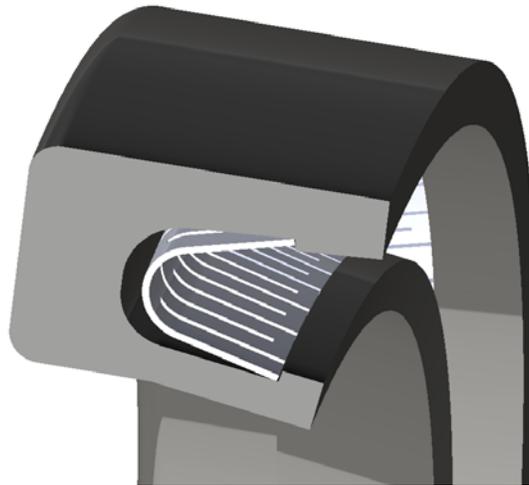


Chapter D10

Barrier seals



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Individual chapters of the Kalsi Seals Handbook™ are periodically updated. To determine if a newer revision of this chapter exists, please visit <https://www.kalsi.com/seal-handbook/>.

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1. Introduction

Several types of barrier seals have been designed by other companies for use outboard of Kalsi Seals® in critical applications like oilfield mud motors and rotary steerable tools. In certain cases, Kalsi Seals can be also used as outboard barrier seals. The intent of using barrier seals is to increase equipment service life. Although barrier seals can be beneficial, they can decrease service life if implemented incorrectly.

2. Barrier seal advantages

The most obvious potential advantage of an outboard barrier seal is allowing the inner rotary seal to operate in a clean environment until the barrier seal fails.

A wide range of chemicals are encountered in oilfield drilling fluids. For example, bromides are sometimes encountered in brine based drilling fluids. To provide a broader range of chemical resistance, the outboard barrier seal can be made from a different material than the inner seal. For example, the barrier seal could be a spring-loaded aramid fiber filled FEPM lip-type barrier seal, and the inner seal could be an HNBR Kalsi Seal.

The barrier seal geometry can be selected for improved resistance to the differential pressure reversals that occur in drilling tools due to mud pressure fluctuation, swab and surge conditions¹, and annulus blockages². For example, an Axially Constrained Kalsi Seal™ is more resistant to swab and surge related low level differential pressure reversals, compared to a Kalsi Seal™ that has been designed for high differential pressure acting from the lubricant side. For another example, some types of lip-type barrier seals are configured to bite down harder against the shaft if a temporary pressure reversal occurs.

3. Potential disadvantages of barrier seals

It is critical to avoid trapping pressure between pairs of rotary shaft seals

Whenever pairs of rotary shaft seals are employed in high ambient pressure conditions, the lubricant pressure between the two seals must be balanced to the ambient pressure. If no pressure balancing is provided, the only pressure between the seals is the atmospheric pressure that was trapped there at the time of assembly — unless the seals can move or deform enough to balance the pressure. In the absence of pressure balancing, both seals are exposed to a high differential pressure that is equal to the ambient pressure (Figure 1). As a result, both the inner seal and the barrier seal will quickly fail. This is a

¹ For a description of swab and surge pressure, see U.S. Patent 6,220,087.

² For information on wellbore hole collapse, see Bourgoyne, et. al., **Applied Drilling Engineering**, 1991 and Bradley, et. al, **Petroleum Engineering Handbook**, 1992 (Society of Petroleum Engineers, Richardson, TX).

very serious problem in oil well downhole drilling tools, because the ambient pressure can be extremely high due to well depth and the weight of the drilling fluid column.

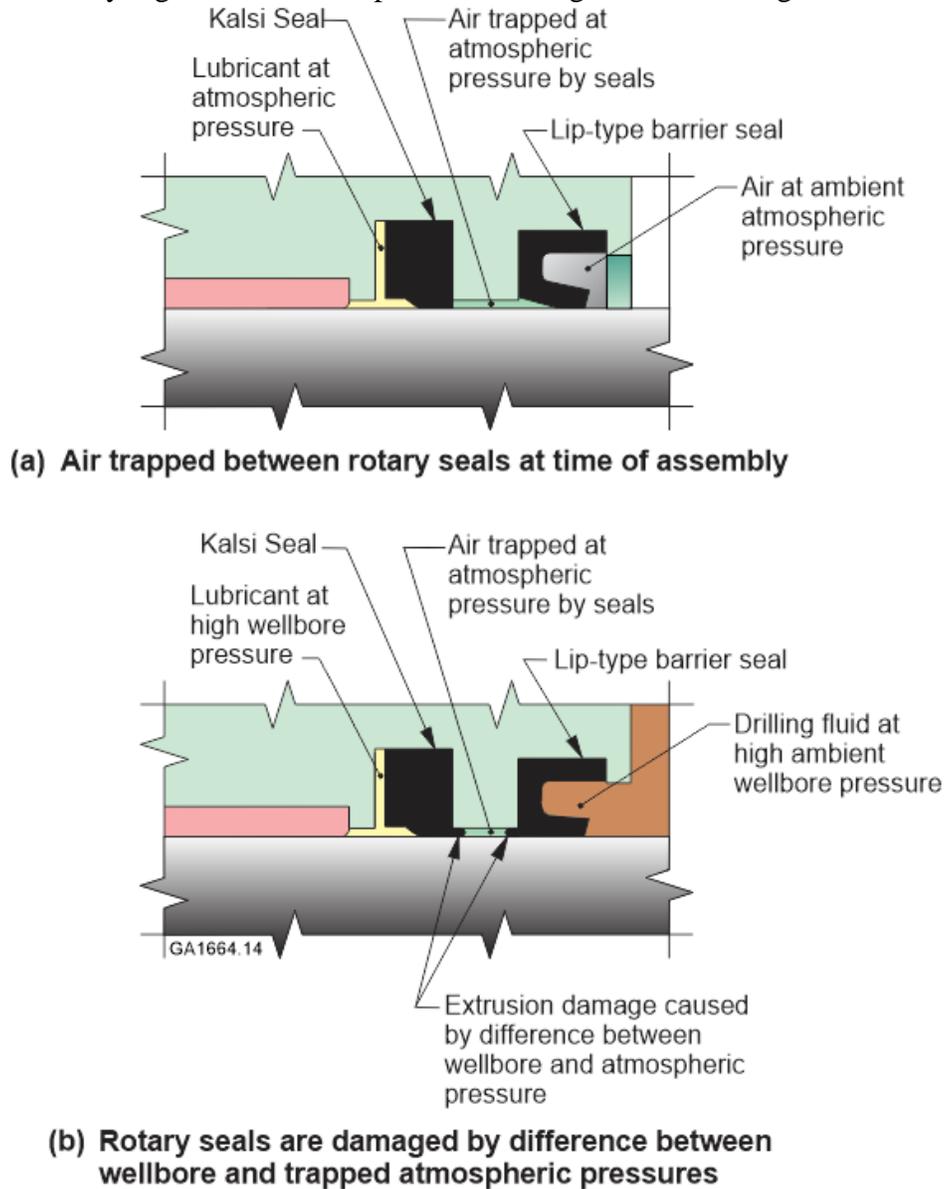


Figure 1

Avoid trapping atmospheric pressure between redundant seals (pressure locking)

Air trapped between rotary seals at the time of assembly will cause damage when the equipment is immersed in a high ambient pressure environment such as a wellbore, even if the pressure of the main lubricant supply is balanced to the high ambient pressure.

Other potential barrier seal issues

Other barrier seal issues involve design tradeoffs. Barrier seals consume axial length, which increases overall tool length, and increases the overhang of the shaft beyond the

radial bearings that guide the shaft. These factors are not a concern in most applications, but may be a factor in miniature equipment or applications with heavy side loads.

Barrier seals increase seal startup and running torque, and isolate the inboard rotary seal from the cooling effect of the surrounding environment. Increased torque isn't a concern in many applications, but it may be a concern in applications with limited available torque or poor heat transfer. Isolation of the inboard rotary seal from the cooling effect of the surrounding environment isn't a concern in applications that have ample cooling due to fluid flow through a hollow shaft, but may be a concern in some higher speed solid shaft applications.

If both the inboard seal and the outboard barrier seal are Kalsi Seals, some accommodation may be required to address the possibility that the hydrodynamic pumping related leak rates of the seals may be different.

Lip type seals are sometimes selected as barrier seals without testing, in the mistaken belief that any type of lip seal will vent to allow the hydrodynamic pumping related leak rate of the inboard Kalsi Seal to pass through the dynamic interface of the lip seal. While this is true of some lip type barrier seals, it is not true of all of them. For example, at elevated temperature, thermal expansion of the body of some varieties of lip seals can cause enough dimensional growth to cause the body to establish a direct interference sealing relationship with the gland. For another example, seals designed such that the static and dynamic lips have equal axial length are unlikely to vent Kalsi Seal leakage unless they are mounted on a specially designed pedestal that prevents the dynamic lip from contacting the environment-side groove wall.

Lip-type barrier seals that lack a spring energizer may quickly lose sealing force with respect to the shaft, due to the high flexural set characteristics of typical sealing materials. Lip-type barrier seals with garter spring energizers may shed the energizer over time, as lip flexing causes environmental abrasives to work their way between the spring and the lip.

4. Using a radially sliding O-ring to prevent pressure locking

A compact method for providing pressure balance to the barrier lubricant region between a Kalsi Seal and an outboard lip-type barrier seal is shown in Figure 2. An O-ring is installed in a deep internal radial groove which establishes sealing by compressing the O-ring axially. Radial vent holes communicate the environment pressure to the O-Ring. Radially inward movement of the O-ring balances the barrier lubricant pressure to the environment pressure. Kalsi Seal leakage passes through the dynamic interface of the barrier seal, flushing the interface and lubricating the lip of the barrier seal.

