Chapter E1

Using Kalsi Seals in rotating control devices

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1. Introduction

A rotating control device[1] (RCD) reduces formation damage in oilwell drilling (compared to overbalanced drilling) by maintaining the pressure of the annular fluid column of drilling mud at a pressure below, or comparable to, that of the reservoir. The reduction in formation damage helps to optimize the production potential of the well. Drilling with an underbalanced pressure condition allows the evaluation of well effluents while drilling. It also reduces differential sticking, and allows less expensive drilling fluids to be used.

Early versions of Kalsi-brand rotary seals began to be used in RCD's starting in 1991. Since then, a number of advances in technology enable our seals to operate in more adverse RCD sealing conditions, including higher pressure, higher speed, less cooling, lower viscosity lubricants, and less complicated lubricant supplies.

2. Pressurized lubricant versus gravity fed lubricant

Prior to the year 2014, Kalsi Engineering only offered rotary seals for RCDs that use a pressurized seal lubricant. In 2014, Kalsi Engineering completed development of seals that are appropriate for gravity fed seal lubricant, where the drilling fluid pressure can be up to 1,000 psi greater than the pressure of the seal lubricant.

As a result of the new seal technology, this chapter now includes a brief section (Section 3) on RCD's that use gravity fed lubricant. Other sections of this chapter have been updated to clarify whether information is applicable to lubricant overpressure type RCDs, gravity fed lubricant-type RCDs, or both.

3. Kalsi Seals for RCD's with gravity fed seal lubricant

Kalsi Engineering has developed two new types of rotary seals for applications like economy RCDs, where the drilling fluid pressure is greater than the pressure of the seal and bearing lubricant. One of these rotary seals is an all-elastomer chamfered enhanced lubrication seal (Chapter C15) for 500 psi service, and the other is a new type of composite grooved seal for 1,000 psi service. We have tested both seal types against abrasives at relatively high surface speeds for durations that exceed the testing duration described in the dynamic pressure rating test portion of API specification 16RCD.

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1 Also known as rotating heads, rotary blowout preventers, rotating blowout preventers, rotating drilling heads, rotary BOPs, rotary control devices, and rotating diverters.

Advantages and disadvantages

The rotary seals in RCDs that supply a pressurized seal lubricant can operate at higher well pressures than in RCDs that use a gravity fed lubricant. At the same time, RCDs that provide a pressurized seal lubricant are too complicated and expensive for many jobs.

Testing of the all-elastomer seals with gravity fed lubricant

As described in Chapter C15, the all-elastomer, Chamfered Enhanced Lubrication Seals have been tested against 450 to 500 psi drilling fluid for 300 hours at 540 feet/min, and were lubricated by an ISO 150 viscosity grade lubricant at 0 psi that was maintained at 162°F by coolant circulation.

The testing was performed with 0.010” radial extrusion gap clearance on both sides of the seal. The size of the extrusion gap was not critical to seal performance, because there was no evidence that the 500 psi pressure differential caused enough radial deformation to expose the seal body to the extrusion gap clearance.

The breakout torque of Chamfered Enhanced Lubrication Seals is relatively high because they have a relatively wide dynamic lip. We recommend that they be purchased with the low friction treatment option when used as RCD seals.

Testing the composite grooved seals with gravity fed lubricant

The composite grooved Kalsi Seals have been tested against 1,000 psi drilling fluid for 100 hours at 540 feet/min, and were lubricated by an ISO 150 viscosity grade lubricant at 0 psi that was maintained at 162°F by coolant circulation.

The testing was performed with 0.010” radial extrusion gap clearance on the lubricant side of the seal, and 0.065” clearance on the drilling fluid side of the seal. The low pressure end of the test seals is undamaged, and there is no indication that such a small extrusion gap clearance is required. More testing is required to determine the level of sensitivity this type of seal has to extrusion gap clearance. Until such testing is completed, some designers may wish to implement these seals with a floating seal carrier or a floating backup ring arrangement (Chapters D16 and D17, respectively). With the floating backup ring, a diaphragm or other device is required to partition the balancing fluid from the drilling fluid.

Although specific breakout torque data is presently unavailable for the composite grooved seals, the breakout torque will be far less than conventional all elastomer Kalsi Seals because of the low friction characteristics of the dynamic lip material and because of the reduced lip loading associated with the grooved seal. The composite grooved Kalsi Seal can likely be designed to fit existing RCD seal grooves.

