

Chapter D16

Axially force-balanced, laterally translating seal carriers



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1. Introduction

Many applications involve significant levels of unavoidable shaft runout, deflection and misalignment. In such applications, laterally translating seal carrier, backup ring, or washpipe arrangements should be considered.

This chapter describes several axially force-balanced laterally translating seal carrier arrangements. These arrangements can significantly improve rotary seal life in high differential pressure applications that have large shaft deflection, misalignment and runout. The seal carrier designs accommodate the small extrusion gap necessary for high-pressure oil seal operation, and eliminate problems due to high frictional heat and seal damage that occur with conventional unbalanced seal carrier designs (Figure 1), which require large forces to move laterally.

Background Information

To implement Kalsi-brand rotary seals properly, any high differential pressure application must meet two basic extrusion gap requirements:

1. The extrusion gap must be small, to minimize seal extrusion.
2. The extrusion gap must be large enough to avoid heavily loaded metal-to-metal contact.

These two requirements are difficult to meet simultaneously with shafts that have high side loads and deflection. When lateral shaft motion exceeds extrusion gap clearance, the extrusion gap becomes a de-facto radial bearing and generates seal-damaging heat. The heat reduces the modulus of elasticity of the rotary seal, lowering seal extrusion resistance. The heat buildup also accelerates seal compression set. In severe cases, local seal melting can occur. The heavily loaded metal-to-metal contact can wear the shaft and housing, increasing the extrusion gap, roughening the shaft, and damaging (burring) the critical extrusion gap corner (Chapter D7). If relative axial motion occurs due to assembly clearances and component elasticity, then further damage can occur to the rotary seal, from riding over the roughened shaft surface. Roughening at the extrusion gap corner between the seal groove and the extrusion gap can also significantly accelerate extrusion damage.

If the extrusion gap is too large, then the differential pressure causes the rotary seal to protrude into the extrusion gap. Runout and pressure breathing can flex and destroy the protruding material, and leave a jagged seal edge that interferes with optimum seal lubrication. The differential pressure causes more protrusion, and the damage cycle continues until the seal is destroyed.

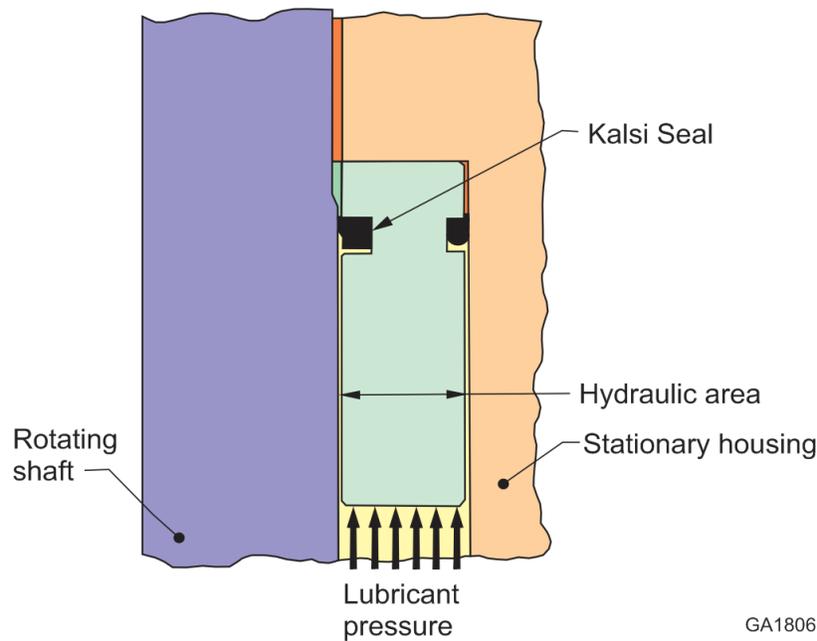


Figure 1

Conventional high-pressure seal carriers cannot move laterally

Conventional high-pressure seal carriers have differential pressure acting over the large annular area that exists between the stationary and rotary seals. The result is a large hydraulic force that loads the seal carrier against the internal shoulder of the stationary housing, creating high friction that prevents the seal carrier from moving laterally in response to lateral shaft motion. The result is high frictional heat generation, from rubbing between the seal carrier and the shaft. Such rubbing damages the seal carrier and generates temperatures that damage the rotary seal.

2. Force-balanced laterally translating seal carrier (stepped)

Stepped laterally translating seal carriers appear in Figures 2 through 6. Intended for higher rotating pressure, the pressure-staged configuration of Figure 4 divides the lubricant pressure between two rotary seals. The figures depict seal carriers that have a journal bearing relationship (Chapter D15) with the rotary shaft; however, other types of radial bearings can be used.

The environment end of the seal carrier has a sliding face sealing relationship with the housing. The face seal is preferably selected for resistance to spiral failure¹. As Figure 2 shows, the static sealing interface diameter B and the shaft diameter S (which defines the dynamic sealing diameter) are substantially the same size, so little or no hydraulic net axial force acts on the seal carrier, leaving it free to move laterally in response to shaft

¹ For more information on spiral failure and its prevention, see Leonard J. Martini's 1984 book "**Practical Seal Design**".

motion. The pressure-induced radial deflection shown in Figure 3 must be taken into consideration when designing such seal carriers.