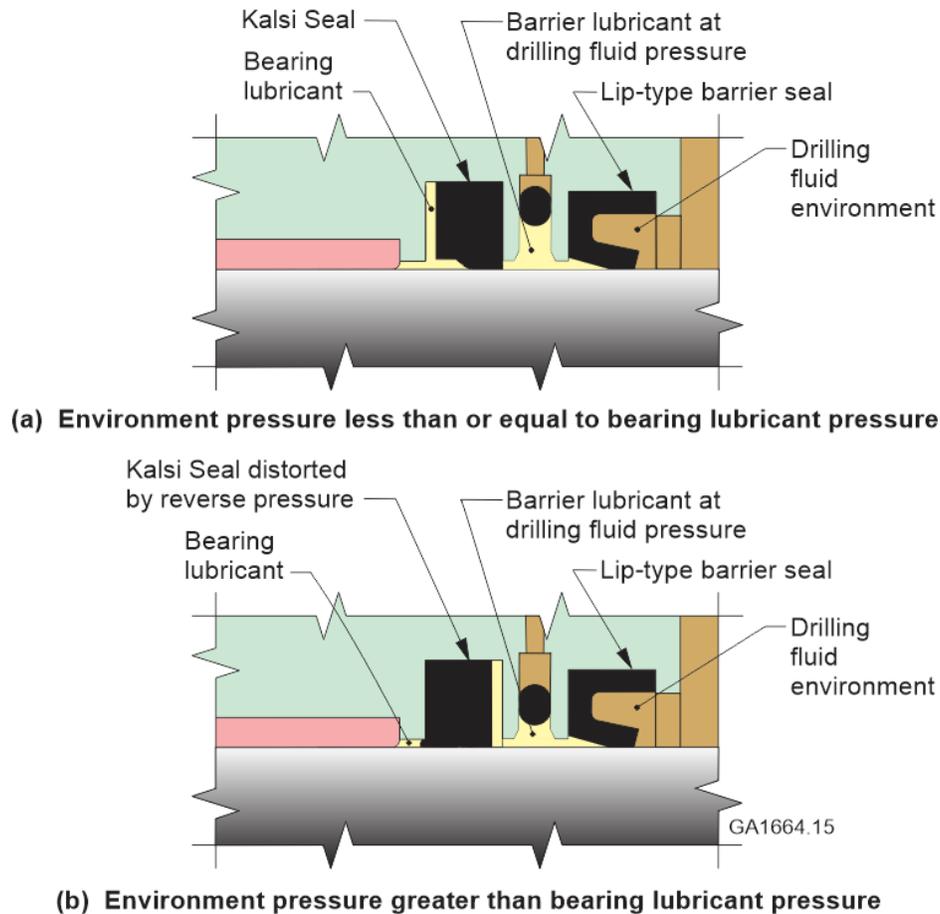


Figure 2

Radially sliding O-ring prevents pressure locking, barrier seal helps the Kalsi Seal withstand temporary periods of high reverse pressure

In these images, the pressure of the barrier lubricant is balanced to the pressure of the drilling fluid environment by the radially sliding O-ring. Other pressure balancing means, such as diaphragms, can be used to perform the same pressure equalizing function. In the upper image (a) the pressures of the drilling fluid environment and the barrier lubricant are less than or equal to the pressure of the bearing lubricant. In the lower image (b), the pressure of the drilling fluid and the barrier lubricant are temporarily much greater than the pressure of the bearing lubricant, and the Kalsi Seal is distorted by this "reverse pressure" situation. Nevertheless, the Kalsi Seal is likely to survive because it is operating in the clean environment which is made possible by the barrier seal.

One technique for achieving a good lubricant fill between the rotary seals

The assembly method shown in Figure 3 can be used to flood the region between the Kalsi Seal and the barrier seal with an oil type lubricant. Even though the lubricant will contain some entrained air at atmospheric pressure, the O-ring can slide radially inward to compress the entrained air and balance the lubricant pressure to the environment pressure. During rotation, the hydrodynamic pumping related leakage of the Kalsi Seal passes under, and lubricates the dynamic sealing lip of the barrier seal.

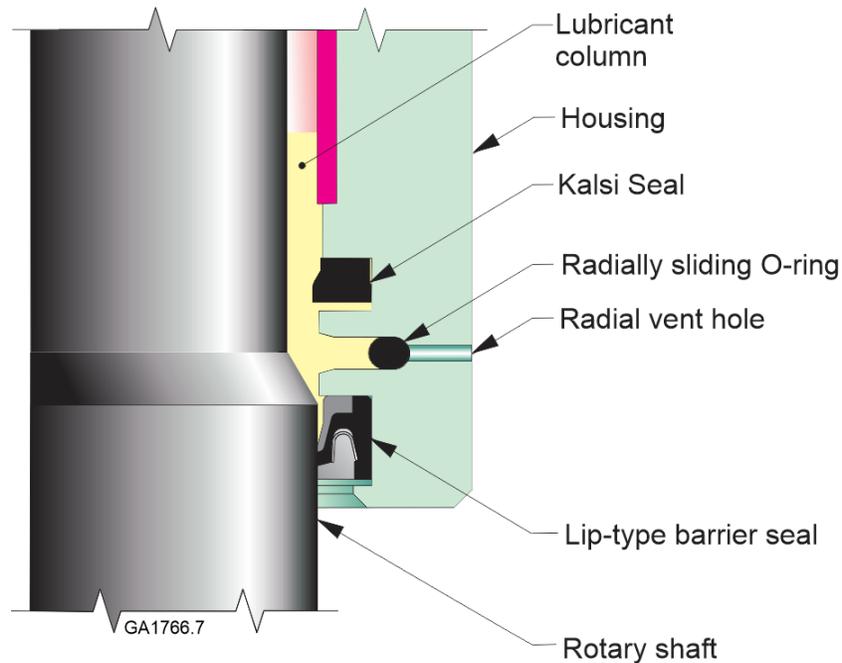


Figure 3

A method for filling the region between two rotary seals

This shows a way to provide a good lubricant fill between a Kalsi Seal and an outboard lip-type barrier seal. Position the radially sliding O-ring as deeply as possible within the groove during assembly of the tool. Engage the barrier seal on the rotary shaft, add de-aerated lubricant until the Kalsi Seal is submerged, then complete the installation. When exposed to environment pressure via the radial vent holes, the O-ring slides radially inward and the Kalsi Seal slides toward the barrier seal, balancing the barrier lubricant pressure to the environment pressure, and collapsing any entrained air within the barrier lubricant.

The deep groove can be incorporated at the interface between two components

Figure 4 shows a convenient way to manufacture the deep groove for the radially acting O-ring. The groove is produced by a circular recess at the interface between two housing components. Although the housing components are illustrated as being connected with a bolt flange, the concept works equally well with two housing components that thread to one another.

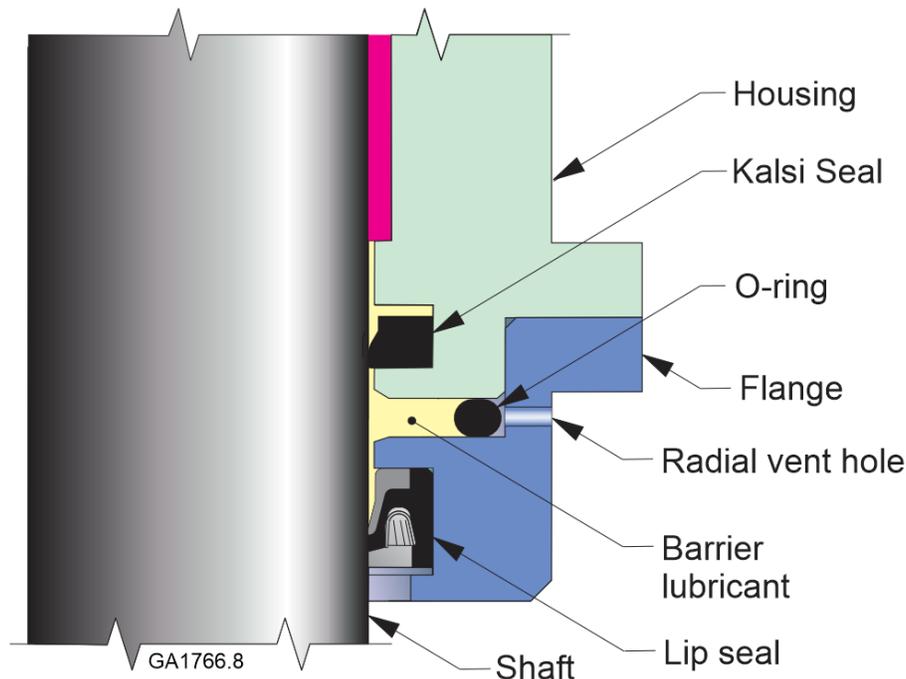


Figure 4

The groove for a radially acting O-ring can be defined between components

As shown by this figure, the deep groove for a radially acting O-ring can conveniently be formed between the ends of two mating housings, while providing a pilot between the housings. The same result can be achieved with two housings that thread together.

The barrier seal can be mounted in a removable groove wall

Figure 5 shows a removable carrier for the barrier seal that permits the Kalsi Seal to be axially spring loaded. The barrier seal carrier serves as a removable groove wall for the Kalsi Seal, so that the backup washer and wave spring(s) can be installed. When exposed to a high pressure ambient environment, the un-vented anti-rotation O-Rings generate significant friction, and help to prevent the barrier seal housing from rotating with the shaft. Alternately, the carrier for the barrier seal can be keyed to the main housing to prevent rotation.

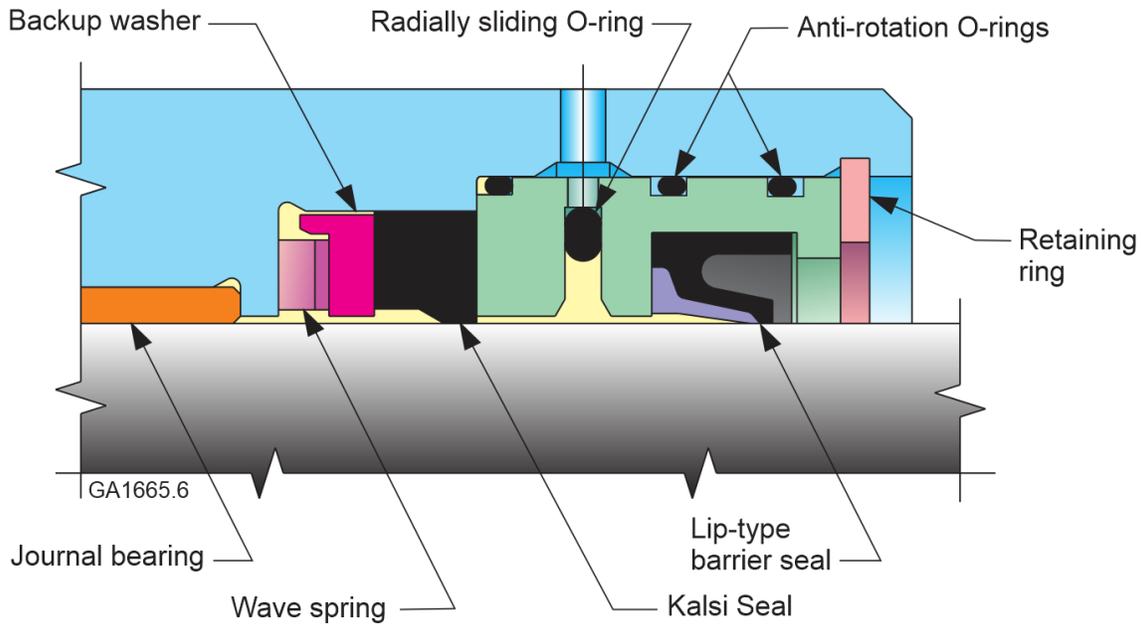


Figure 5

Pressure balancing between a spring-loaded Kalsi Seal and a barrier seal

The carrier for the lip-type barrier seal incorporates a radially sliding O-ring, and forms a removable groove wall for the spring-loaded Kalsi Seal. Environmental communication with the radially sliding O-ring is provided by radially oriented vent holes which meet at an annular groove. The radially sliding O-ring is only suitable for pressure compensation of small spaces, owing to the limited available stroke.

