Chapter E2

Using Kalsi Seals in hydraulic swivels

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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 www.kalsi.com/seal-handbook.htm.

NOTICE: The information in this chapter is provided under the terms and conditions of the Offer of Sale, Disclaimer, and other notices provided in the front matter of this handbook.
1. **Introduction to the hydraulic swivel chapter**

Sections 2 to 6 of this chapter employ schematic figures to convey the basic aspects of using Kalsi-brand rotary seals in high pressure hydraulic swivels. Section 8 covers detailed hydraulic swivel design for the highest fluid pressures and longest service life. Although this chapter focuses on multi-port hydraulic swivels, where the manifold housing ports are oriented perpendicular to the shaft ports, many of the same design techniques are applicable to straight-through, coaxial hydraulic swivel joints.

2. **What is a hydraulic swivel?**

Hydraulic swivels communicate hydraulic fluid pressure between a shaft and a housing that have relative rotation with respect to each another. Kalsi Seals utilize the hydraulic fluid for lubrication of the dynamic sealing interface. Contact Kalsi Engineering for recommendations on how to use Kalsi Seals in your swivel application.

3. **Basic hydraulic swivel design practices for Kalsi Seals**

Kalsi Seals should be implemented into a hydraulic swivel in a manner that isolates them from reversing pressure. Exposing the seals to reversing pressure is undesirable for two reasons:

- Reversing pressure produces a back and forth seal shuttling movement. Shuttling tends to lubricate the static sealing interface between the seal and the mating housing groove, making the seal more prone to circumferential seal slippage. Such slippage can damage both the static and dynamic sealing lips.

- Most Kalsi Seals are designed to operate in a particular pressure direction. Reversing pressure distorts them in ways that affect lubrication of the dynamic sealing interface.

The schematic illustrations of Figure 1 show how to isolate Kalsi Seals from reversing pressure when used in a hydraulic swivel. In the left-hand schematic, a pair of Kalsi Seals defines each hydraulic circuit. A drain port returns the hydrodynamic pumping related leakage of facing pairs of Kalsi Seals to the hydraulic fluid reservoir, and prevents the two inboard seals from pumping into a dead cavity. In the right hand schematic, the pressure in Port 1 is never greater than the pressure of Port 2. The radial holes in the shaft are recessed to prevent damage to the rotary seals during assembly.

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1 Multi-port hydraulic swivels are sometimes referred to as rotating manifolds, side port swivels, or side entry swivels.
Provide enough room between ports to allow installation and tightening of fittings and hoses that are attached to the manifold housing.

**Grit blast the bores of the seal grooves**

We recommend grit blasting the groove bore to inhibit circumferential seal slippage; see Chapter D5. Grit blasting is not practical in hydraulic swivel designs that expose the rotary seals to reversing pressure, because the back and forth seal motion would abrade the seal.

![Diagram of hydraulic swivel arrangements](image)

**Figure 1**

**Schematics of right angle, multi-port hydraulic swivel arrangements**

These schematics show two ways to protect the Kalsi Seals from reverse differential pressure when used in a right angle, multi-port hydraulic swivel. The illustration does not show the required radial bearings. The radial holes in the shaft are recessed to prevent seal damage during assembly of the swivel.

4. **Extrusion gap clearance**

The radial extrusion gap clearance between the swivel housing and shaft has a significant influence on high pressure rotary seal performance. For maximum performance, use the smallest extrusion gap that can be obtained without risk of heavily loaded housing-to-shaft contact. If heavily loaded housing to shaft contact occurs, then the resulting friction can severely damage the seals, shaft and housing. For extreme pressures, consider using the hydraulic swivel design described in Section 8.