In Figure 2, the pressure-balancing face seal exerts a downward compressive force on the seal carrier, which tends to open the extrusion gap of the face seal. Some designers may wish to intentionally include a slight amount of upward force imbalance to close the face seal extrusion gap. When a bushing is used to define the journal bearing, the bushing should be a shrink fit, and the journal bearing bore should be machined after installation. The shrink fit needs to be tight enough to keep the bushing from spinning with the shaft across a range of temperatures.

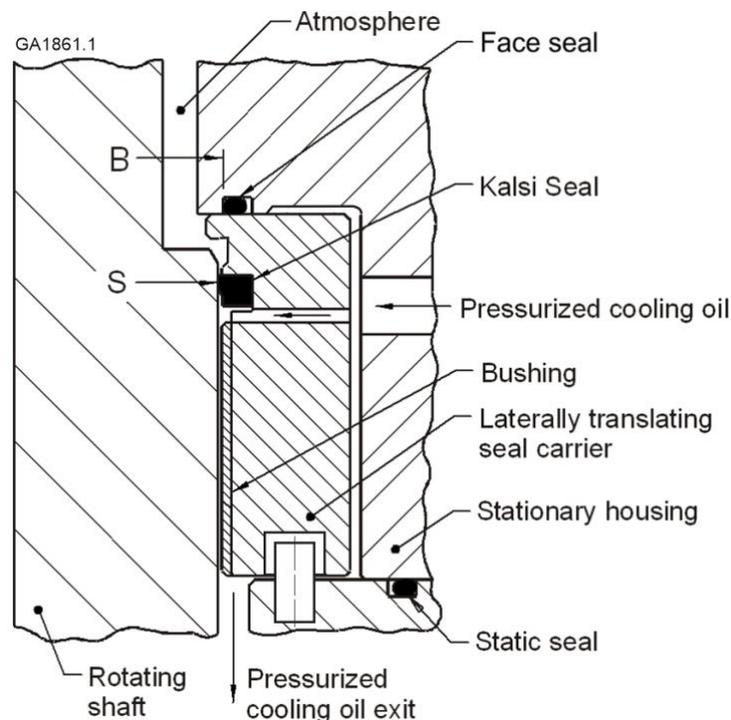


Figure 2

Force-balanced laterally translating rotary seal carrier (stepped)

The force-balanced laterally translating seal carrier imposes equal and opposite hydraulic forces on the seal carrier to eliminate axial hydraulic thrust (Expired U.S. Patent 5,195,754). The force balance allows the seal carrier to move laterally in response to shaft offset. This dramatically improves high-pressure seal life by reducing extrusion damage and by preventing heavy radial loading between the seal carrier and the shaft. This type of carrier can help RCD designers fulfill the API dynamic pressure rating tests at relatively high pressure. If desired, a pump can be used to circulate the oil (as shown) to cool the shaft and thereby prolong the life of the rotary seal. In the absence of a pump, spiral grooves can be incorporated in the bore of the journal bearing bushing to encourage oil movement. To prevent rotation of the seal carrier, it is important to provide a means for anti-rotation between the seal carrier and the surrounding structure, such as the anti-rotation pin shown here.