An axially sliding pressure balancing seal

Figure 6 illustrates an alternate method for balancing the pressure between a Kalsi Seal and a lip-type barrier seal to the pressure of the ambient environment. The balancing seal strokes within a wide groove to pressure balance the barrier lubricant that is located between the Kalsi Seal and the barrier seal.

The stroke of the balancing seal cannot be excessive, because some portions of its circumference will have more friction than others. This means that some portions of the balancing seal will move more easily than others, resulting in a stretched seal circumference. The stroke needs to be limited to a moderate length so that circumferential tension from the uneven axial movement cannot cause breakage of the barrier seal or cause a loss of radial compression.

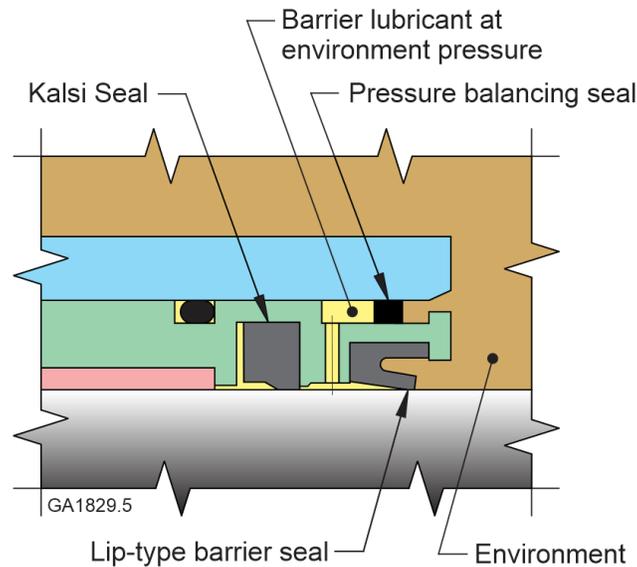


Figure 6

An axially sliding pressure balancing seal

The pressure balancing seal shown here balances the pressure of the barrier lubricant to the pressure of the environment by moving axially in a wide groove. Such seals tend to move unevenly due to unevenly distributed friction, resulting in circumferential stretch. The stroke of such balancing seals needs to be limited, so that the circumferential stretch cannot break the seal or cause it to lose compression.³

5. Minimizing pressure locking in existing equipment

Introduction

Engineers are sometimes faced with the task of supporting existing fleets of downhole oilfield equipment that do not compensate the pressure of the barrier lubricant to the surrounding drilling fluid environment. Sometimes there may be enough room between the Kalsi Seal and the barrier seal to retrofit the radially sliding O-ring that is shown in Figure 2. Even if there isn't enough room to incorporate a radially sliding O-ring, certain assembly steps can be taken to minimize pressure locking incidents.

Achieving a good lubricant fill between the Kalsi Seal and the barrier seal

If you are encumbered by existing equipment that does not have enough room to incorporate the radially sliding O-ring of Figure 2, develop a method for achieving the best possible lubricant fill in the region between the Kalsi Seal and the barrier seal. One such fill method is shown in Figure 7.

³ One prominent O-ring manufacturer recommends against using O-rings in sliding applications with a surface speed of less than one ft/minute, especially in conditions of low or zero differential pressure, because of the possibility of spiral damage.

Simply getting a good initial fill between the pair of rotary seals should help to alleviate pressure locking in a certain percentage of assemblies. When the unit is exposed to high ambient pressure, axial movement of the Kalsi Seal, and inward movement of the lip of the barrier seal can compensate for a modest amount of entrained air in the lubricant which is located between the two seals. (This assumes that the bearing lubricant pressure is properly equalized to the high pressure ambient environment.)

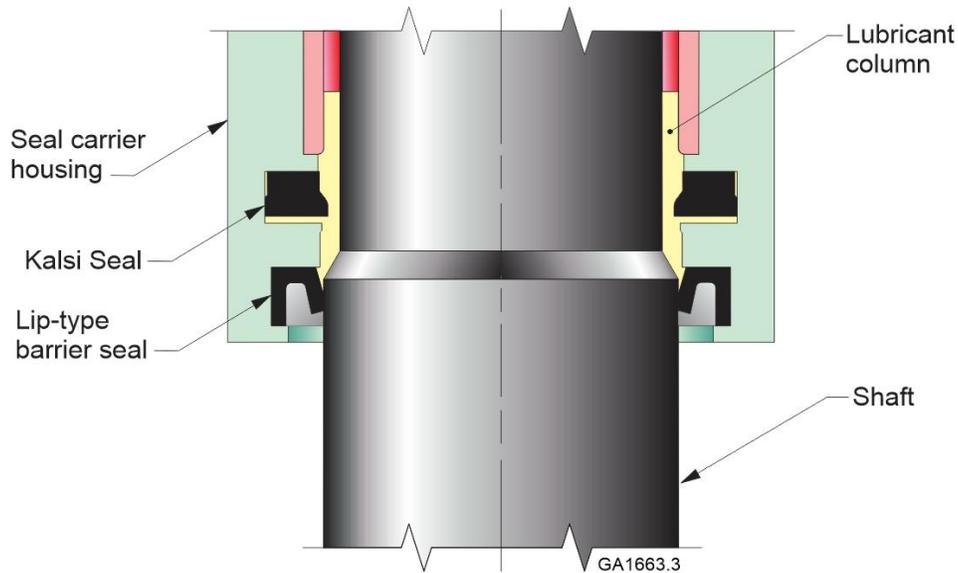


Figure 7

A potential way to help to alleviate pressure locking in existing hardware

This figure shows one possible way to help alleviate air-entrapment between rotary seals in existing hardware that fails to provide pressure compensation between the seals. This method is **not** suggested for new designs. During installation, push the Kalsi Seal away from the lip-type barrier seal. Engage the barrier seal on the rotary shaft, add de-aerated lubricant until the Kalsi Seal is submerged, then complete the installation. (Lower viscosity lubricants are more easily de-aerated.) The potential axial movement of the Kalsi Seal and flexing of the barrier seal will compensate for a small amount of entrained air between the seals, and may help to prevent pressure locking. If the barrier seal is suitably designed, it will vent lubricant thermal expansion, and will also vent the hydrodynamic pumping related leakage of the Kalsi Seal, and will be lubricated in the process.

Direct venting to prevent pressure locking

Because pressure locking can quickly destroy rotary seals in oilfield downhole tools, pressure locking must be avoided at all costs. It is better to provide a small passageway to allow the ambient pressure into the barrier lubricant chamber, rather than risk pressure locking, even though the passageway introduces environmental abrasives into the barrier lubricant.

Arguably the best way to provide such a passageway is by cutting a vent hole into the barrier seal (Figure 8). Ideally, one should experiment with the location and shape of

the vent hole so that it is a self-sealing hole that vents in one pressure direction, and seals in the other. Such a self-sealing vent hole causes Kalsi Seal leakage to pass through the dynamic interface of the barrier seal, instead of passing through the vent hole. Pack the annular cavity of the barrier seal with grease so that this grease enters through the vent hole and into the barrier lubricant chamber to equalize the barrier lubricant pressure to the ambient drilling fluid pressure. Obviously, it is better that grease enters through the vent hole to balance the barrier lubricant pressure, compared to abrasive environmental media.

The use of a vent hole through the barrier seal is preferred to incorporating a vent hole in the seal housing. Small vent holes in the seal housing may become cemented shut with drilling fluid, and will require cleaning every time the drilling tool is brought to the surface and rebuilt. If the vent hole is incorporated in the barrier seal, the vent hole is automatically replaced each time the seal is replaced.

Do not notch the dynamic sealing lip to prevent pressure locking (Figure 8). As the abrasive laden environmental fluid enters such a notch, abrasives are swept circumferentially into the dynamic interface between the shaft and the lip, resulting in rapid abrasive destruction of the lip. If a notch must be used as a vent, notch the static sealing lip instead of the dynamic sealing lip.

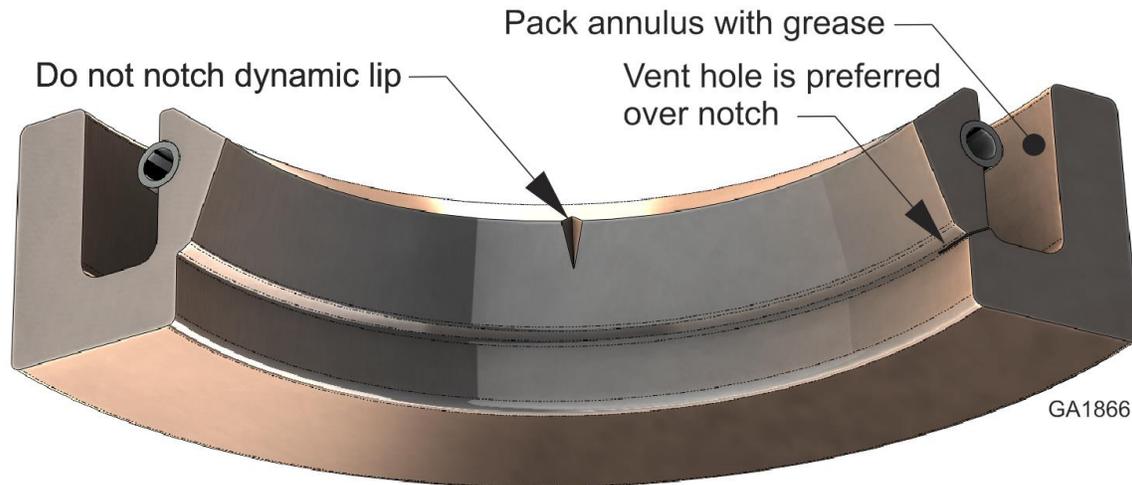


Figure 8

Modifying the barrier seal to prevent pressure locking

One can provide a vent hole in a barrier seal to prevent pressure locking. Fluid from the environment side of the dynamic lip enters through the vent hole to balance the pressure between the rotary seals to the ambient drilling fluid environment pressure. If the annulus of the barrier seal is packed with grease, this grease will be the fluid that enters through the vent hole to balance the pressure. Do **not** notch the dynamic lip to provide a pressure vent, because such a notch introduces abrasives into the dynamic interface, causing rapid abrasive wear of the lip.