4. Pressurized lubricant systems

Lubricant overpressure systems

The conventional approach to implementing Kalsi Seals in a rotating control device is to provide a lubricant supply that maintains the lubricant pressure at a value that is greater than the fluctuating drilling fluid pressure (Figure 1). The purpose of the lubricant overpressure system is to properly orient the mud-to-oil partitioning seal against the mud-side gland wall for good abrasive exclusion. In active RCD designs, the differential pressure may also be used to activate the packing element.

Chapter D11 describes various types of pressurized lubricant supplies. Of these, oilfield industry literature indicates that systems with computer-controlled pressure are successful in RCDs, and maintain the lubricant pressure approximately 300 psi above the drilling fluid pressure. Computer controlled systems also have the advantage of a large lubricant reservoir, which is good from a lubricant cooling standpoint, and for accommodating the increased hydrodynamic pumping related leakage of Enhanced Lubrication Seals (Section C5). Wintertime operating conditions may require lower viscosity lubricants or lubricant heaters, to facilitate the lubricant circulation that is employed in computer controlled systems.

A proposal for a very simple pressurized lubricant system

In passive RCD designs, where the packing element is energized by interference with the drill string (i.e. stretch) and the pressure of the wellbore, a lubricant overpressure system is a complexity that is sometimes difficult to justify. One alternative would be to axially spring load the Kalsi Seal that partitions the drilling fluid from the seal and bearing lubricant, and use a diaphragm or bladder to balance the seal lubricant pressure to the drilling fluid pressure. A diaphragm or bladder has very little hysteresis, which will make the pressure of the seal lubricant substantially the same as the pressure of the drilling fluid. The axial spring load of the partitioning seal can be provided with a circle of coil springs, ad described in Chapter D9.

The Figure 1 schematic shows RCDs with pressurized lubricant systems

Figure 1 is a schematic that illustrates two different ways to arrange rotary seals in a passive oilfield RCD. The heart of the assembly is a rotating elastomeric packing element that seals around the rotating drillstring. The packer element is mounted on a bearing guided rotating shaft within a stationary housing. Rotary seals partition the drilling fluid from the lubricant, retain the lubricant, and withstand the pressure difference between the drilling fluid and the atmosphere.

Due to scale, the seal carriers in Figure 1 are highly schematic, and do not represent the axially force-balanced, laterally translatable seal mounting arrangements that are actually recommended for use in RCDs that have pressurized lubricant systems.

In both images of Figure 1:

- The partitioning seal partitions pressurized drilling fluid from the pressurized seal lubricant, and the high-pressure seal retains the pressure of the seal lubricant.
- If the partitioning seal is axially spring loaded, the pressure of the pressurized lubricant could be balanced to the pressure of the drilling fluid using a bladder or diaphragm arrangement.
- If the partitioning seal is not axially spring loaded, the pressure of the pressurized lubricant is pressurized to a value that is greater than the pressure of the drilling fluid in the wellbore.
- The lubricant is preferably circulated for cooling purposes, extracting heat generated by the seals and bearings.

In the left-hand image of Figure 1, oppositely facing Kalsi Seals are mounted above and below the bearings, and a pressurized lubricant is introduced between the seals. This arrangement has the disadvantage of pressurizing and expanding the bearing housing, which decreases bearing guidance of the rotating shaft.

In the right-hand image of Figure 1, oppositely facing Kalsi Seals are mounted below the bearings, and a pressurized seal lubricant is introduced between the seals. This arrangement has the advantage of isolating the bearing housing from pressure, which helps to maintain bearing guidance of the rotating shaft. A third rotary seal, at the top of the unit, retains the bearing lubricant and protects the bearings from environmental contaminants. If the bearing lubricant is not pressurized, this upper seal can simply be a spring energized lip seal. If desired, pressure can be staged across the middle and upper rotary seals by introducing the bearing lubricant at a pressure that is about half that of the seal lubricant. Pressure staging requires that the upper seal be a type capable of withstanding significant differential pressure..