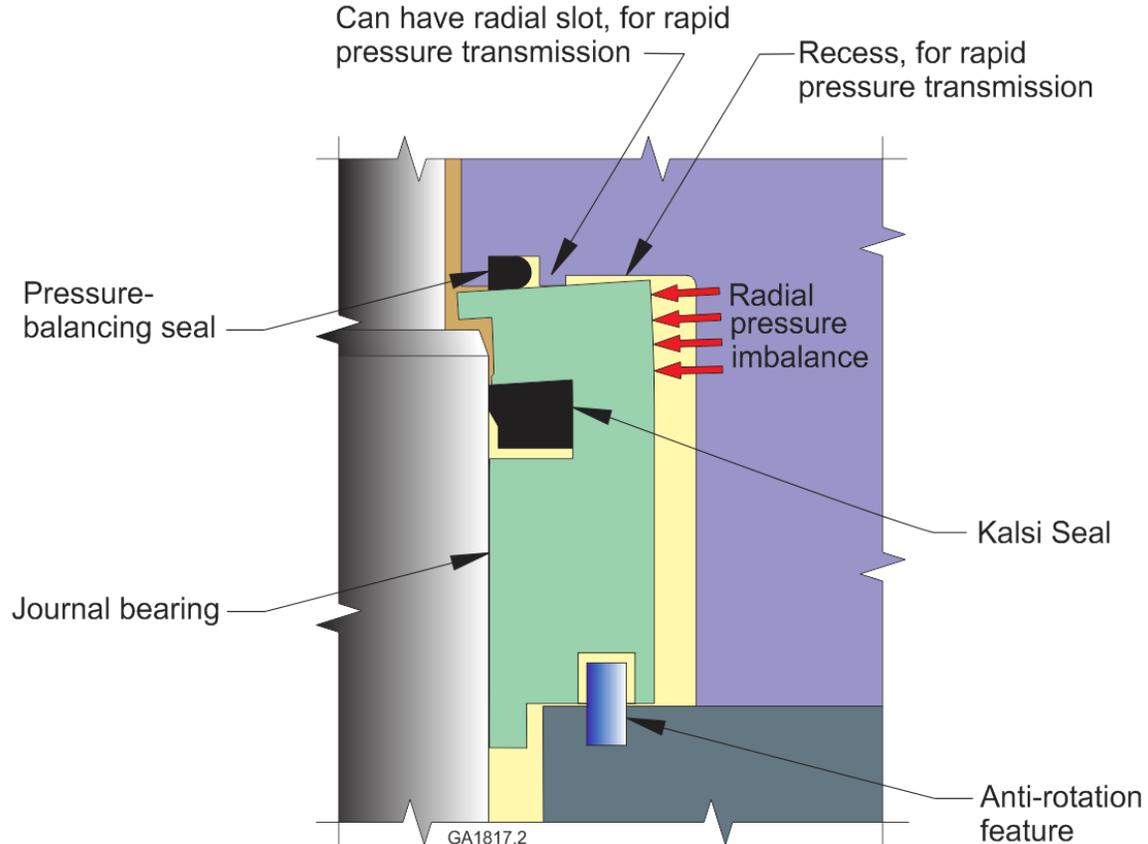


Figure 3

Seal carrier deflection due to radial pressure imbalance

The portion of a laterally translating high-pressure seal carrier between the rotary seal and the pressure-balancing face seal experiences a radial pressure imbalance that causes an inward deflection of the seal carrier. The outer surface area of the seal carrier is larger than the inner surface area. This also causes inward deflection, because the area difference produces a radial force imbalance even where the pressure acting on the inner and outer surfaces is identical. These pressure related deflections are important to consider when designing the journal bearing fit, the extrusion gap fit, and the axial fit of the seal carrier with respect to the surrounding support structure. This drawing depicts the deflection of the seal carrier using exaggerated scale. The rotary shaft should also be evaluated for pressure induced dimensional changes.

This drawing shows a recess that is located radially outward of the pressure-balancing seal, to ensure rapid transmission of pressure to the upper end surface of the seal carrier. The remaining area of the narrow seal carrier end surface must be large enough to accommodate any intentional or unintentional upwardly acting axial force imbalance. This narrow surface can have radial slots to speed pressure transmission to the pressure balancing seal. If pressure reversals are possible, such radial slots should be machined with a ball end mill, and should extend close to, but not actually break into, the groove for the pressure retaining face seal.

The seal carrier pocket that receives the anti-rotation pin must have enough lateral clearance with the pin to accommodate the lateral motion of the seal carrier. Size the anti-rotation pin to withstand the breakout torque of the journal bearing and the rotary shaft seal.