Proper design of the extrusion gap clearance requires a review of tolerances, bearing fit, bearing internal clearance, pressure-induced shaft and housing deformation, and the potential for differential thermal expansion between the shaft and housing.
5. **Bearing guidance**

Hydraulic swivels are used in various ways. Selecting and implementing an appropriate bearing arrangement to accommodate the various design forces is the Design Engineer’s responsibility. Some of these potential forces relate to:

- Weight of the swivel components that are supported by the bearings
- Weight of associated fluid filled hoses, pipe, tubing, and fittings
- Reaction of bearing and seal torque to prevent rotation of the housing or shaft
- Hydraulic pressure imbalance
- Stiffness of high pressure hoses
- Hydraulic pressure within hoses
- Mechanical misalignment of mating machine components
- Weight of mating equipment borne by the swivel bearings
- The method of causing swivel rotation
- Differential thermal expansion between the shaft and the housing.
- Forcing misaligned metal tubing into alignment with ports

**Bearing mounting practices**

Bearing manufacturers provide literature that details practices for mounting bearings. One critical swivel design mistake is implementing wide separation between thrust-capable bearings. The bearing and seal generated heat goes into the shaft, causing the shaft to thermally expand more than the housing. If a wide separation exists between the thrust bearings, and there is little to no end play, then the axial differential thermal expansion can impose enormous axial forces that quickly ruin the bearings. In the swivel concept shown in Figure 2, the thrust-capable angular contact bearings at the lower end of the housing are close together, making them insensitive to longitudinal differential thermal expansion. The rollers of the bearing at the upper end of the shaft have a clearance fit with the shaft, making that bearing immune to longitudinal differential thermal expansion.

The bearing at the upper end of the shaft could also be a ball bearing with inner and outer races, provided that one of the races is free to slip axially to accommodate shaft thermal expansion, in accordance with normal bearing mounting practices.

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Typically, the manifold housing will be mounted to a structure and support the shaft through the bearings, or the shaft will be mounted to a structure and support the manifold housing through the bearings.
In this multi-port hydraulic swivel concept, the thrust-capable lower bearings are close together so axial differential thermal expansion between the shaft and the housing cannot bind the bearings. Because the shaft rotates relative to the load, the lower bearings are a press fit to the shaft and a slip fit with the housing. The radial holes in the shaft are recessed to prevent seal damage during assembly of the swivel. The drain prevents pressure buildup between pairs of rotary seals.
In bearings that have inner and outer races, it is common practice to mount one race with an interference fit, and the other with a clearance fit. Which race is press fitted depends on which race has relative rotation with respect to the bearing-supported load. Failure to have an interference fit on the race that needs it typically causes slippage of the race and wear of the mating component. Follow the bearing manufacturer’s mounting guidelines.

**Other attributes of Figure 2**

Figure 2 also shows a cross-drilled drain arrangement, in which a single drain accommodates the hydrodynamic pumping related leakage from all the Kalsi Seals, and then returns it to the hydraulic fluid reservoir. Orienting the drain port at the top of the swivel retains the lubricant by gravity, and effectively lubricates the upper bearing and the conventional lip-type rotary shaft seal that protects the upper bearing.

6. **Cooling hydraulic swivel seals**

Depending on rotary speed and duration, shaft diameter, differential pressure, seal type, and quantity of hydraulic circuits in a given hydraulic swivel design, coolant circulation may be necessary for optimal rotary seal life. Cooling the swivel prevents seal overheating, providing a temperature condition that is desirable from both a seal lubrication standpoint and a seal high-pressure extrusion resistance standpoint. The need for cooling increases as the speed and duration of rotation increases.

Figure 3 is a hydraulic swivel schematic that shows a convenient way to use circulating hydraulic fluid as the coolant. Low-pressure hydraulic fluid flows in at the coolant inlet, and reaches the shaft bore via cross-drilled holes. A sleeve guides the flow along the length of the shaft. Seal-generated heat transfers from the shaft to the flowing fluid. Cross-drilled holes guide the flow to a coolant drain that returns the hydraulic fluid to the reservoir.
Figure 3

Schematic illustrating a hydraulic swivel with circulating under-sleeve coolant

Coolant circulation allows higher speed operation, and promotes better seal lubrication and extrusion resistance. This schematic of a hydraulic swivel shows the use of a sleeve to form an internal cooling jacket that accommodates coolant circulation. This schematic does not illustrate the radial bearings this type of arrangement requires. This schematic assumes a rotating shaft and a non-rotating housing. In swivels that have a non-rotating shaft and a rotating housing, the coolant inlet and outlet would connect to the shaft, and no rotary seals are needed to define the coolant circuit.