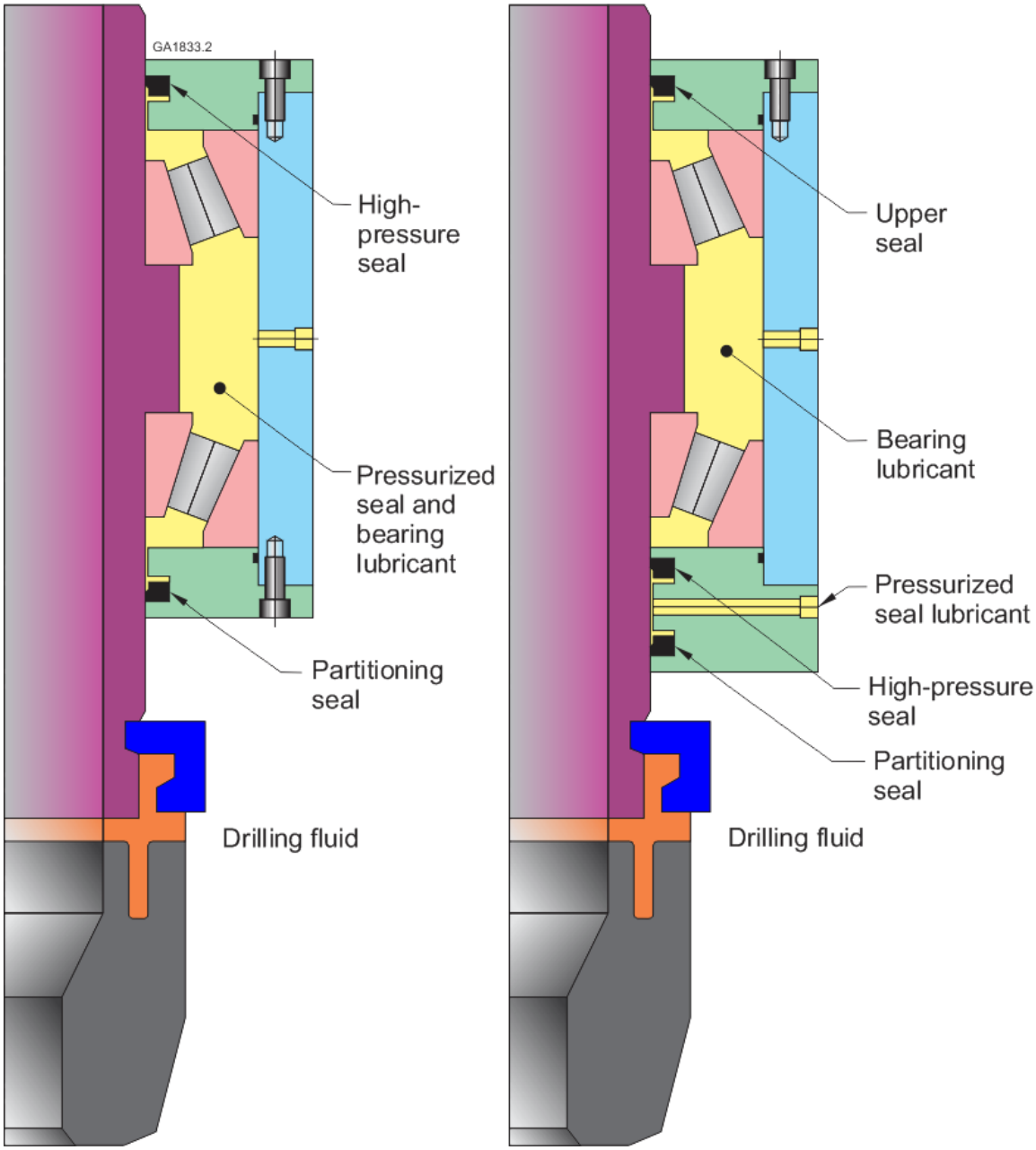

Figure 1

Schematic of rotary seal locations in an RCD using pressurized seal lubricant

This schematic of a passive RCD illustrates the rotary seal locations in an RCD that uses a pressurized seal lubricant. Due to scale, the schematic does not illustrate the laterally translating seal support mechanisms (Chapters D16, D17) that are ordinarily recommended for this application. The seal lubricant is pressurized to a value equal to or greater than the pressure of the drilling fluid. The lubricant over-pressure, or axially acting springs, hold the partitioning seal flat against the lower wall of the seal groove, to prevent skew-induced wear. The high-pressure seal withstands the pressure difference between the lubricant pressure and the atmosphere.