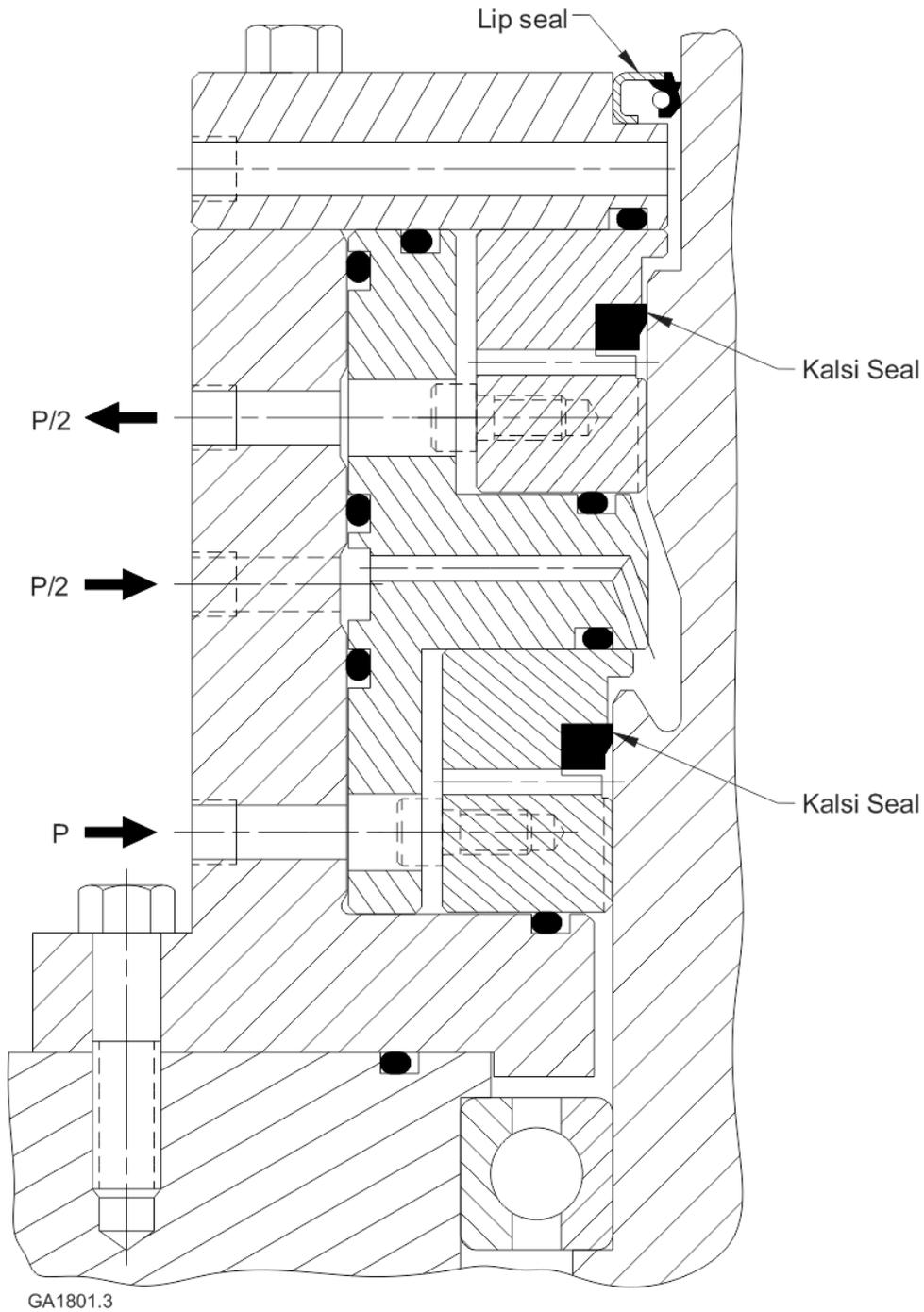


Figure 4

Pressure-staged laterally translating seal carrier arrangement

Originally developed for oilfield rotary control device (RCD) sealing, this laterally translating seal carrier arrangement divides the lubricant pressure P across two Kalsi Seals[®] using pressure staging. The radial holes in the seal carriers here (and on the chapter cover) help to assure that

lubricant reaches the level of the Kalsi Seals during the initial lubricant filling process. (Expired U.S. Patent 6,227,547).

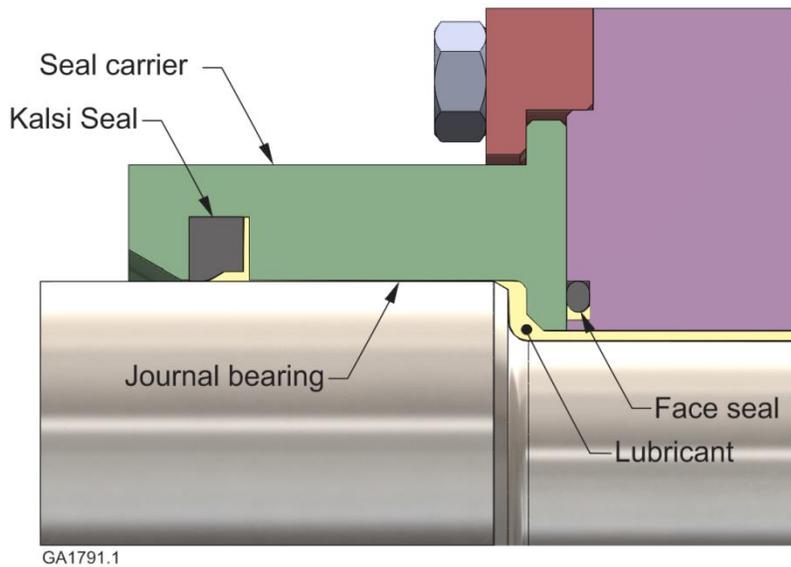


Figure 5

Force-balanced laterally translating rotary seal carrier for small diameter shafts

In this arrangement, the effective sealing diameters of the face seal and the rotary seal are identical. This causes the seal carrier to be hydraulically force-balanced in the axial direction, regardless of lubricant pressure. This allows the seal carrier to move laterally to align on the shaft. In high-pressure applications, this arrangement is only suitable for smaller diameter shafts, because the surfaces of the seal carrier that define the journal bearing bore and the extrusion gap are pressure responsive (Expired U.S. Patent 5,195,754).

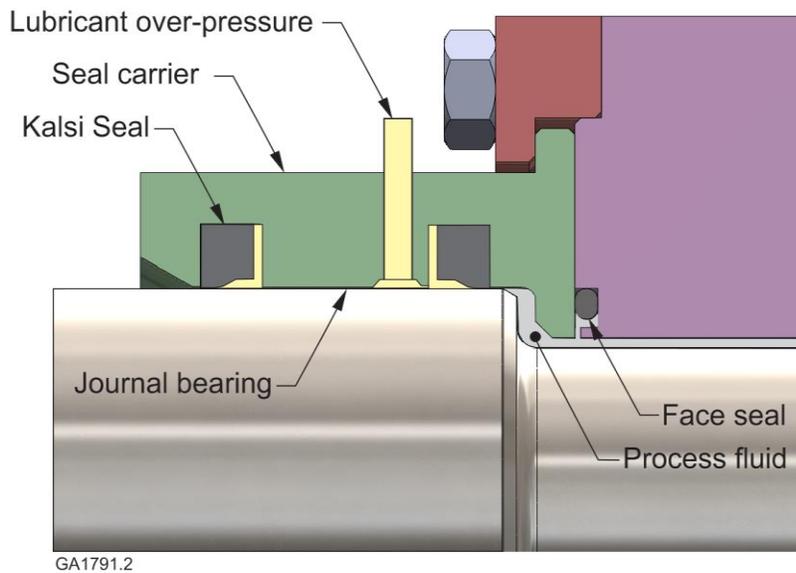


Figure 6

Force-balanced laterally translating seal carrier for retaining a process fluid

In this arrangement, lubricant over-pressure is provided between a pair of seals. The right-hand seal partitions the process fluid from the lubricant, and the left-hand seal retains the lubricant.

3. Force-balanced laterally translating seal carrier (un-stepped)

Certain applications cannot easily accommodate the stepped shaft that is necessary with the laterally translating seal carriers of Figures 2 to 6. Figure 7 shows a seal carrier arrangement that does not require a stepped shaft. The rotary seal and the outer face seal contain the lubricant, while the arrangement maintains lubricant pressure at a value greater than that of the process fluid. The pressurized lubricant and the process fluid produce opposing, unequal axially acting hydraulic forces that act on the seal carrier. A balancing pressure, applied between two face seals, causes the net axially acting hydraulic force to be negligible. This allows the carrier to move laterally in concert with lateral deflection of the rotary shaft. A bearing arrangement, such as the journal bearing shown, causes the seal carrier to closely align on the shaft (Chapter D15 provides information on journal bearing design; other types of bearings may also be suitable). The extrusion gap clearance is larger than the bearing clearance, so the extrusion gap bore cannot rub on the shaft and cause seal damage (see Chapter D7).