Figure 3 assumes a rotating shaft and a non-rotating housing. In a hydraulic swivel with a non-rotating shaft and a rotating housing, the inlet and outlet for the circulating coolant can plumb directly into the shaft. Although Figure 3 shows the coolant sleeve used with a hydraulic swivel, coolant sleeves can apply in other types of swivels, such as side port process fluid swivels.

7. Rotary seals for high pressure hydraulic swivels

Rotary seals are the most critical component of a high pressure hydraulic swivel, because they define the hydraulic circuits between the housing assembly and the relatively rotatable shaft. The three principal sealing challenges of hydraulic swivels are high differential pressure, seal-generated heat, and the ability to lubricate in high differential pressure conditions with relatively low viscosity hydraulic fluids.
Enhanced lubrication seals (Figure 9) were developed to lubricate efficiently with low viscosity lubricants, to reduce seal running torque (i.e. seal drag), seal generated heat, and wear in the high differential pressure conditions encountered in applications such as high pressure hydraulic swivels.

Figure 4
Enhanced Lubrication Kalsi Seals for hydraulic swivels

The Enhanced Lubrication Seal facilitates the use of lower viscosity lubricants and higher pressures and speeds. The upper seal shown here has a high strength plastic liner for maximum high pressure extrusion resistance. The lower seal is a dual durometer seal, where a higher modulus elastomer is incorporated at the dynamic lip to improve extrusion resistance over single durometer seals. While dual durometer seals can be made with existing tooling that was originally made for single durometer seals, plastic lined seals require special dedicated tooling.

Enhanced Lubrication Seals are available in single durometer, dual durometer, and plastic lined configurations. In the dual durometer and plastic lined configurations, the inner part of the seal has a higher modulus than the outer part of the seal, for improved high pressure extrusion resistance. The dual durometer and plastic lined configurations further reduce breakout and running torque, and seal generated heat, while augmenting extrusion resistance. For additional information about Enhanced Lubrication Seals, see the catalog and technical section of this rotary seal handbook.

Make sure the seal material is compatible with the selected hydraulic fluid. For example, phosphate ester based fire resistant hydraulic fluids are not compatible with HNBR.

8. A modular hydraulic swivel design for extreme pressure sealing

When hydraulic swivels that provide the longest service life at the highest service pressures are required, Kalsi Engineering recommends the modular swivel design that is represented by Figures 5 to 9.
The key to the pressure capacity of this type of an arrangement is the patent-pending floating backup ring, which aligns itself on the swivel shaft while providing the minimum practicable extrusion gap clearance. The backup rings are hydraulically force balanced in the axial direction, which allows them to translate freely in the lateral direction to accommodate shaft misalignment and runout. The backup rings are also radially pressure balanced, to minimize pressure-related dimensional changes at the extrusion gap clearance. This arrangement provides the best high pressure sealing performance of any mechanical arrangement we have ever tried.

Our modular high pressure hydraulic swivel design is robust, and easy to assemble and disassemble. It also minimizes the number of precision machined surfaces, making it economical to manufacture. Unlike typical high pressure hydraulic swivel designs, there is no long housing, with precision diameters along the entire length.

**Licensing information**

Kalsi Engineering prefers to license the patented and patent pending features of the modular hydraulic swivel design with a simple unilateral license that grants permission to a specific manufacturer to manufacture, use, and sell the design, provided that it is used with rotary seals that are purchased from Kalsi Engineering. When this type of license arrangement is used, the licensing fee can be included in the price of the seals, or as a per-seal or per-swivel licensing line item, or for a part number representing a combination that includes the seal and the hardware technology license. Bidirectional licenses are also possible, but less economical, because they inevitably involve extended and expensive interaction between legal departments, which consumes time and resources, delays project completion, and inflates the licensing cost.

**Overview of the high pressure hydraulic swivel illustrations**

Figures 5 through 9 are section views of a high pressure hydraulic swivel that are taken at different angles, in order to show various internal details. Figure 5 is a section view taken through the pressure-retaining bolts. Figure 6 is a section view taken through the bearing housing bolts. Figure 7 is a section taken through the bearing lubricant/drain port. Figure 8 is a section view taken through the internal pressure porting. Figure 9 is an enlargement that show details of the internal porting that is associated with the floating backup rings.