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2. Adverse conditions encountered in RCD sealing

The rotating control device (RCD) presents many difficult rotary sealing challenges, including:

- Large sealing diameter
- Large manufacturing tolerances
- Large assembly clearances
- Limited axial space for the rotary seals
- Misalignment and runout due to severe mechanical loads
- Pressure induced breathing of large housing components
- Significant seal and bearing generated heat
- Large differential thermal expansion
- High differential pressure
- High surface speed

3. Maintaining a suitable high-pressure extrusion gap in RCDs with pressurized lubricant

Background information

Properly implementing Kalsi Seals in high differential pressure applications requires meeting two basic extrusion gap requirements (Chapter D7):

1. The radial extrusion gap clearance must be small to control seal extrusion, and
2. Heavily loaded metal-to-metal contact at the extrusion gap must be avoided.

These two requirements are difficult to meet simultaneously with rotary shafts that have high side load and deflection. When lateral shaft motion exceeds radial extrusion gap clearance, the extrusion gap bore becomes a de-facto radial bearing and generates seal-damaging heat. As a result, the seal experiences a lowered modulus of elasticity, which lowers its 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 RCD shaft and housing, thereby increasing the extrusion gap, roughening the shaft, and damaging (burring) the critical extrusion gap corner on the low-pressure side of the seal. If relative axial motion occurs due to assembly clearances and

component elasticity, then damage can result to the RCD 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 seal extrusion damage.

If the radial extrusion gap clearance is too large, then the differential pressure causes the seal to protrude into the extrusion gap. Runout and pressure breathing can flex and destroy the protruding material, leaving a jagged seal edge that interferes with optimal seal lubrication. The differential pressure causes more protrusion, and the damage cycle eventually destroys the seal.

Description of the problem

A number of factors prevent a small shaft-to-housing extrusion gap in conventionally designed large diameter equipment such as RCDs. Manufacturing tolerances are necessarily large,[2] which directly affects the size of the extrusion gap. Large manufacturing tolerances also increase bearing internal and mounting clearances, thus permitting increased shaft runout and misalignment. Large components are often subject to significant elastic deformation when exposed to high pressure or large mechanical loads. Significant dimensional variability from differential thermal expansion caused by seal and bearing heat is also a concern. Such dimensional variability can have a dramatic effect on assembly clearances and bearing internal clearances, which can permit large dynamic runout and articulation of the shaft, and can cause large variations in the radial extrusion gap clearance. As a result, in large diameter equipment such as rotary control devices, if the extrusion gap is sized for useful high-pressure extrusion resistance, *then it is impossible to guide the shaft so precisely that it will not rub on the housing at the extrusion gap, without the use of a laterally translatable seal assembly*.

Description of the preferred solution

The solution for misalignment and pressure breathing issues, like those described above, lies in using laterally translating seal assemblies. Chapters D16 and D17 address these design issues, and describes solutions that significantly extend rotary seal performance, compared to conventional non-translating designs. These laterally translating arrangements provide the small radial extrusion gap clearance necessary for optimum rotary seal operation in pressurized lubricant systems, while preventing the high frictional heat generation that can occur between the rotary shaft and a conventional seal carrier.

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2 Figure 2.11 of the book "**Technical Drawing**", Seventh Edition (Macmillan Publishing Co.), provides total tolerance recommendations for diameters up to 21 inches (533.4 mm) for various machining methods. Divide total tolerance by two for bilateral tolerance.

We strongly recommend laterally translating seal assemblies for Kalsi Seals that are used in rotating control devices. If possible, the partitioning seal should be mounted in a laterally translating seal carrier arrangement (Chapter D16).[3] The high pressure seal can be mounted in either laterally translating seal carrier arrangement (Chapter D16) or a laterally translating backup ring arrangement (Chapter D17). The laterally translating backup ring arrangement permits a smaller extrusion gap clearance, and for this reason is superior to the laterally translating backup ring arrangement for high pressure sealing. When the laterally translating backup ring arrangement is used in an RCD, an outboard seal of some type may be required to protect the journal bearing surface of the backup ring.

Possible alternate solutions when laterally translating assemblies cannot be used

Existing equipment may not accommodate the use of laterally translating seal assemblies, and may have relatively large extrusion gap clearance to accommodate shaft runout, misalignment, and vibration. Consider using plastic lined Kalsi Seals or Extra Wide Kalsi Seals with the low friction treatment in such situations, to have the best chance of bridging larger extrusion gap clearances.

5. Heat dissipation in RCDs

Dissipation of seal and bearing generated heat is a matter of significant concern in many types of equipment because high temperatures negatively impact seal pressure capacity and life. In large diameter, high pressure equipment such as rotary control devices, high surface speed increases the concern. Chapter D8 provides general information about heat transfer considerations. While third party patents protect certain approaches to heat dissipation in rotary control devices, expired patents mention other approaches.[4]

Our thermal analysis of rotary control devices indicates that circulation of a low-pressure coolant immediately outboard of the high pressure rotary seal is very effective at controlling seal temperature. This arrangement requires a low pressure outboard seal, a small pump, and a heat exchanger. In our analysis, even a coolant flow rate as low as one gallon per minute was very effective at minimizing seal temperature.