Various suitable means can supply the balancing pressure, such as the simple balancing piston that is shown in Figure 7. The piston can be isolated from the process fluid by a diaphragm, as shown. The piston can be mounted remotely, or as part of a small hydraulic cylinder assembly that is inserted into the machine body. In certain cases, the piston can also be mounted within the seal carrier itself. See U.S. Patent 9,316,319 for examples of alternate arrangements, including a pressure-staged variation that does not require two different rotary seal diameters. Contact Kalsi Engineering for licensing information.

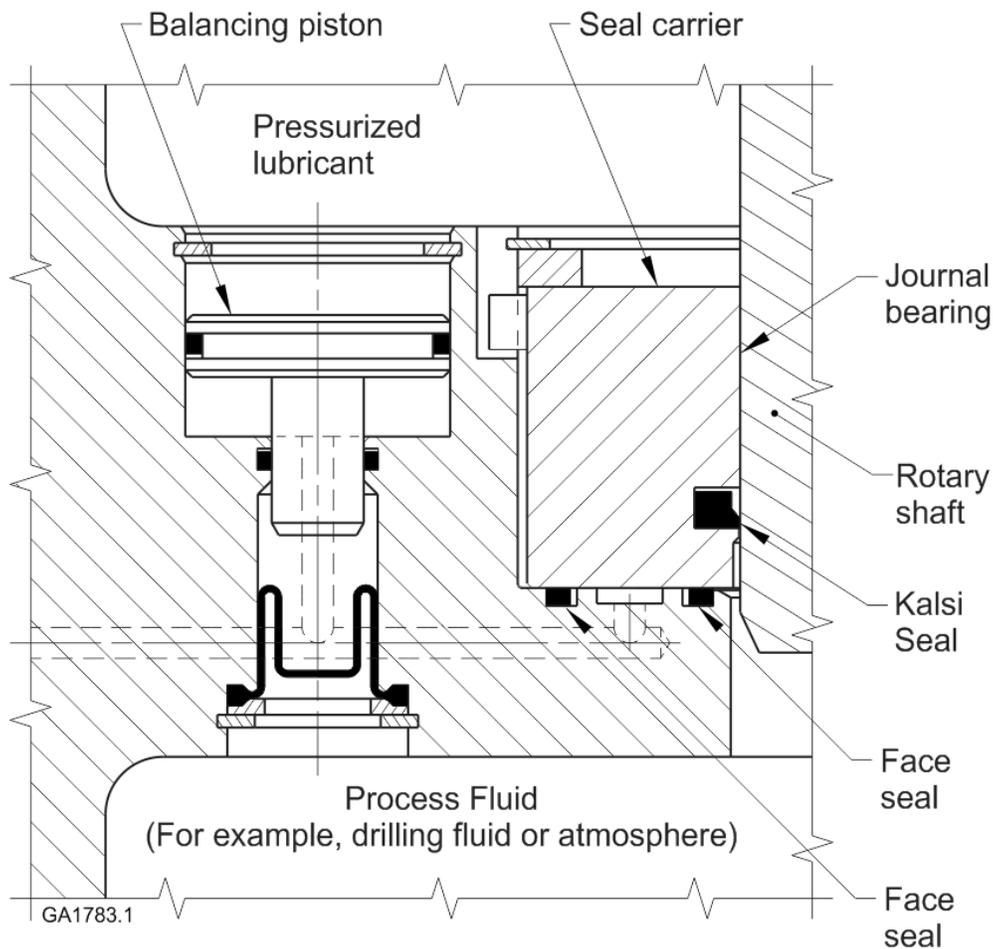


Figure 7

Force-balanced laterally translating rotary seal carrier (un-stepped)

This patented force-balanced laterally translating seal carrier uses a pressurized balancing fluid to achieve a condition where the net axially acting hydraulic force on the seal carrier is negligible. A simple stepped piston, shown, can pressurize the balancing fluid. The hydraulic force balance allows the seal carrier to move laterally in response to shaft offset. This dramatically improves high-pressure seal life by reducing extrusion damage and by preventing heavy radial loading between the seal carrier and the shaft. This figure shows how the arrangement can be incorporated into a rotating control device (RCD).

4. Combination seal carrier design

Figure 8 shows an axially force-balanced seal carrier that incorporates the operating principles of both the stepped and un-stepped seal carriers. The purpose of Figure 8 is to show that the basic operating principles of U.S. Patent 9,316,319 can be applied in various ways. The Figure 8 arrangement could be used below the bearings of a rotating control device (RCD) to contain drilling fluid at pressure P1.

The pressure P1 of the process fluid does not produce an axial force on the seal carrier. This is because the diameter of the inner face seal that defines Area 1 has the same effective sealing diameter as the rotary shaft seals. Pressure P2 is greater than pressure P1 in order to orient the right-hand rotary shaft seal for optimum abrasion resistance. Pressure P3 is created with a stepped piston.