**General arrangement of the washpipe assembly (Figures 5 to 7)**

As shown by Figure 5, the modular high pressure swivel consists of a stack of relatively simple housings that are held together by a pattern of pressure-retaining bolts, and form a pressure housing assembly. The housings are aligned to one another with axially short pilots. Due to their short length, such pilots are impossible to bind, even
when very tight piloting clearances are used. This is because only single point contact can occur at the pilot, and binding requires two points of contact.

As shown by Figure 6, the shaft is guided by rolling element bearings that are mounted in bearing housings that are bolted to the ends of the assembly. The shaft is located axially by a set of thrust bearings. The thrust bearings also locate one end of the shaft radially. Radial support at the opposite end of the shaft is provided by a radial bearing. This bearing is mounted without housing shoulders, so that it is free to slide axially within the bearing housing in response to differential thermal expansion between the shaft and the housing assembly. A bearing lubricant is retained by suitable bearing oil seals, such as the conventional radial seals that are illustrated. One advantage of having the pressure housing assembly separate from the bearing housings is that the pressure housings do not expand as a result of hydraulic pressure, and the fit between the bearing housings and the outer races of the bearings remains constant regardless of system pressures. This helps to minimize shaft runout, and thereby improve the pressure capacity and life of the rotary seals.

As shown by Figure 7, an axial oil communication hole allows bearing lubricant to pass from the thrust bearing region to the radial bearing region. The interfaces from one housing to the next are sealed with small local O-rings. This axial oil communication hole also connects to a drain that collects the hydrodynamic pumping related leakage of the Kalsi Seals, to prevent pressure buildup between the Kalsi Seals. The bearing lubricant is vented to atmosphere at the drain port. The drain port can be connected to a hose that returns hydrodynamic pumping related seal leakage to the hydraulic fluid reservoir.

**Assembly sequence of the stacked housing hydraulic swivel**

The general assembly sequence is:

1. Assemble the pressure retaining components that are held together by the pressure retaining bolts that are shown in Figure 5; i.e. assemble the pressure housing assembly.

2. Install the thrust bearings onto the shaft.

3. Install the thrust bearing housing over the thrust bearings, and capture them on the shaft with a retaining ring (as shown) or with another suitable retainer, such as an AFBMA lock nut (not shown).

4. Lubricate the inside diameters of the Kalsi-brand rotary shaft seals, and the outside diameter of the shaft, and install the shaft through the pressure housing assembly.
5. Bolt the thrust bearing housing to the pressure housing assembly.

6. Install the radial bearing onto the shaft, and capture it on the shaft with a retaining ring (as shown) or with another suitable retainer, such as an AFBMA lock nut (not shown).

7. Install the radial seal into the radial bearing housing, following the manufacturer’s recommended installation practices to ensure that the seal is squarely seated against the internal shoulder of the bearing housing.

8. Lubricate the installation path for the radial seal, and install the radial seal housing over the radial bearing.

9. Install the radial seal into the radial seal housing, following the manufacturer’s recommended installation practices to ensure that the seal is squarely seated against the internal shoulder of the bearing housing.

10. Install the radial O-ring onto the radial seal housing, and bolt the radial seal housing to the thrust bearing housing.

11. Add the bearing lubricant.

**Hydraulic circuit details (Figures 8 and 9)**

Figure 8 shows the hydraulic circuits that communicate between the housing assembly and the relatively rotatable shaft. Figure 9 is an enlarged view that shows the cross-drilled holes that communicate hydraulic pressure to the sealed areas on the back sides of the floating backup rings. The sealed area on the back sides of the floating backup rings is approximately the same size as the projected area of the Kalsi Seals. As a result, each end of the backup ring is exposed to approximately the same hydraulic force. As a result, the backup rings are substantially force balanced in the axial direction.

Figure 8 also illustrates the anti-rotation pins that prevent the floating backup rings from rotating with the shaft.

**Floating backup rings provide the minimum possible extrusion gap clearance**

The key to the high pressure performance of the hydraulic swivel assembly that is shown in Figures 5 through 9 is the use of our patent pending floating backup rings. These rings, which are axially force balanced and radially pressure balanced, are guided radially by a journal bearing-type fit with the shaft. This fit, and the radial pressure balance, allow the minimum possible extrusion gap clearance to be established, thereby achieving maximum seal extrusion resistance. The axial force balance allows the backup ring to move laterally to accommodate runout and misalignment of the washpipe, while
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avoiding heavily loaded metal-to-metal contact at the extrusion gap, and the seal-damaging heat that such contact would produce.