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3 A partially balanced seal carrier may also work. The use of a custom O-ring can bring the axial pressure load acting on the carrier within the range of axial force needed to compress the O-ring.

4 For examples of patents that mention fluid circulation in rotary control devices, see US Patents 4,143,881, 4,383,577, 5,178,215, 5,224,557, 5,588,491, 6,227,547, and 7,836,946.

Seal generated heat

Seal generated heat is a function of running torque and rotary speed. Among the various types of Kalsi Seals used in pressurized lubricant type RCDs, seals with enhanced lubrication wave patterns have the lowest running torque.

6. Seal breakout torque

Rotary seal breakout torque can be a concern in passive pressure control devices, because they may depend on friction between the packer and drillstring to overcome seal and bearing breakout friction.

Among the various types of Kalsi Seals used in pressurized lubricant type RCDs, plastic lined Kalsi Seals have the lowest breakout torque. The breakout friction of Kalsi Seals with elastomeric lips can be reduced significantly with our low friction (LF) treatment. See Chapter C12 for information on the treatment, and for breakout torque test data.

In our 7 day, 1,000 psi room temperature breakout torque tests, seals with -106 construction were used as the baseline. Seals with the -106 construction *and* the low friction treatment had about 56% of the breakout torque of the baseline seals, and seals with the -307 plastic lined construction had about 32% of the breakout torque of the baseline seals. The breakout torque of -303 plastic lined seals was only slightly greater than -307 seals. A low viscosity lubricant, Aeroshell 560, was used to assemble the tests.

7. RCD seal selection for RCDs with pressurized lubricant

The pressure retaining seal

While several types of Kalsi Seals are used as pressure retaining seals in rotating control devices, not every type of Kalsi Seal is suitable for sealing high differential pressure with the relatively low-viscosity lubricants that such devices may use. With 0.007” (0.18 mm) radial extrusion gap clearance, standard width Enhanced Lubrication Kalsi Seals are suitable for 1,500 to 2,000 psi (10.34 to 113.8 MPa) operation with lubricant viscosities as low as an ISO 32 viscosity grade, and can handle greater pressures with increased lubricant viscosity. Enhanced Lubrication Seals run much cooler than Wide Footprint Kalsi Seals, and are available in extra-wide dynamic sealing lip widths.

Enhanced Lubrication Seals have greater hydrodynamic pumping related leakage than Wide Footprint Seals, particularly in conditions with lower operating pressure or low operating temperature. It is important to design the lubricant supply system with a

sufficient volume capacity. Figure 2 shows a dual seal arrangement where the outer seal captures leakage of the inner seal, and then returns it to the lubricant reservoir. For achieving the lowest breakout and running torque, the outboard seal can be a simple spring loaded lip seal.

We have tested PN 682-5-303 extra wide plastic lined seals in conjunction with a floating backup ring (Chapter D17) that simulated the 0.008" diametric clearance that a 10" floating backup ring would require. The lubricant pressure was 3,000 psi, and the shaft runout was 0.010" FIM. One test completed the scheduled 200 hours duration, and another completed the scheduled 300 hours. The rotary seals were still effective at the conclusion of the tests.