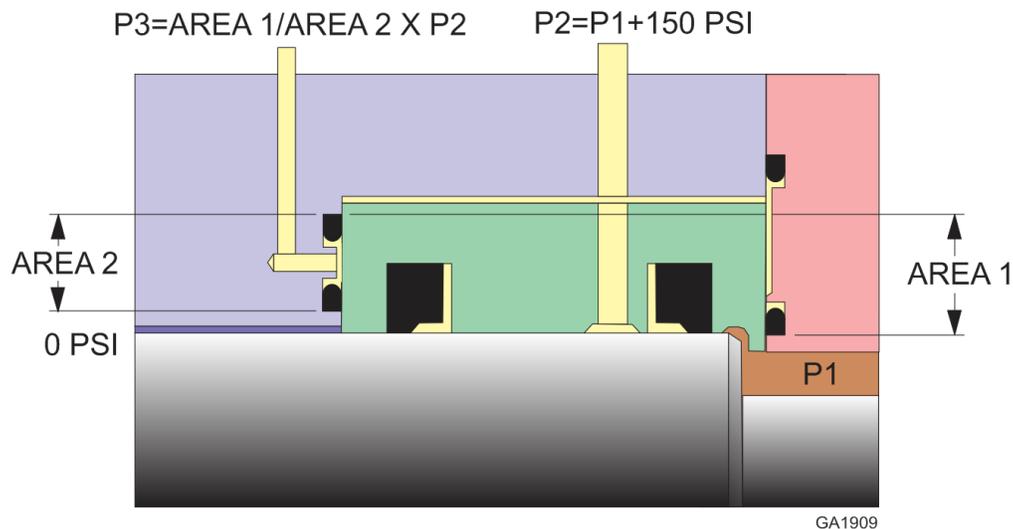


Figure 8
Combination seal carrier

This laterally translating rotary seal carrier is a combination of the stepped and un-stepped designs. The unit has atmospheric pressure on the left, and a process fluid at pressure P1 on the right. A lubricant overpressure is provided between the rotary seals at pressure P2, to orient the right-hand rotary seal against the right-hand gland wall for proper abrasion resistance. The left-hand rotary seal retains the lubricant pressure P2. The force resulting from pressure P1 acting on Area 1, is equal and opposite to the force resulting from pressure P2 acting on Area 2.

5. Simplified un-stepped seal carrier design

Figure 9 shows a patented axially force-balanced un-stepped seal carrier that incorporates a simple cross-drilled hole to provide axial force balance to allow the seal carrier to float laterally in response to runout and misalignment of the rotary shaft. As with other floating seal carriers in this chapter, this seal carrier is located laterally by a journal bearing type fit with the shaft. Because no step is required, the seal carrier shown Figure 9 can be above or below the bearings of a rotating control device (RCD) to contain the lubricant overpressure.

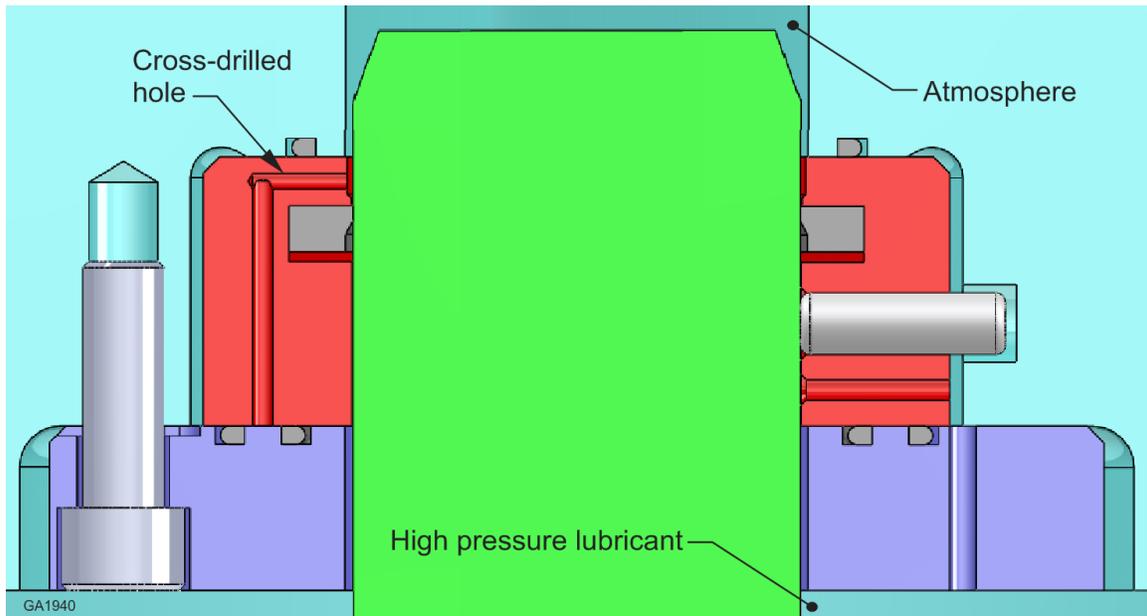


Figure 9
Simplified un-stepped seal carrier

This patented floating seal carrier does not require a shaft step to achieve axial force balance. Instead, axial force balance is achieved by incorporating a simple cross-drilled hole. As a result of the cross-drilled hole, the same pressures are applied to the same areas on opposite ends of the seal carrier. The seal carrier has a journal bearing-type relationship with the shaft. As a result, the seal is located laterally by the shaft, and follows shaft runout and deflection. Contact Kalsi Engineering, Inc. for licensing information.

6. Force-balanced articulating rotary seal carrier

In Figure 10, an elongated tube comprises the articulating seal carrier. It houses a rotary seal at one end, and a static O-ring at the other. The rotary seal centers the environment end on the shaft, and the O-ring centers the lubricant end.