6. Preventing pressure locking with a compensation piston

One way to use an Axially Constrained Kalsi Seal as a barrier seal is to mount it in an axially movable compensation piston (Figure 9) that is located outboard of the fixed location rotary seal. This barrier compensation piston⁴ can move axially to balance the lubricant pressure between the rotary seals. This allows the piston to compensate for any air entrained in the lubricant, and also allows it to compensate for lubricant thermal expansion and a moderate amount of differential hydrodynamic pumping related seal leakage. The piston can also serve a very useful purpose as a shaft deflection limiter, preventing metal to metal contact at the extrusion gap of the fixed location seal. One negative is that barrier compensation pistons add significantly to shaft length, and may not be appropriate for some equipment, such as oilfield short radius mud motors. Design information for compensation pistons is provided in Chapter D14.

Because the barrier seal slides axially along the shaft to compensate for thermal expansion and differential hydrodynamic pumping related seal leakage, the barrier seal can be exposed to contaminants on the shaft, and worn portions of the shaft. The barrier seal is also subjected to low levels of reversing pressure due to the friction of the sliding seals mounted on the OD of the piston. (In Figures 9, 10, and 11, the right hand sliding seal has a sealing function, and the two left hand sliding seals provide additional friction to prevent the piston from spinning with the shaft.) Another design tradeoff associated with using a barrier compensation piston is the additional length of the shaft that must be coated with expensive tungsten carbide, and then ground and polished to serve as a seal running surface.

Because the fixed location Kalsi Seal leaks into the barrier seal lubricant and the barrier seal leaks out of the barrier seal lubricant, differential hydrodynamic pumping related seal leakage will cause the piston to move in one direction or the other over time. If eventual overfilling of the barrier compensation piston due to differential hydrodynamic pumping related seal leakage is a concern (or is a design intention), you may want to provide a pressure relief valve to vent any excess buildup of barrier lubricant pressure. The venting pressure setting should be set high enough that normal equipment vibration and environmental pressure pulsations do not cause inadvertent venting that allows the piston to ratchet to an empty position.

⁴ For examples of sealed bearing mud motors that incorporate a barrier compensation piston mounting a barrier seal, see U.S. Patents 5,150,972, 5,248,204, and 5,664,891.

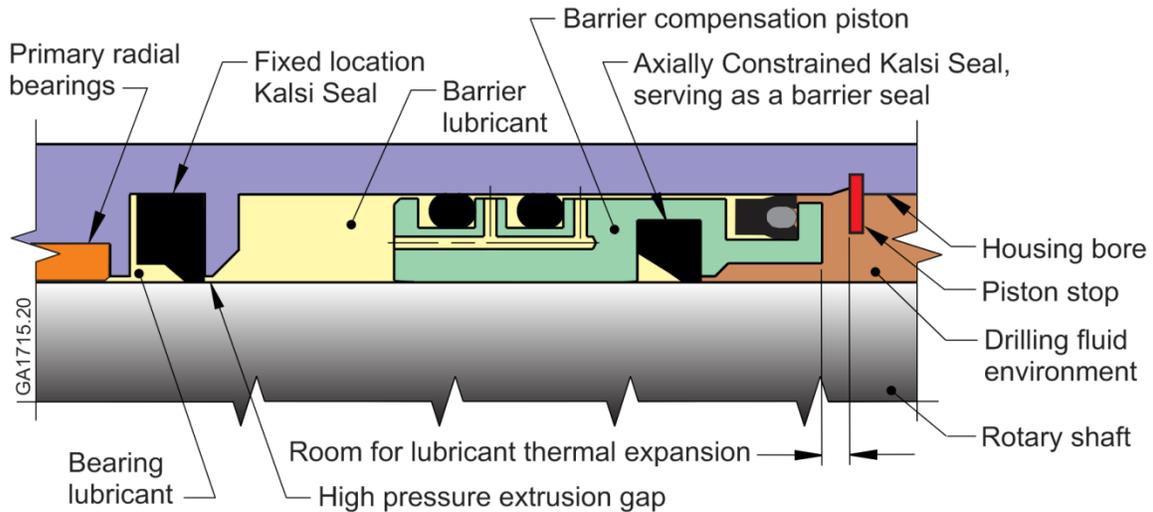


Figure 9

Preventing pressure locking with a piston-mounted seal

In this mud motor seal arrangement, the fixed location Kalsi Seal retains the bearing lubricant, which is normally at a much higher differential pressure than the drilling fluid in the well annulus. The fixed location Kalsi Seal is protected from drilling fluid abrasives by the piston-mounted Axially Constrained Seal™. The piston moves axially to pressure balance the barrier lubricant to the drilling fluid environment, and serves as a deflection limiter that prevents metal to metal contact at the high-pressure extrusion gap. The main reason for using a retaining ring as piston stop is to allow the barrier seal to temporarily retain differential pressure if the fixed location Kalsi Seal fails.

Avoid overfilling the barrier compensation piston

As shown by Figure 9, the barrier compensation piston needs room to travel to accommodate lubricant thermal expansion. As shown by Figure 10, failure to provide room for lubricant thermal expansion leads to rapid seal failure.

The lubricant has a much higher coefficient of thermal expansion, compared to metals, and is essentially incompressible. If insufficient piston stroke is provided to accommodate lubricant thermal expansion, the result is extremely high lubricant pressure as the tool heats up during service. This pressure quickly destroys both the fixed location Kalsi Seal and the barrier seal and may even yield the metal components (as shown schematically in Figure 10).

Train your service technicians to avoid overfilling the barrier compensation piston, and then retrain them periodically. Under-filling also damages seals (Figure 11).

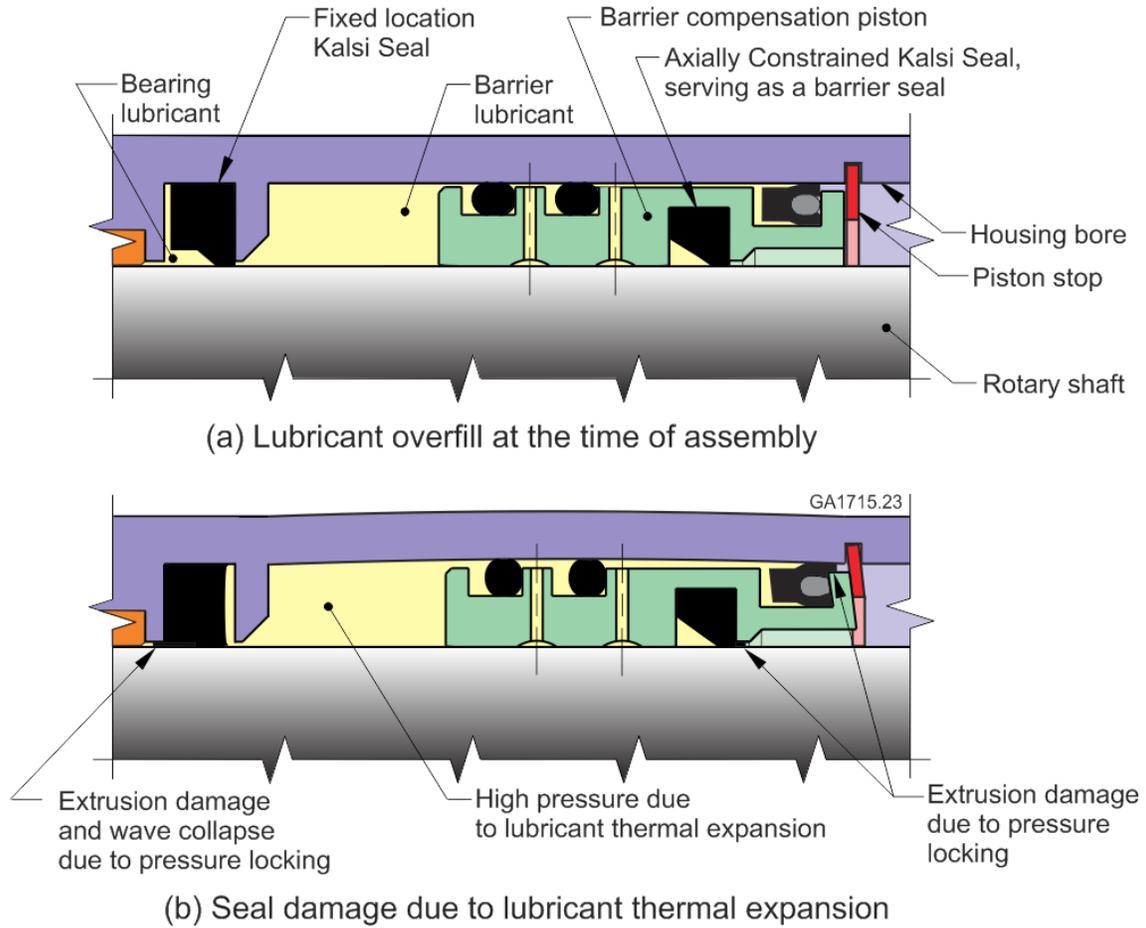


Figure 10

Piston overfill will result in seal failure due to lubricant thermal expansion

Overfilling the barrier lubricant reservoir is a critical mistake that leads to premature failure of the rotary seals. Failure to allow room for thermal expansion of the lubricant leads to extremely high pressures that damage the seals, and can even permanently deform the metal components.

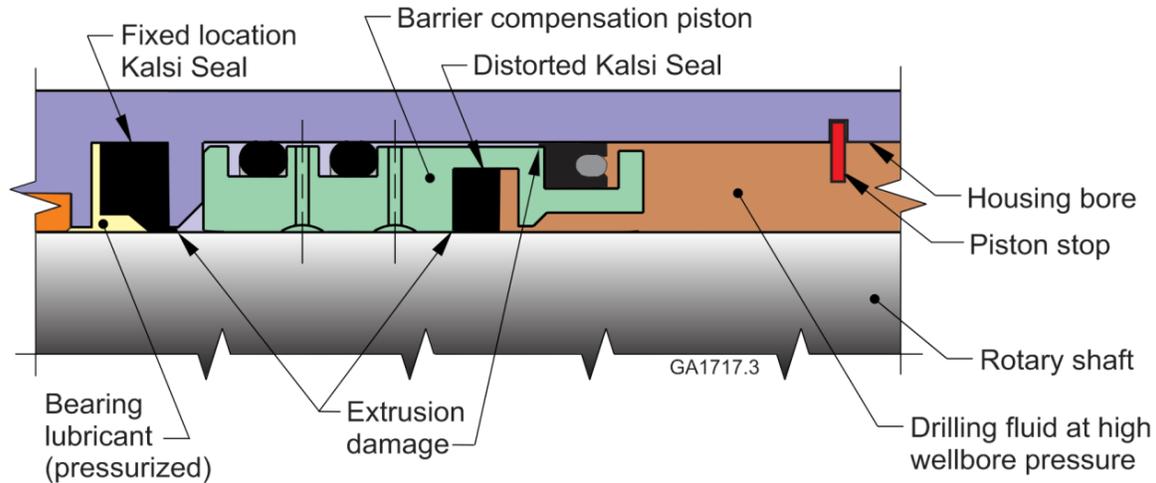


Figure 11

Piston under-fill will result in seal failure due to ambient pressure

If the barrier lubricant is absent, the rotary seals will fail due to extrusion damage and seal distortion resulting from the high ambient downhole pressure.