Backup ring design

Detailed instructions for designing the backup rings are provided in Chapter D17 of this rotary seal handbook. As shown by Figure 8 of this chapter, the anti-rotation pin can be a loose pin that is inserted from the ID of the backup ring, and retained by the shaft. The mating hole in the bulkhead housing has to be large enough to accommodate the maximum lateral and angular motion of the anti-rotation pin.

The inside diameter of the backup ring is designed to be as tight of a fit as possible with respect to the shaft, while still assuring freedom of relative rotation between the shaft and the backup ring. Design of this fit requires the designer to consider tolerances, differential thermal expansion, and pressure induced deformation. The outer diameter of the backup ring is designed to always extend radially beyond the outer force balancing O-ring gland, considering the maximum anticipated lateral motion of the backup ring and the tolerance stackup of the backup ring and the O-ring gland.

Radial pressure balance of the backup rings is accomplished primarily by the radial vent passages through the backup rings that are shown in Figure 7. If desired, additional vent passages can be provided by drilled holes that communicate with the drain holes that pass through the cyan colored bulkhead housings in Figure 7.

Shaft design considerations

The surfaces of the shaft that are contacted by the rotary seals and the backup rings are protected by a ground and polished tungsten carbide coating, per the normal practices described in Chapter D2 of this rotary seal handbook. Annular grooves are provided at the hydraulic circuits to ensure efficient flow as the shaft rotates, as shown by Figure 8. Installation chamfers are provided to ease the rotary seals onto the shaft, and past the annular grooves, as described in Chapter D3 of this handbook. Bearing mounting diameters are prepared in accordance with the instructions of the bearing manufacturer.

Bearing housing design considerations

The bores that receive the outer races of the bearings are prepared in accordance with the instructions of the bearing manufacturer. The thrust bearings are located axially by a thrust shoulder that is integral to the thrust bearing housing, and by the seal housing for the bearing oil seal. The bolts that retain the seal housing, and the bolts that retain the thrust bearing housing, are sized to carry the anticipated thrust loads. The thrust shoulder that is integral to the thrust bearing housing is sized to accept a tool for extracting the thrust bearings from the housing. The housing for the radial bearing does not provide a thrust shoulder for the radial bearing, in order to allow the radial bearing to slide in
response to differential thermal expansion and contraction between the shaft and the housing assembly.

The assembly that is shown, and the assembly practices that are described above, assume that the bearings are a press fit with the shaft and a slip fit with the bearing housings. The actual location of the press fit depends on whether the load rotates relative to the housing assembly, or relative to the shaft. Follow the bearing manufacturer’s recommended fitting practices, and design the assembly and assembly practices accordingly.

The bearings are selected to handle the component weight, and anticipated external loads.

**Design considerations common to the bulkhead and seal housings**

The bolts that hold the pressure housing assembly together are sized to withstand the rejection force of the internal pressure that acts over the sealed area during normal operation and during proof testing. The stacked housings that comprise the pressure housing assembly are sized to provide adequate wall thickness to accommodate the necessary bolt size, and to keep stress levels within acceptable design limits when exposed to operating pressure, and proof pressure loads.

Refer to Figure 8 for an overall view of the pressure porting. Porting details are best understood by referencing the enlarged view that is provided by Figure 9. The pressure porting includes axial ports communicating balancing pressure to the back sides of the backup rings, to provide axial force balance. This pressure is communicated through the housing interfaces via small diameter local O-rings. The use of these small local O-rings minimizes hydraulic thrust area, and thereby minimizes the pressure load acting on the pressure retaining bolts.

Several of the housing end surfaces are sealing surfaces for face sealing O-rings, and must have a suitably smooth surface finish: A 32 micro-inch AA or better surface finish is recommended. The end surfaces impact overall alignment of the housings, and must be machined parallel to one another, and perpendicular to critical bore surfaces.