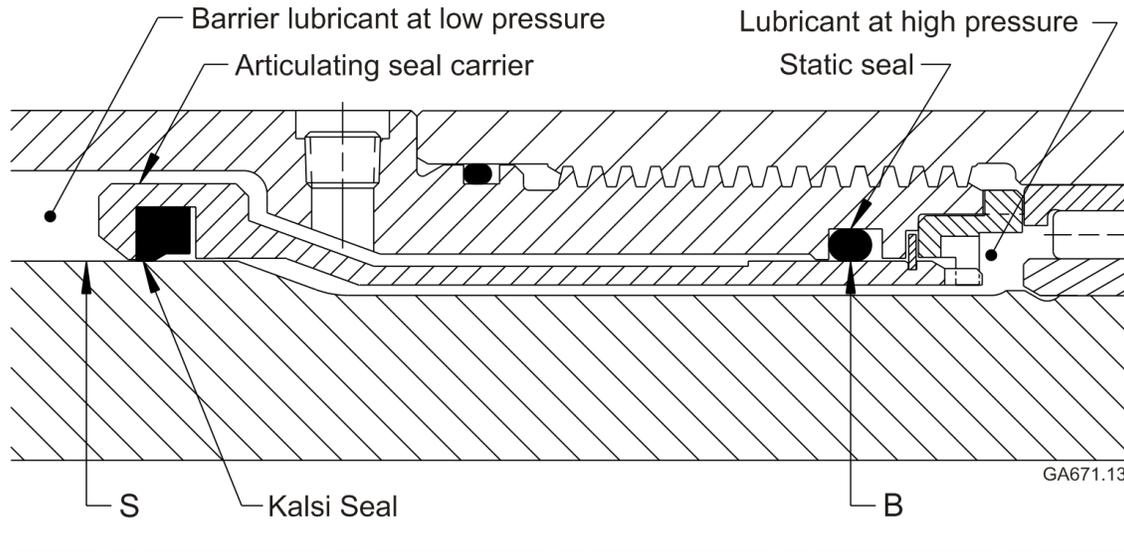


Figure 10

Force-balanced articulating rotary seal carrier

The force-balanced articulating seal carrier improves high pressure rotary seal performance by articulating in response to shaft runout and misalignment. The seal carrier minimizes extrusion damage and prevents heavily loaded contact between the seal carrier and the shaft (Expired U.S. Patent 5,195,754).

Tests show that pressurized Kalsi Seals can transfer substantial side loads from a shaft to a seal carrier. Exploiting this phenomenon causes the environment end of the seal carrier to articulate in unison with the shaft, as the lubricant end pivots on the O-ring. This permits a small extrusion gap without danger of heavy metal-to-metal contact. The small clearance immediately to the right of the rotary seal can also provide guidance if appropriately dimensioned.

Although the extrusion gaps are small at both the rotary seal and the static seal, the axial widths of the extrusion gaps are short. As a result, there is adequate mechanical clearance to permit a significant amount of articulation, and seal resiliency accommodates the motion. The shaft diameter S and static sealing diameter B are essentially the same size, so there is no net axial hydraulic force acting on the seal carrier, leaving it free to articulate with lateral shaft motion.

The articulating seal carrier easily follows rotary shaft vibration, deflection and runout, thereby minimizing relative lateral motion between the carrier and shaft, eliminating extrusion gap contact and minimizing extrusion damage. As a result, rotary seal life and pressure capacity extend beyond that of conventional implementations.

If the articulating seal carrier is used with an abrasive environment instead of a barrier lubricant, keep the rotary seal and the static seal far apart, to minimize angle change between the shaft and the seal carrier. Minimizing the angle change minimizes the amount of skew between the Kalsi Seal™ and the direction of shaft rotation, which improves abrasive exclusion.

7. Partially balanced laterally translating seal carriers

In applications with little differential pressure, partially balanced, journal bearing guided seal carriers (Figure 11) can follow lateral shaft movement. Such carriers reduce detrimental movement-induced changes in extrusion gap size and rotary seal compression. They also reduce groove wall wear by minimizing the radial sliding motion between the rotary seal and the groove wall. Such seal carriers are beneficial at partitioning seal locations, such as the RCD seal location that partitions the seal and bearing lubricant from the drilling fluid environment.

Regardless of whether a seal carrier is fully or partially balanced, in a partitioning seal application the lubricant path to the rotary seal should be as non-restrictive as possible, so that:

- Lubricant can easily reach the rotary seal during the lubricant filling operation.
- Changes in lubricant pressure reach the rotary seal with minimal delay.

In Figure 11, changes in lubricant pressure are transmitted to the rotary seal rapidly through radially oriented holes.

An anti-rotation feature must be provided to prevent the seal carrier from spinning with the shaft. In Figure 11, the anti-rotation feature is an axially oriented pin that engages a groove in the shaft. The radial clearance between the groove and the pin is sized to accommodate the lateral motion of the seal carrier. Likewise, the radial clearance between the housing and the seal carrier and between the retainer and the shaft are designed to accommodate the anticipated level of lateral shaft motion.

The surfaces of the retainer, housing, and seal carrier that experience sliding motion should be smooth, to minimize friction. The corrosion resistance of the surfaces of the seal carrier and the retainer that are exposed to the environment needs to be considered.