7. Preventing pressure locking with a diaphragm

A barrier seal can also be employed in fixed axial relation to an inner rotary seal if a diaphragm is provided to compensate the barrier lubricant to any high ambient environmental pressure. One simple arrangement is shown in Figure 12.

Diaphragms have low hysteresis, and respond quickly to pressure changes. This means that the lubricant pressure between the seals can track the environment pressure very accurately, eliminating pressure reversals on the outer seal. As a result, the pressure reversals are borne by the inner seal. This can be a distinct advantage, because the inner seal is operating in a clean lubricated environment, and the geometry distortion of the inner seal that is caused by the pressure reversal is less likely to cause seal damage.

If the outboard barrier seal and/or the inboard seal are Kalsi Seals, the diaphragm will also have to accommodate any differential hydrodynamic pumping related leakage, or be designed to vent the higher leakage of the inner seal to the environment. For an example of a diaphragm that vents differential pressure in one direction, see U.S. patent 4,727,942. Alternatively, if the barrier seal is a lip seal, the ability of the diaphragm to expand can intentionally be limited by design, forcing the hydrodynamic pumping related leakage of the inboard Kalsi Seal through the dynamic interface of the lip seal.

For an example of an annular diaphragm, see U.S. Patent 4,462,469. For examples of a rolling diaphragm, see U.S. Patents 335,033 and 3,220,496. For an example of an annular rolling diaphragm, see U.S. Patent 4,036,112.

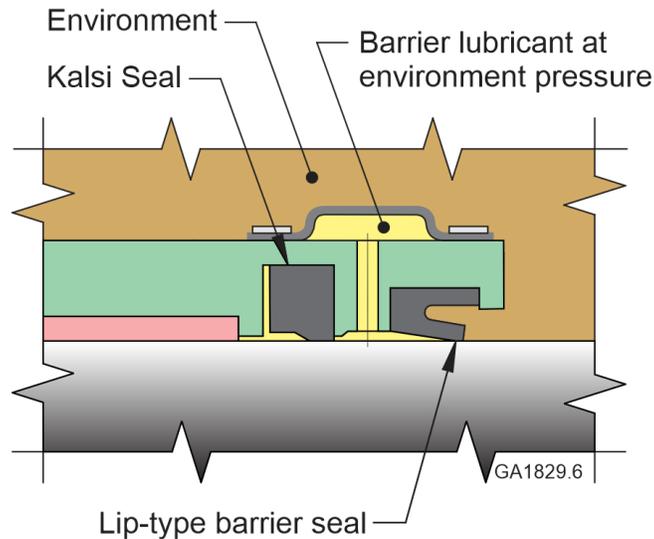


Figure 12

A diaphragm can be used to pressure balance between rotary seals

This shows a simple diaphragm being used to balance the pressure of the barrier lubricant to the pressure of the environment. Other types of diaphragms may also be appropriate. In downhole drilling tools, the diaphragm may require protection from rock cuttings that are present in the annulus of the well. If you can devise a way to intentionally restrict the outward movement of the diaphragm, the leakage of the inboard Kalsi Seal can be forced through the dynamic interface of the outboard lip seal. For example, the outward movement of this diaphragm could be restricted with a surrounding metal housing (not shown). This arrangement can be used with multiple lip seals (not shown) if the pressure of the environment is greater than the venting pressure of the inner lip seal, because the inner seal will vent lubricant to the region between the lip seals.

8. Using a barrier seal to deal with reversing downhole pressures

As a general downhole tool design comment, unexpected differential pressure, positive or negative, can occur across rotary seals for a number of reasons, including:

- Pressure compensation system hysteresis.
- Pressure related to drilling fluid displacement that is caused by drillstring axial movement (swab and surge pressure).
- Mud pulse telemetry.
- Pressure drop along the length of the tool due to flow resistance, relative to the location of the pressure compensation system(s).
- Packing off (clogging) of the annulus between the bottom hole assembly (BHA) and the wellbore due to inadequate cuttings removal, tight clearances, and/or wellbore collapse. This causes circulation to slow or cease, and causes pressure to increase dramatically.

No matter what the cause of pressure reversal across the rotary seals, the pressure reversal is undesirable because it causes seal distortion that reduces the ability of the seal to exclude abrasives. It is therefore highly beneficial to employ a barrier seal, with the region between the seals pressure balanced to the environment by a low hysteresis pressure balancing system. Such arrangements protect the outboard rotary seal from the reversing pressure, so that it remains undistorted and therefore more effective at abrasive exclusion. This arrangement protects the inner rotary seal from abrasives, so that any reverse-pressure induced distortion of the inner seal cannot encourage abrasive invasion at the seal to shaft interface of the inner seal. In other words, with such arrangements, it is the inner seal that is exposed to any reversing pressure, not the mud-exposed outer seal (Figure 12).

In such redundant seal systems, as long as the inner seal is intact, the outer seal experiences little or no differential pressure. To prevent skew induced wear, the outer seal should be an Axially Constrained Kalsi Seal, an axially spring-loaded Kalsi Seal, or a lip-type barrier seal that is constrained to an unskewed lip configuration by its engagement with the housing.

9. Monitoring barrier seal integrity in surface equipment

Figure 13 shows how a redundant sealing arrangement can be served by an independently monitored lubricant reservoir in surface equipment such as mining type drilling machines. The eventual failure of the barrier seal can be detected by reservoir depletion, so that maintenance can be scheduled before the inner seal fails. Although gas charged reservoirs are illustrated, the concept is also applicable to other types of lubricant reservoirs. If desired, the reservoirs can be instrumented for remote monitoring or automatic equipment shutdown.⁵

Although Figure 13 shows two independent lubricant supplies, one lubricant supply can be pressurized by the other, if desired. For example, the lubricant between the two rotary shaft seals can be pressurized by a piston or diaphragm that is pressurized by the primary lubricant reservoir.

⁵ For examples of redundant rotary sealing arrangements that are served by independent lubricant reservoirs, see U.S. Patent 5,823,541 and U.S. Patent Application 20030205864.

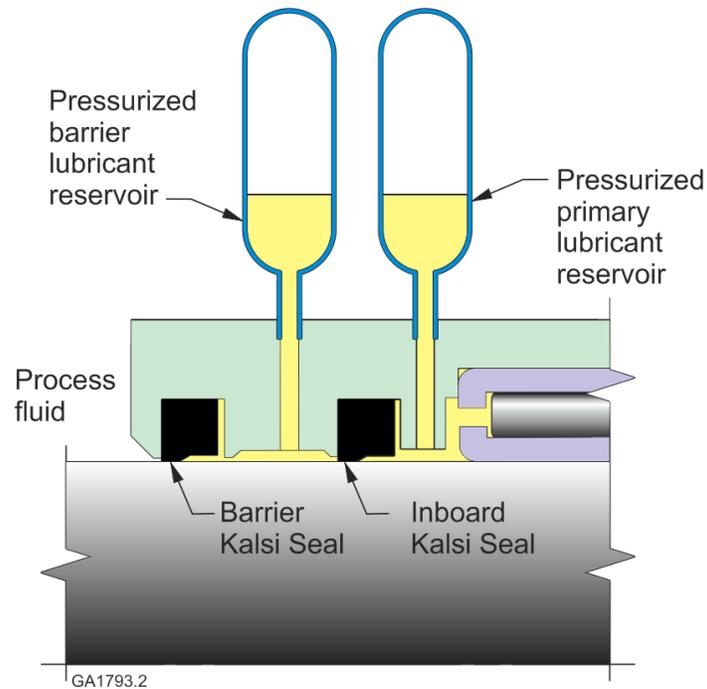


Figure 13

Using a separate reservoir to monitor barrier seal integrity in surface equipment

By using independent lubricant reservoirs pressurized to a value above the process fluid pressure, barrier seal integrity can be monitored. In this machine schematic, the lubricant reservoirs are illustrated as pressurized air over oil reservoirs (reservoirs are not drawn to scale), but the concept is applicable to other types of reservoirs as well.

Figures 14 and 15 show methods for pressurizing the barrier seal lubricant in any kind of surface equipment that can tolerate a significantly increased lubricant leak rate for short periods of time. When the outboard rotary seal fails, the leak rate of the seal lubricant will increase significantly. The leak rate can be monitored manually, or the lubricant reservoir can be instrumented for remote leak rate monitoring.

The Figure 15 arrangement is similar, but incorporates a valve. Once the leak rate increase is detected, the valve can be closed, returning the leak rate to the normal range until the inboard rotary seal fails.

With either arrangement, once the increased leak rate has been detected, the equipment can be shut down for maintenance at the operator's convenience. Although Figures 14 and 15 illustrate the lubricant reservoir as a gas over oil system, the concepts are equally applicable to many other types of lubricant reservoirs.

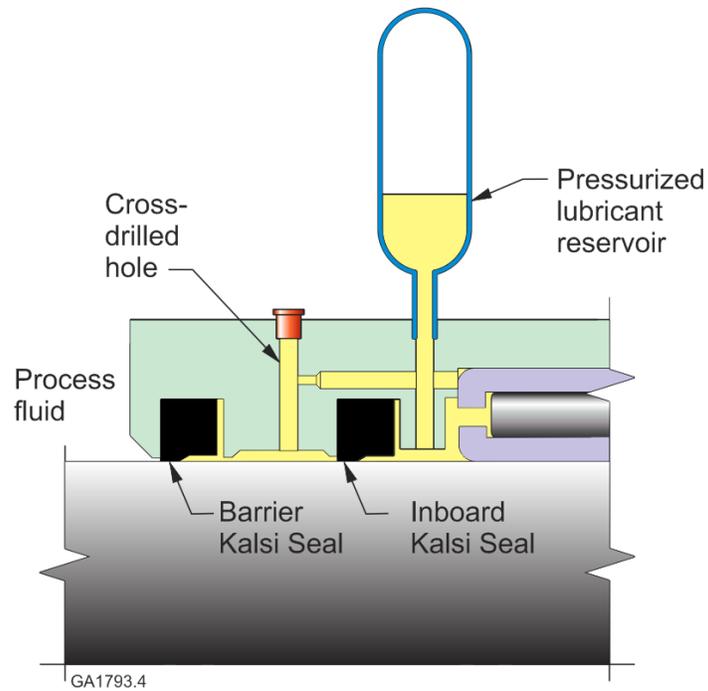


Figure 14

Monitoring leak rate to monitor rotary seal integrity in surface equipment

In this schematic, the cross-drilled hole balances the pressure between the rotary seals to the pressure of the lubricant reservoir. Failure of the barrier seal causes an increased leak rate through the cross-drilled hole. Once the increased leak rate is detected, the equipment can be shut down for maintenance at the operator's convenience.