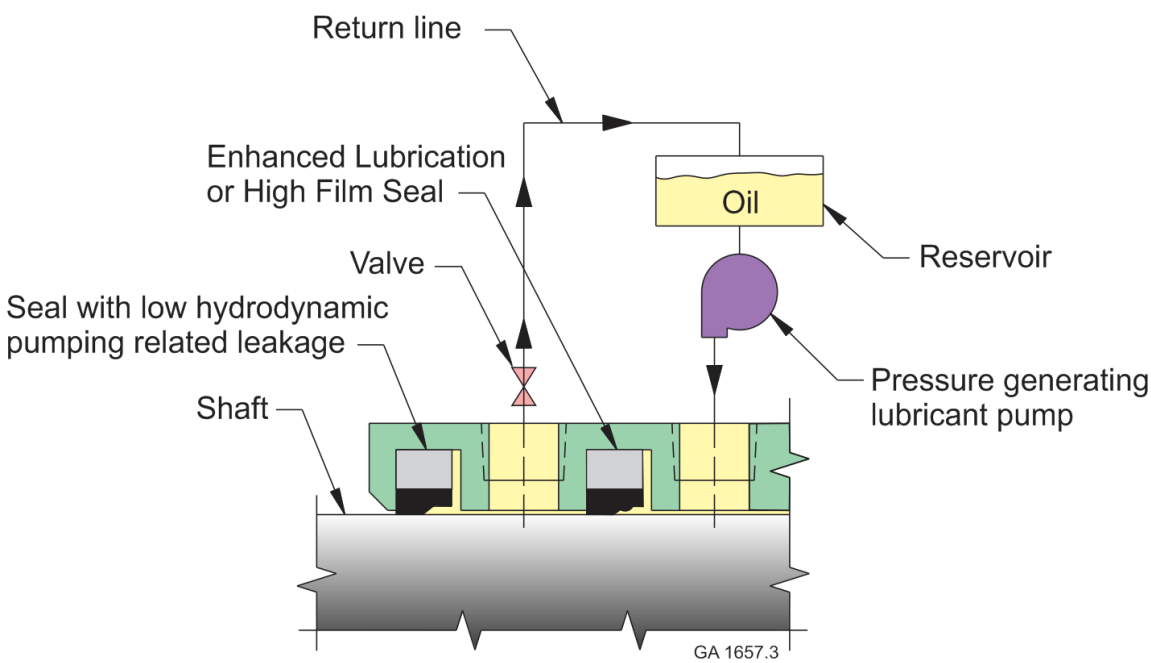

Figure 2

Redundant seal arrangement for rotary control devices

In some surface applications such as rotary heads and rotary control devices, a pump generates lubricant pressure equal to the process fluid pressure, in order to help to exclude the process fluid from the bearing lubricant. In such applications, using a low leakage seal outboard of an Enhanced Lubrication or High Film Kalsi Seal can provide redundancy and reduced seal-generated heat, as this figure shows schematically. The inboard rotary seal retains the lubricant pressure, with minimal seal-generated heat. The outboard rotary seal runs with minimal seal generated heat at low differential pressure, and captures the relatively high hydrodynamic pumping related leakage of the inboard seal. If the inboard seal eventually fails, then the operator closes the valve and continues to operate using the outboard seal to contain the lubricant pressure.

8. Subsea devices

Some systems, such as subsea devices, have one lubricant retention seal that excludes a pressurized environmental fluid and an opposite seal to exclude a variable pressure process fluid. In these systems, we recommend pressure compensating the lubricant to both fluids; this will keep the lubricant balanced to whichever is the greater of the two fluid pressures.

9. Lubricant considerations

Figure 1 lubricant viscosity implications

In the arrangement shown on the right-hand side of Figure 1, the seal lubricant is separate from the bearing lubricant. This means that the viscosity of the bearing lubricant can be selected based on the viscosity requirements of the bearings, and the viscosity of the seal lubricant can be optimized for the high-pressure and partitioning seals. For example, if enhanced lubrication seals are being used, the seal lubricant can be a relatively low viscosity lubricant, to minimize hydrodynamic pumping related seal leakage.

In the arrangement shown on the right-hand side of Figure 1, the rotary seals and the bearings share the same lubricant, and viscosity requirements of both must be met. For example, and ISO 150 viscosity grade lubricant may be satisfactory for the bearings, but the viscosity may be too low for some types of Kalsi Seals. For another example, an ISO 680 viscosity grade lubricant may be satisfactory for the bearings, but will cause substantial hydrodynamic pumping related leakage with enhanced lubrication seals.

Temperature considerations

Lower temperatures increase lubricant viscosity, which increases hydrodynamic pumping related seal leakage. In RCDs that circulate the lubricant through a pinch valve to control lubricant overpressure, lower temperatures can increase the lubricant viscosity to the point where circulation becomes impossible. Regardless of how the lubricant overpressure is created, wintertime conditions can increase the lubricant viscosity to the point that the lubricant pressure can no longer track the mud pressure.

Since an RCD may be used in wintertime conditions, these temperature implications require an engineered solution. Possibilities include:

- Using lower viscosity lubricants in wintertime conditions.
- Using lubricant heaters.
- In seal arrangements like the right-hand side of Figure 1, using an arctic grade, high viscosity index hydraulic fluid as the seal lubricant.
- Using higher lubricant overpressure until the equipment warms up.