Lubricant overpressure conditions

Assuming the lubricant pressure is greater than the environment pressure, the primary axial forces acting on the partially balanced seal carrier of Figure 11 are:

- The compressive force of the face seal, acting to the right.
- The differential pressure between the lubricant and the environment, acting over the annular area between the face seal and the dynamic sealing diameter of the rotary seal. This force acts to the left.

These forces partially cancel one another out, however the axial force of the face seal can be difficult to predict.

Balanced pressure conditions

In partitioning seal applications where the pressure of the seal and bearing lubricant is balanced to the environment pressure with a diaphragm, the differential pressure acting across the seal carrier is essentially zero, and the primary force acting on the seal carrier is the compressive force of the O-ring, acting to the right. In balanced pressure conditions, consider using an Axially Constrained Kalsi Seal™ as the rotary seal, because such seals are specially designed to inhibit the skew-induced wear associated with balanced pressure conditions.

Reducing sliding friction

If desired, sliding friction can be reduced, to reduce the radially oriented journal bearing load between the seal carrier and the shaft. For example:

- A low-friction treatment, such as a diamond coating, can be applied to the sliding faces of the seal carrier, the retainer, and the housing.
- If desired, the face seal can be treated with the Kalsi Engineering low friction rubber treatment.

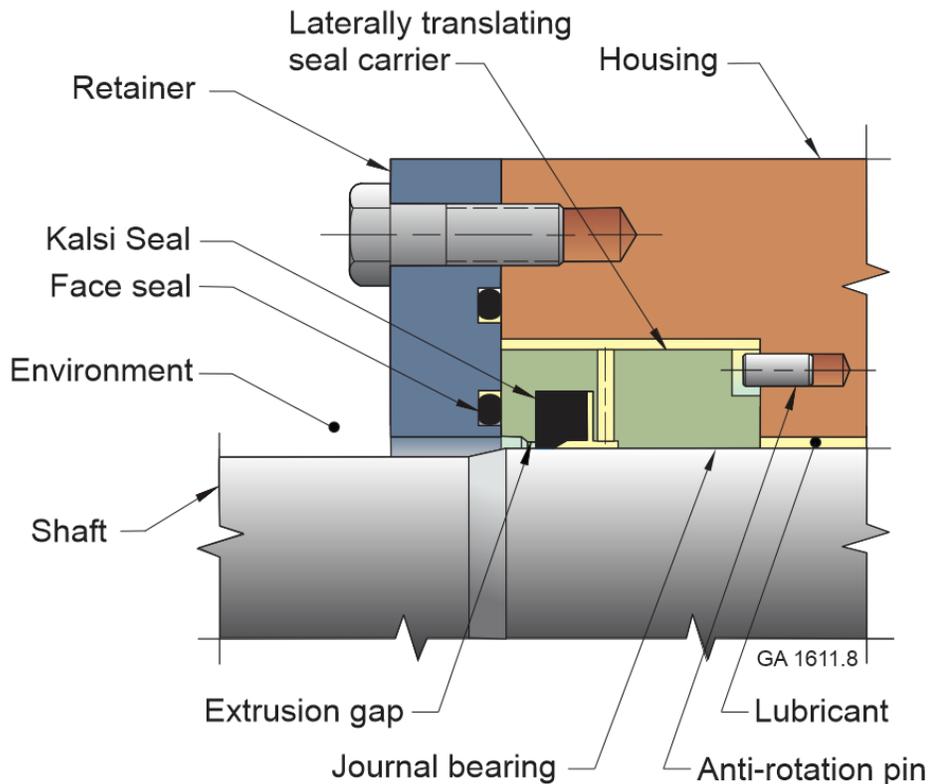


Figure 11

Partially balanced rotary seal carrier for low differential pressure service

The partially balanced laterally translating seal carrier improves low-pressure rotary seal performance by moving in response to shaft offset. This maintains rotary seal compression in a useful range and prevents heavy metal-to-metal loading between the seal carrier and the shaft. The seal carrier is designed to allow lubricant pressure changes to transmit rapidly to the Kalsi-brand rotary shaft seal, and to help lubricant reach the seal during the filling process. Size the anti-rotation pin to withstand the breakout torque of the journal bearing and the rotary shaft seal.

8. Extrusion gap considerations

Introduction

Some laterally translating seal carriers are used in high differential pressure conditions, and some are used in low differential pressure conditions. Some are used with clean environments, and some are used with highly abrasive environments. These conditions influence design choices for the extrusion gap width and the extrusion gap radial clearance. See Chapter D7 of this handbook for the latest published recommendations.

As a general overview:

- Smaller radial extrusion gap clearance is typically used with higher differential pressure, to minimize rotary seal extrusion damage.
- In abrasive environments, the axial width of the extrusion gap should be minimal, to reduce third body wear of the rotary seal.
- In low differential pressure conditions, the radial extrusion gap clearance is typically increased, to reduce third body wear of the rotary seal.
- In high differential pressure conditions with a clean environment, the extrusion gap can be made as small as practicable, to minimize rotary seal extrusion damage.
- The seal carrier bore that defines the extrusion gap should be larger than the journal bearing bore, so that the bore does not drag on the shaft.

9. Designing the journal bearing

Chapter D15 provides information on journal bearing design for applications such as laterally translating seal carriers. The journal bearing length needs to be sized to carry the expected lateral bearing load. Consider all relevant lateral loads, such as:

- Breakout friction of the face seal(s).
- Friction from axially imbalanced hydraulic force that may be present.
- Friction from axial compression of the face seal(s).
- The weight of the seal carrier, and any lateral g-force that may be present.