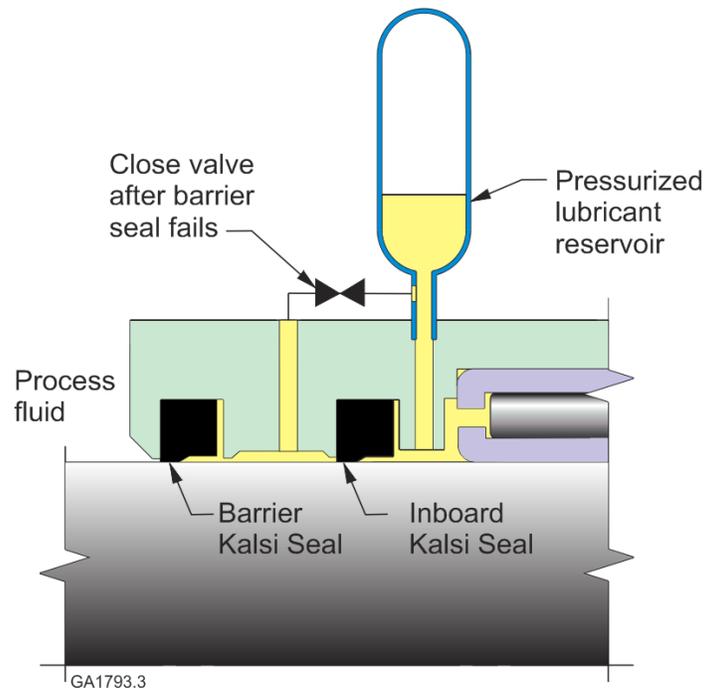


Figure 15

Monitoring leak rate to monitor rotary seal integrity in surface equipment

In this arrangement, operation begins with the valve open, allowing the pressurized lubricant for both seals to be provided by a single lubricant reservoir. Failure of the barrier seal causes a significantly increased leak rate. Once the increased leak rate is detected, the valve is closed to allow operation on the remaining seal, with a normal hydrodynamic pumping related lubricant leak rate. This arrangement allows the equipment to continue to run for an extended period of time on the remaining seal.

10. Using a piston with a lip-type barrier seal

Figure 16 shows a piston being used to balance the barrier lubricant to the process fluid pressure in a staged high-pressure side entry swivel for abrasive fluids such as oilfield drilling fluid. The barrier seal protects the Kalsi Seal from momentary pressure reversals due to lubricant pressure lag, and also protects the Kalsi Seal from the abrasive and chemical effects of the process fluid. Whenever piston seal friction, or the illustrated shoulder, prevents the piston from moving toward the process fluid, the hydrodynamic pumping related leakage of the uppermost Kalsi Seal will pass through and lubricate the dynamic interface of the lip seal.

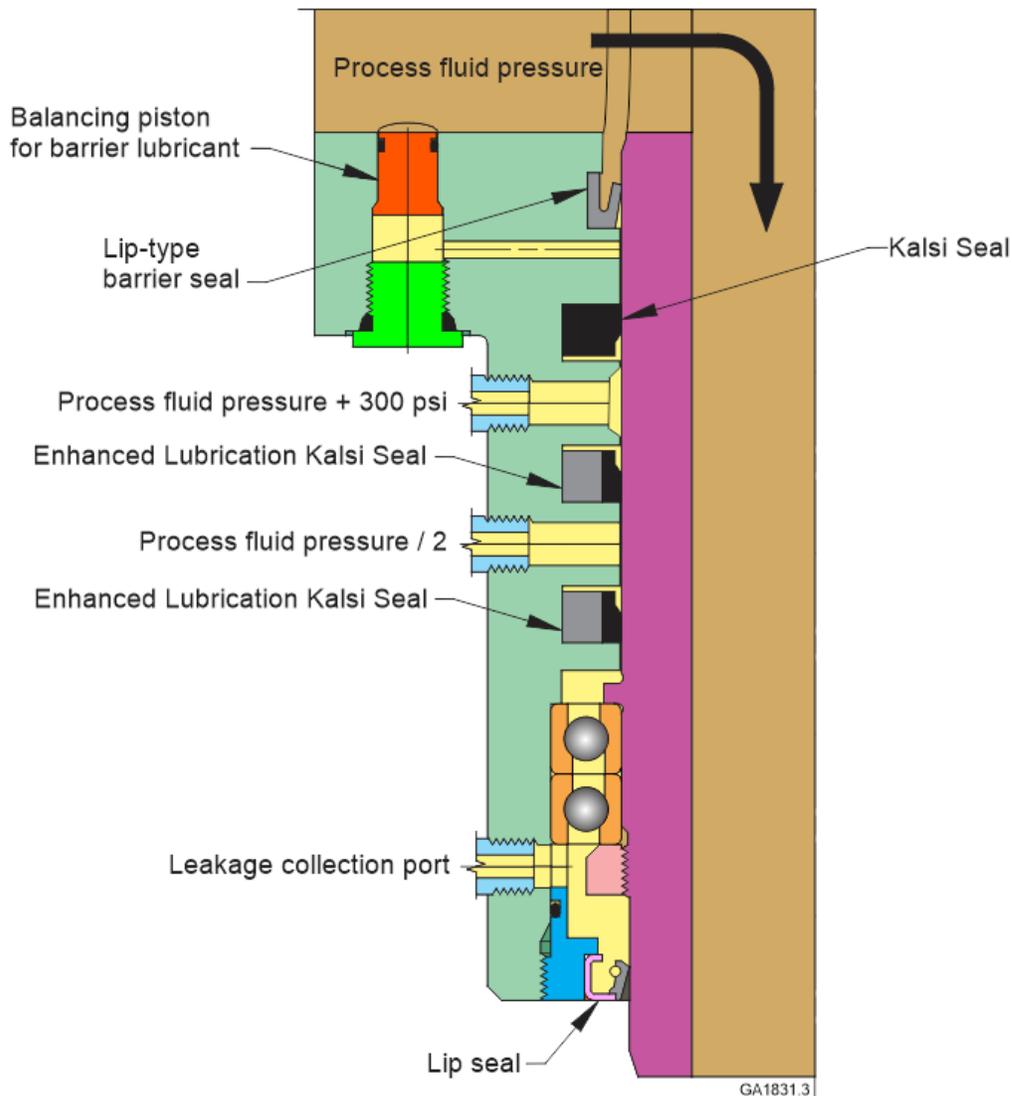


Figure 16

Using a piston with a lip-type barrier seal (schematic)

The piston balances the pressure of the barrier lubricant to the pressure of the process fluid. If the piston bottoms out in the position shown, the hydrodynamic pumping related leakage of the Kalsi Seal will vent past the lip of the barrier seal, lubricating the dynamic interface of the barrier seal. The barrier seal protects the uppermost Kalsi Seal from the abrasive and chemical effects of the process fluid, and protects the Kalsi Seal from momentary pressure reversals which may occur due to lubricant pressure lag.

11. Flushing and lubricating lip-type barrier seals

As shown in Figure 17, the high hydrodynamic pumping related leak rate of High Film Kalsi Seals™ can be used to lubricate and flush a set of lip-type barrier seals. The same flushing and lubrication effect can be achieved with Enhanced Lubrication Seals™.

The hydrodynamic pumping related leak rate of Enhanced Lubrication Seals is less than that of High Film Seals, but still significant in low differential pressure conditions. The lip-type barrier seal used in the cement pump cartridge shown in Figure 17 incorporates a foam based energizer that is not appropriate for the high ambient pressure encountered in oil well drilling.

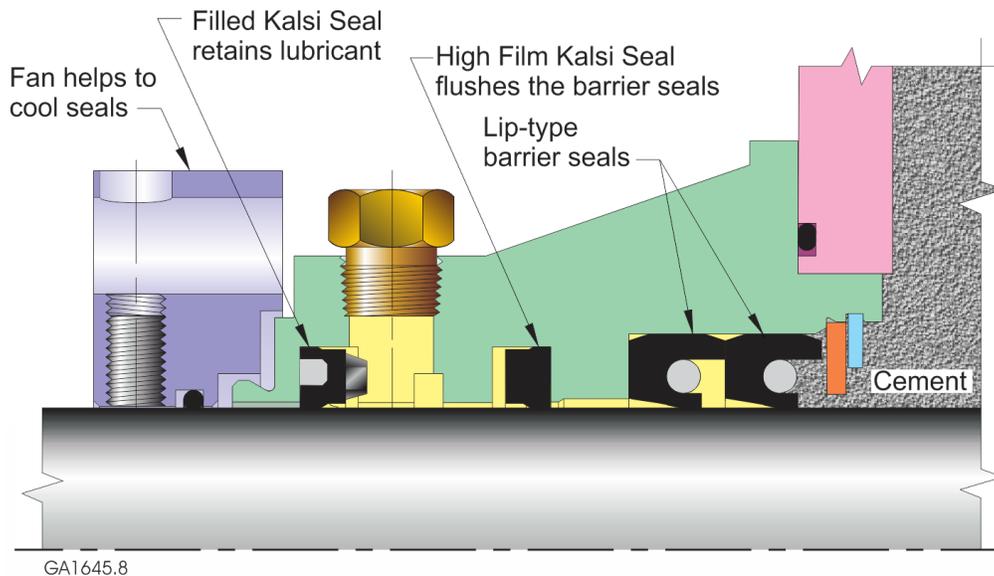


Figure 17

High Film Seals flush a pair of barrier seals in a cement pump cartridge

In Kalsi Engineering's cement pump seal cartridges, the aggressive hydrodynamic geometry of a High Film Seal™ is used to create pressure and lubricant flow that lubricates and flushes a pair of lip-type barrier seals which face the cement (U.S. Patent 7,798,496).

12. Observations on lip-type barrier seals

Rotary testing of a garter spring energized lip seal

Kalsi Engineering does not manufacture or sell lip-type barrier seals, and therefore we do not ordinarily test them. One type that we did test is shown in Figure 18. It was tested outboard of High Film Kalsi Seals at 2,400 rpm on a 2" shaft (1,256 ft/min). They reliably vented the hydrodynamic pumping related leakage of the High Film Seals, but heavy slurries tended to expel the garter spring. Whether garter spring loss would be a problem at slower speeds, or with a non-slurry media, would have to be determined by further testing. The spring loss was related to the heavy slurry working its way behind the spring, apparently due to shaft runout and deflection.

