may fail. Double balance can be created by O-ring shift, which requires wider seal faces, or by using geometric double balance, which is created by establishing two balance areas with two O-rings. Double balance created by shifting O-rings use extra wide seal faces that generate high amounts of frictional heat.

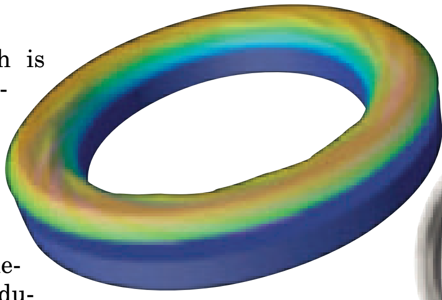

FIGURE 18. (above) Gas seals operate on a fluid film of inert nitrogen or clean gas rather than liquid

FIGURE 19. (right) Cassette sealing gives the user the full benefits of modularity

FIGURE 20. Micro-polished surfaces enhance seal responsiveness, especially under transient conditions

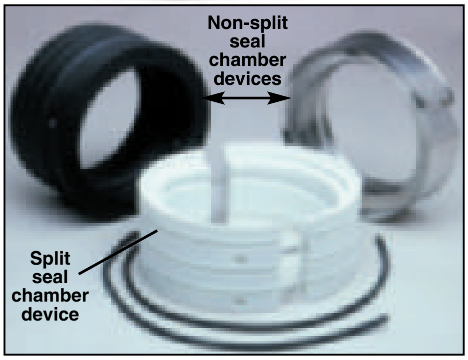

FIGURE 21. By seamlessly changing the environment around the seal in the stuffing box, seal reliability can be dramatically increased

Modularity. Most recent seal designs claim a high degree of modularity to allow for common part use. However, such modularity often benefits the manufacturer, not the end user. In some cases, the design of the seal is sacrificed to increase the use of common components. In fact, one of most common areas for such sacrifice is one of the most critical aspects of any seal — the seal face width, which has the greatest impact on the amount of frictional heat generated at the seal face. Such heat generation should be kept to a minimum, as it increases the likelihood of process fluid vaporization, greater leakage, inadequate lubrication, polymerization, oxidation, crystallization and elastomer failure.

In many seal designs, the inboard dual seal face has to be extra wide to allow for double balance design as discussed earlier. When this is done and that same seal face is also used on the single seal and outboard of the double seal, the entire seal line performance has been sacrificed to aid in common parts usage. This wider seal face generates more frictional heat and is now used throughout throughout the seal solely for modularity purposes. These modular seal designs can be easily identified as they will have their maximum pressure capabilities reduced to 300 psi (20 bar) maximum due to the use of a wide seal face and its resulting higher heat generation.

Some models do utilize modularity in such a way to benefit the end user. For instance, some designs can easily be swapped over from a single seal to a dual seal using cassette technology (Figure 19). The cassettes easily slide into a common seal gland, to enable the user to easily move from one seal type to another.

Responsiveness. First-generation seals in many instances wore grooves into equipment shafts, causing damage and calling for the use of equipment sleeves. These fretting grooves also cause seal failure due to lack of responsiveness.

Second-generation seals, which often incorporated metal sleeves into the their design, allowed for the use of stronger, solid equipment shafts. However, grooves resulting in seal failure were still created.

Third-generation seals eliminate fretting grooves by the use of hard, non-oxidizing, seal face materials such as silicon and tungsten carbide instead of softer oxidizing metals such as stainless steel. In addition, these surfaces are now micropolished so seal responsiveness and reliability are maximized (Figure 20).

Seal environment. Changing the environment around the seal can enhance performance. Most seals are mounted inside stuffing boxes designed for packing. Seal chambers are increasing in popularity and are available in numerous design configurations from taper bores to cylindrical or even C-shaped chambers. Another option is to use special devices mounted in the bottom of the stuffing box or seal chamber, which modify the fluid flow around the seal. These devices typically use the centrifugal and centripetal forces that result from fluid rotation inside the seal chamber to clean the seal chamber of particulates during operation (Figure 21).

There are many factors to consider when selecting a mechanical seal. Choosing the best seal for a given application requires a complete understanding of the advantages and disadvantages of each seal design. ■

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