The housings are aligned to one another by overlapping piloting surfaces near the OD of the housings. The MMC fit of the pilots should correspond to the MMC condition of an RC 3 class fit. The LMC fit can be looser than the LMC condition of an RC 3 class of fit, so that tolerances can be looser than RC 3 tolerances. The axial length of the overlap of the piloting surfaces should be kept short, to prevent the possibility of misalignment-related binding due to the “sticky drawer” effect. A concentricity tolerance should be provided between the housing pilots and critical interior surfaces, such as the extrusion
gap bore of the upper housing, the recess bores that receive the backup rings, the recesses that receive the rotary seals, and the smallest inside diameters of the bulkhead housings.

Preferably, the housings incorporate indexing features, to ensure that they are assembled in proper angular alignment. One practical indexing feature is the use of axially oriented indexing pins, and corresponding recesses in the mating parts. If desired, the indexing pins can be formed by socket head cap screws.

The material used to construct the swivels is selected for compatibility with the environment the swivel will be used in, and for required strength. Hydraulic swivels with rotating shafts typically incorporate some way of mounting the housing assembly to a supporting structure. The alignment between the mounted housing and any structure that the rotating shaft interacts with should be taken into consideration during setup, to prevent misalignment related side loads on the swivel bearings.

**Seal housing design**

The cylindrical bore and lubricant side wall of the recess for the Kalsi Seals are designed in accordance with the instructions for the comparable seal gland surfaces in Chapter D5 of this seal handbook.

An annular housing groove is provided between the Kalsi Seals to help ensure efficient flow as the shaft rotates. The flow ports are sized to handle anticipated flow rates, and the threaded connections on the flow ports are designed to be compatible with the mating hydraulic hoses. Provide enough room between flow ports to accommodate the wrench size that is required to tighten the fittings that will be attached, and to accommodate any valves or other devices that may be mounted on the exterior of the swivel assembly.

**Bulkhead housing design**

The cyan pressure housings are referred to as bulkheads because they receive and resist the axial force resulting from internal hydraulic pressure. Design the thickness of the bulkheads accordingly, considering both stress and deflection.

The axial depth of the recess that receives the backup ring is critical, because it controls the face-type extrusion gap clearance that the outer portion of the rotary seal is exposed to. The axial length of the backup ring and the depth of the recess are tightly tolerated, assuring that the backup ring is just a few thousandths of an inch shorter than the recess depth. These are two of the most critical dimensions of the assembly. (Other critical dimensions are the sealing diameter of the shaft, the mating inner diameter of the backup ring, and the pilot diameters between housings.)
The inside diameter of the bulkhead is designed to accommodate the maximum anticipated runout and misalignment of the shaft. The inner diameter of the groove for the inner force balancing O-ring should be sized and tolerated so the minimum wall thickness between the seal gland and the bulkhead bore is adequate to keep the stress levels within the design limits when exposed to operating pressure, and proof pressure loads. The outer diameter of the groove for the outer force balancing O-ring and the inner diameter of the groove for inner O-ring should be sized to create a projected pressure area that is substantially the same as the projected pressure area of the installed Kalsi Seal. When sizing the projected area established by the force balancing O-rings, include tolerance stackup to ensure the projected area is never larger than the projected area of the Kalsi Seal. We ordinarily design the projected area that is established by the force balancing O Rings to be a little smaller than the projected area of the Kalsi Seals, in order to create a slight axial force imbalance that is sufficient to compress the force balancing O-rings, and close the face type extrusion gap of the force balancing O-rings.

The diameter of the recess that receives the backup ring OD is designed to accommodate the maximum anticipated lateral motion of the backup ring, in MMC tolerance conditions.

**Bearing oil seals**

The bearing oil seals are typically conventional radial lip type seals, to minimize seal-generated heat. Radial seals that incorporate a dust lip should be considered for hydraulic swivels that are used in a dirty environment. In extremely dirty environments, a rotating dust cover of the type shown in our U.S. Patent 8,505,924 may be desirable to help to isolate the bearing seals from the environment.
Cross-section through the pressure retaining bolts of a high pressure hydraulic swivel

Figure 5
Figure 6
Cross-section through the bearing housing bolts of a high pressure hydraulic swivel
Figure 7
Cross-section through the drain port of a high pressure hydraulic swivel
Figure 8
Cross-section through the hydraulic circuits of a high pressure hydraulic swivel
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Figure 9
Enlargement of the cross-section through the hydraulic circuits of a high pressure hydraulic swive