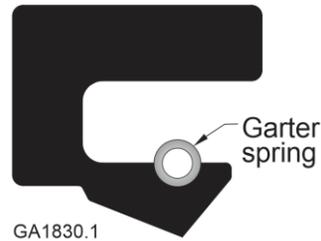


Figure 18

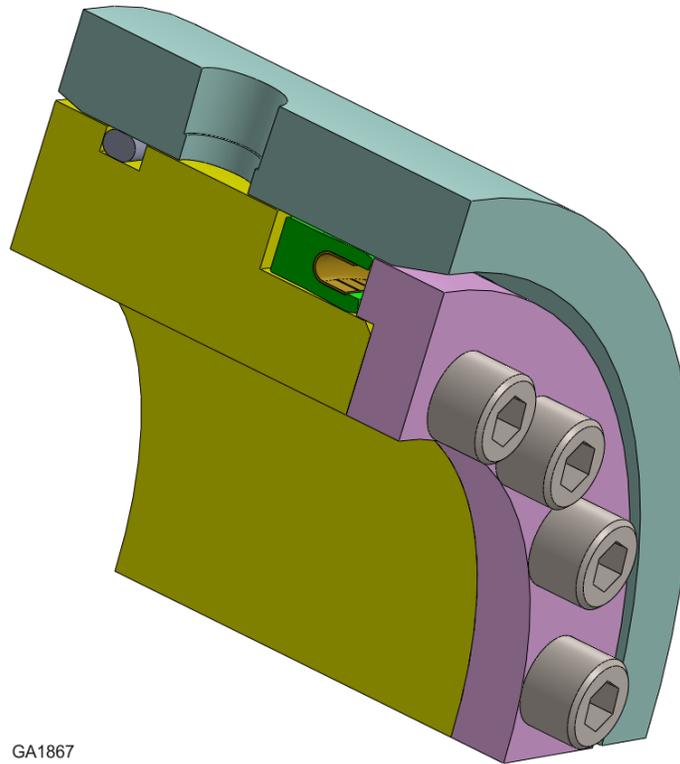
Garter spring energized lip-type barrier seal was tested against a heavy slurry

Garter spring energized lip-type barrier seals reliably vented the hydrodynamic pumping related leakage of a High Film Kalsi Seal™, but over time the garter springs were wedged out of position by the sand particles within the test slurry. (Based on limited rotary testing.)

Lip seal venting considerations

Kalsi Engineering built a test fixture of the general type shown in Figure 19 to test the venting characteristics of several lip seal designs that had equal length lips.⁶ The seals that were tested were an O-ring energized elastomeric lip seal and a reinforced PTFE lip seal that was energized by a conventional cantilever spring. Both seals were oriented with the lips facing a removable environment-side groove wall, as shown in Figure 19. Within the range of pressure tested, neither seal successfully vented pressure when used with a flat groove wall.

⁶ Kalsi Engineering internal report, KEI™ file no. 45.6.4, "Using a Static Spring Loaded V-Type Seal as a Pressure Relief Device", 1992.



GA1867

Figure 19**Venting pressure test fixture**

When tested in this configuration, lip seals with equal length lips did not vent internal pressure. Instead, the lips established a sealing relationship between the removable environment-side groove wall and the cylindrical surfaces of the gland.

Axial force resulting from the test pressure caused the inner lip of both seals to establish a sealing relationship with the removable groove wall, as shown in Figure 20. This situation prevented the seals from venting because the pressure acting between adjacent sealing points increased lip load. The spring-loaded lip seal successfully vented pressure at room temperature when tested with the support pedestal shown in Figure 21. The annular relief groove shown in Figure 21 was required to ensure venting when the seal was tested at 250°F (121.1°C). Without the relief groove, thermal expansion caused the body of the seal to establish sealing between the cylindrical groove wall and the shaft, which prevented the seal from venting pressure. Ideally, the body of the seal should be designed to have radial clearance at the maximum anticipated temperature.

Figure 22 shows a pedestal shape that provides more radial clearance with the spring, compared to the pedestal used in our testing. The additional clearance may provide a benefit when the seal is exposed to dirty environments.

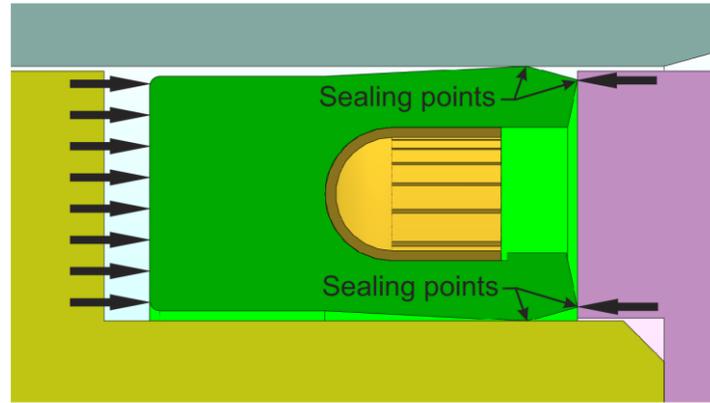


Figure 20

Spring loaded lip seal with equal length lips did not vent pressure

During our initial testing, pressure acting from the left (arrows) caused both lips to establish sealing with the right-hand groove wall. This created a radial pressure imbalance that increased radial sealing force. At the pressures tested, the seal did not vent as intended. Unequal lip lengths are preferred when reliable venting is needed. (A shorter lip is less likely to establish a sealed relationship with the groove wall.)

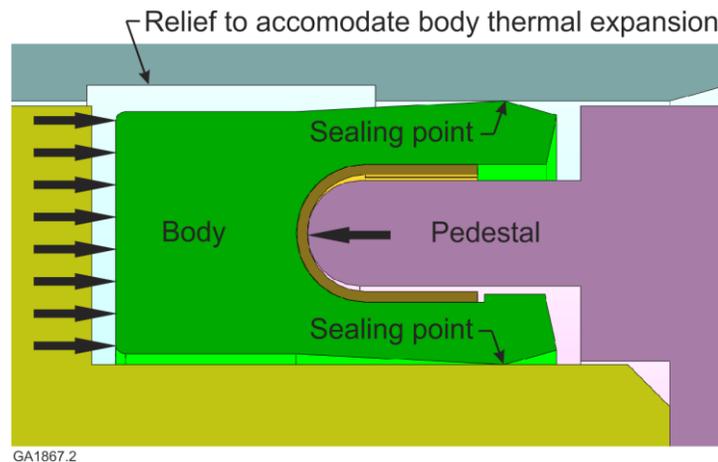


Figure 21

A circular pedestal allowed the spring-loaded lip seal to vent pressure

When we tested with this arrangement, pressure induced force acting from the left (arrows) was reacted by the pedestal. The pedestal prevented the lips from contacting the right-hand groove wall, leaving them free to vent pressure. The relief groove was required to prevent the body of the seal from establishing sealing between the shaft and the cylindrical groove wall in elevated temperature conditions. The need for such a relief groove is dependent on the specific geometry of a given seal design, and the thermal expansion characteristics of the material used to make the seal. Ideally, the radial body depth of a rotary shaft seal should be designed so that elevated temperature doesn't cause such issues.

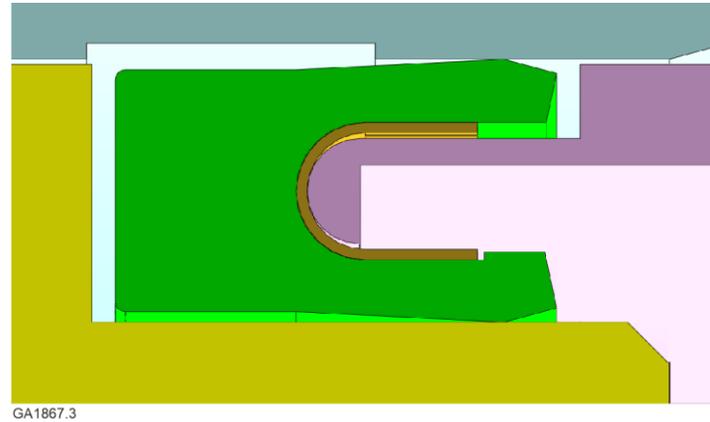


Figure 22

Suggested pedestal shape for dirty environments

The preceding figure (Figure 21) shows the shape of the pedestal that was used in our testing. The pedestal configuration shown here is likely to be better for use with dirty environments.

Testing a V-spring energized lip seal

We performed rotary testing of the type of V-spring energized lip seal that is shown in Figure 23. These composite seals, which are manufactured and sold by a third party, incorporate a spring loaded elastomeric lip that is reinforced by a layer of reinforced PTFE. While we have not tested such rotary seals extensively, the design performed well against oilfield drilling fluid in zero differential pressure conditions, with and without shaft runout. In our rotary testing, performance degraded rapidly when the pressure of the drilling fluid was raised above the pressure of the seal lubricant. The test results suggest that this type of seal may be useful as a barrier seal in applications where the pressure of the barrier lubricant equals the pressure of the environment.

In addition to rotary seal testing, we also performed stationary (non-rotating) venting pressure testing of several different sizes of such seals, to develop an understanding of the pressure required to vent lubricant past the dynamic lip, and into the environment. We encountered a wide range of venting pressure, and determined that the axially longer static lip of such seals does not always prevent the dynamic lip from contacting, and sealing off against, the environment side groove wall. When this contact occurs, the seal cannot vent excess pressure past the dynamic sealing lip.

With some specimens, lubricant pressure caused enough seal distortion that the dynamic lip reciprocated toward, contacted, and sealed off against the environment side groove wall before the dynamic lip could vent pressure. We were able to prevent the dynamic lip from sealing off against the groove wall by removing the part of the groove wall that the dynamic lip was contacting, leaving only a partial groove wall (Figure 23).

Although this expedient ensures venting, it does not prevent the gross axial reciprocation of the dynamic lip that had been initiating the contact with the previous full-sized groove wall. That gross reciprocation could have a negative effect on seal life when such seals are used with abrasive environments. For this reason, the pedestal approach may be better, but we have not tested it with this type of composite seal.

We encountered some seals of this type that exhibited unusually low venting pressure. We suspect that this may be caused by inadvertent spring yielding related to the distortion the seal experiences during installation into a normal one-piece seal groove. Such installation-related distortion could be minimized by using a groove with a removable environment-side groove wall, or by using a partial groove wall that is only radially deep enough to engage and restrain the static outer sealing lip (Figure 23).

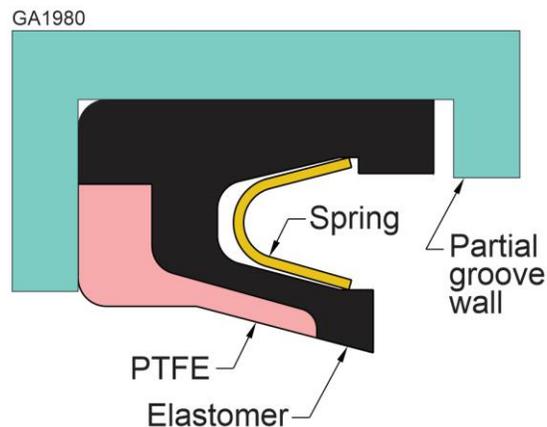


Figure 23

V-spring energized lip-type barrier seal

This composite rotary seal, which is manufactured and sold by a third party, includes a reinforced PTFE heel for resisting extrusion damage from momentary high differential pressure. The elastomer portion is available in HNBR and FEPM. The use of the partial environment-side groove wall eases seal installation, helps to prevent installation-related seal damage, and helps to ensure that the seal can vent lubricant pressure by preventing the dynamic lip from sealing off against the groove wall as a result of differential pressure.

13. Issues with using an outboard chamber as a protective barrier

Introduction

Various barrier seal arrangements in this chapter incorporate an annular chamber between the inboard rotary seal and the outboard barrier seal. Such chambers are intended to reduce the clearance related pumping action that occurs after the barrier seal has failed. The chambers also serve to increase heat transfer, and reduce seal temperature. Based on

the observations described below, long, tight zones of clearance should not be used outboard of such chambers.

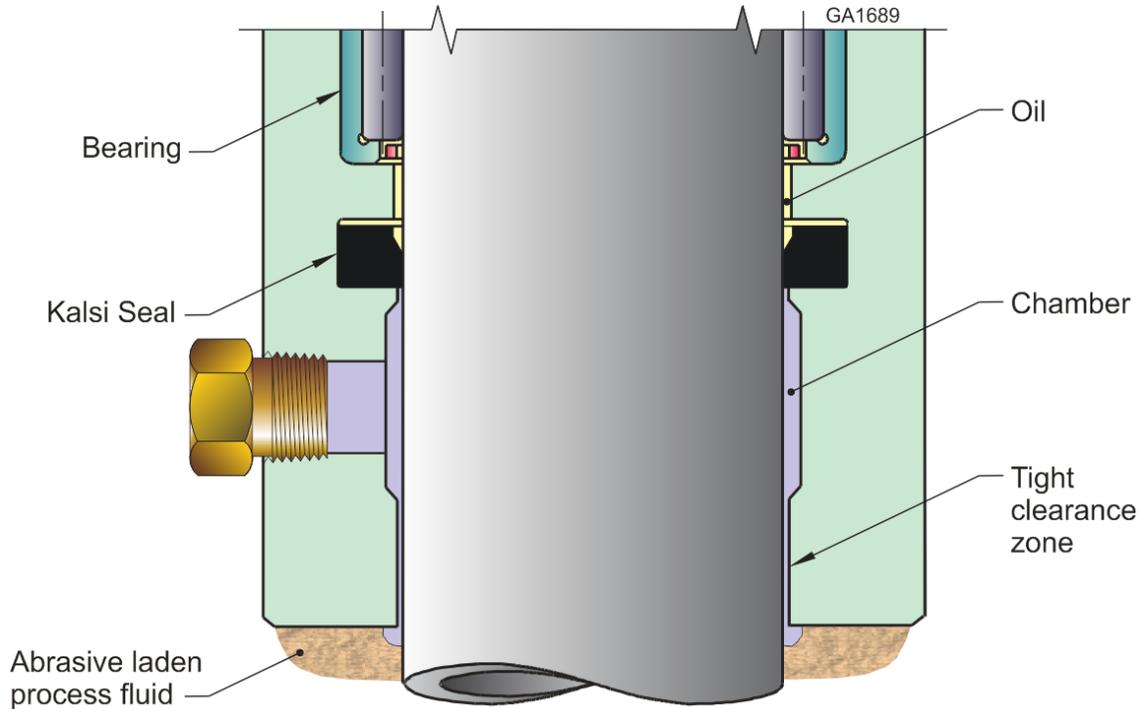


Figure 24

Generic outboard chamber illustration

This seal assembly has a relatively long zone of tight clearance outboard of an annular chamber. Shaft speed and runout produce a radial approach velocity between the shaft and the housing. At the tight clearance zone, this radial approach velocity creates a pumping action that can replace the initial chamber contents with process fluid. In extreme cases, this mechanism can even cause abrasives to pack tightly within the chamber. Whenever a tight clearance zone is exposed to an abrasive process fluid, the length of the clearance zone should be minimized.

Outboard grease chambers can create problems under certain conditions

Figure 24 is a generic representation of a rotary seal implementation. It has an outboard chamber intended to serve as a protective barrier between the Kalsi Seal and the abrasive laden process fluid. It also has a relatively long zone of tight clearance outboard of the chamber.

During operation, shaft speed and runout produce a radial velocity between the shaft and the housing. The radial velocity, acting over the length of the tight clearance zone, produces a pumping effect that moves fluid in and out of the tight clearance zone, and in and out of chamber. The strength of the pumping action depends on factors such as the radial velocity, and the length and clearance of the tight clearance zone.

Even if the chamber and the tight clearance zone are initially filled with grease, the pumping action is very likely to cause the chamber to become filled with process fluid. Part of the reason is the large difference in volume between the process fluid and the grease within the chamber.

When the radial velocity is high and the tight clearance zone is long, the chamber may even become tightly packed with abrasives, with very little fluid remaining.⁷ This is because the liquid fraction of the process fluid is more easily expelled from the chamber than the abrasive particles. For this reason, we are not optimistic about the efficacy of using a grease-packed labyrinth to protect rotary seals from abrasives.

The pumping action and packing tendency have been observed by Kalsi Engineering, but the effects of various parameters have not been explored by testing. Experiments regarding the effect of various extrusion gap lengths and clearances on seals, have, however, provided relevant insights because the same pumping action occurs in extrusion gaps. The extrusion gap tests revealed that the pumping action is stronger with tighter clearance, and with longer axial length of the tight clearance zone. (See Chapter D7 for more information.) For this reason, the length of any tight clearance zone should be minimized if the clearance zone is exposed to an abrasive process fluid.

Outboard chambers can be used for water flush

If the outboard chamber shown in Figure 24 is connected to a water source that is at a higher pressure than the process fluid, the resulting water flow will tend to flush abrasive contaminant matter away from the rotary seal. As a result, the chamber becomes a protective dilution zone, with less abrasive content than the process fluid.

When such a water flush arrangement uses a municipal water source, precautions must be taken to prevent contamination of the municipal water system. Work with applicable governing agencies to assure compliance with all relevant requirements.

⁷ This phenomenon was observed when testing a labyrinth formed from felt rings, in a manner shown by item 47 in Figure 2 of U.S. Patent 4,484,753. On some occasions, the grease chamber became rapidly packed up with sand from the drilling fluid. Despite the buoyancy of the grease trapped in the annular chamber, the grease was replaced by tightly packed sand particles. Apparently, it is much easier for the liquid part of the drilling fluid to be expelled from the annular chamber by shaft runout and vibration, compared to the sand particles.

14. Service conditions with pulsing pressure

When rotary seals are exposed to pressure pulses in the environment, we suggest the diaphragm and barrier lip seal arrangement that is shown schematically in Figure 12. We refer to the lubricant between the seals as the “barrier lubricant”. The diaphragm maintains the pressure of the barrier lubricant at the pressure of the environment, rapidly responding to the pressure pulses. For as long as the lip seal survives and the barrier lubricant has not been depleted, the lip seal is isolated from differential pressure, and the pressure differential is applied to the Kalsi Seal in a clean lubricated environment. In our experience, lip seals provide more consistent exclusion of abrasive environments in low pressure differential conditions.

The diaphragm should be designed to accommodate the depletion of the barrier lubricant without failing. If some lurking mechanism depletes the barrier lubricant, both the diaphragm and the lip seal will be exposed to the full magnitude of the pressure pulses, and should be designed or selected for that service.

More than one outboard lip seal can be used

If the ambient pressure of the environment is greater than the venting pressure of the lip seal, more than one lip seal can be used, because differential pressure acting across the innermost lip seal will cause that seal to vent lubricant to the region between the lip seals. In order to be used in this manner, the outer lip has to be axially longer than the inner lip, to ensure that differential pressure-related venting of the innermost lip seal will occur. (The differential pressure is caused by the atmospheric pressure that is initially trapped between the lip seals at the time of assembly.)

Some of the tradeoffs involved in using more than one lip seal are:

- More seal-related heat is generated.
- More shaft overhang from the bearings.
- The Kalsi Seal is more isolated from the cooling effect of the environment.

Selecting the Kalsi Seal

When dealing with pulsing environmental pressure, consider using the Chamfered Enhanced Lubrication Seal™ as the inboard rotary seal. These seals were developed for applications such as oilfield mud pulse systems and low pressure rotating heads, where the pressure of the environment is up to 500 psi higher than the pressure of the lubricant. As such, they have a better chance of surviving the exposure to the environment that will occur if the outboard lip seal fails.

Ratcheting mechanism unknowns

There are many unknowns that could produce ratcheting mechanisms; i.e. mechanisms that act only one direction. These mechanisms may vary from one hardware configuration to another.

For example, the hysteresis of the diaphragm that balances the pressure of the barrier lubricant to the pressure of the environment could produce a ratcheting mechanism that tends to deplete the barrier lubricant, if axial motion of the Kalsi Seal associated with pressure pulse-induced distortion and relaxation of the Kalsi displaces lubricant past the lip seal instead of causing the diaphragm to move. For this reason, the diaphragm should be strong enough to resist pulse-induced failure when the barrier lubricant within the diaphragm is depleted and the diaphragm is bottomed out.

One has to choose between a long and a short axial length of the lubricant side extrusion gap. A short axial length promotes the rapid transmission of pressure and fluid flow through the gap, and a long axial length discourages the rapid transmission of pressure and fluid flow through the gap. One can imagine scenarios where a long axial length allows trapped lubricant to physically support the Kalsi Seal against pressure pulse-induced distortion because it discourages lubricant within the seal groove from exiting the seal groove when the pressure pulse hits the Kalsi Seal. One can also imagine circumstances where compensation piston hysteresis and the long length of the gap delay oil from flowing back into the seal groove after pressure-pulse induced distortion of the Kalsi Seal occurs, creating a ratcheting mechanism that causes the Kalsi Seal to become more and more distorted by the pressure pulses. An unknown number of factors are in play, such as the temperature and resulting modulus of the seal, the frequency and rate of pressure rise of the pulses, the viscosity of the lubricant, etc. The safest course may be to use a lubricant side extrusion gap with a short axial length, to minimize the risk of the envisioned ratcheting mechanism, which could hold the Kalsi Seal in a distorted position.

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