

HIGH PRESSURE FLUID SWIVEL

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates in general to swivel equipment for transferring fluids. In particular, the invention relates to a fluid swivel joint for a swivel stack assembly adapted for transferring fluids between tankers, storage vessels and the like and one or more conduits beneath the ocean surface. The fluid of the swivel may be product such as hydrocarbons to be transferred from the seabed to a vessel or may be water or gas to be transferred from the vessel to the seabed for well stimulation.

Still more particularly, the invention relates to a sealing arrangement for a fluid swivel joint which uses the mechanical design of the joint with the pressure of the fluid flowing through the joint to substantially prevent seal glands, and extrusion gaps in which dynamic seals are placed, from enlarging as a function of high pressure of the fluid commonly encountered on offshore loading terminals for oil and gas tankers.

2. Description of the Prior Art

The offshore search for oil and gas has greatly expanded in recent years and progressed into deep rough waters such as the North Sea. To facilitate production of oil and gas from remotely located offshore fields, complex mooring systems for offshore loading terminals, which serve as centralized production sites for the entire field, have been developed. Flexible fluid lines, called risers, extend from a subsea location to the mooring site to permit the transfer of fluids between a moored vessel and a subsea location. For example, certain fluid lines may be used to convey oil and gas into the floating vessel while other fluid lines may be used to inject liquids or gases back from the vessel into subsea wells for purpose of control, well stimulation, or storage.

Floating vessels can be moored to a single point mooring system, which permits the vessel to weathervane and rotate 360° about a single mooring point. To permit the vessel to rotate and move freely without causing twisting or entanglement of the various risers to which the vessel is attached, it is necessary to provide a swivel mechanism to connect the fluid lines to the mooring site. Furthermore, since a plurality of risers are involved, it is necessary that swivels be stacked in order to have the capability of accommodating multiple fluid lines or risers.

Separate swivel assemblies are stacked on top of each other with a swivel stack base fixed to a stationary frame anchored to the sea floor.

Prior high pressure product swivels have provided an inner housing and an outer housing which is rotatively supported on the inner housing by a bearing so that the outer housing is free to rotate about the inner housing. A toroidally shaped conduit chamber is formed between the two housings when the two housings are placed in registration with each other. An inlet from the inner housing communicates with the chamber, and an outlet in the outer housing communicates with the chamber. Upper and lower dynamic seals in the form of face seals or radial seals are placed in grooves or gaps between axially opposed or radially opposed surfaces of the inner and outer housings to prevent fluid from leaking past the two facing surfaces while the high pressure fluid is present in the chamber.

When high pressure is present in the inlet and passes through the toroidal chamber and out the outlet, the pressure in the chamber acts to separate the inner housing and the outer housing from each other. In other words, the inner housing is forced to contract radially inward as a consequence of the force generated by the fluid pressure acting on an effective area between the two dynamic seals; the outer housing is forced to expand radially outward by the force of the fluid pressure acting on an effective area between the upper and lower dynamic seals. Separation occurs between the facing surfaces as a result of high fluid

pressure in the chamber. High pressure as used herein is meant to be at the level of 2,000 psi and above.

As the pressure of flowing product increases, the separation between the facing surfaces in which the seals are placed increases. Such separation can be large enough, due to the high product pressures, so as to prevent leak-free operation of the product swivel at the high pressures by seal extrusion failure.

Swivel component deformation has been the subject of much effort by prior developers. The prior art has considered the idea of adding more material to the swivel components so that deformation as a function of pressure--especially high pressure in the 5,000 to 10,000 psi range--will resist deflection. With high pressures, however, the swivel components, i.e., the inner and outer housings, become so large and heavy that they are disadvantageous from weight, cost, handling, and size standpoints, and without necessarily achieving the desired gap control.

The prior art discloses swivels that use exterior pressure sources to apply balancing or "buffer" fluid pressure at the dynamic seal interface. Examples of such "active" pressure compensation for dynamic seal gap control are shown in U.S. Pat. No. 4,602,806 to Saliger; U.S. Pat. No. 4,669,758 to Feller et al., U.S. Pat. No. 5,411,298 to Pollack; U.S. Pat. No. 6,053,787 to Erstad et al., and U.S. Pat. No. 4,662,657 to Harvey et al. All of these patents disclose separate anti-extrusion rings above and below the annular fluid manifold in combination with active pressure compensation.

U.S. Pat. No. 4,555,118 to Salinger discloses, at FIG. 4, a free floating anti-extrusion ring placed above and below a toroidal passage between inner and outer rings. The free floating antiextrusion ring is initially displaced (i.e., at zero pressure) from the inner joint ring by a small seal extrusion gap. In operation, the internal pressure of the pressurized fluid in the toroidal passage is transmitted to the outer side of the anti-extrusion ring such that the

pressure differential across the seal presses the anti-extrusion ring against the outer surface of the inner ring. In other words, the seal extrusion gap width varies as a function of internal pressure. Metal to metal contact of the anti-extrusion ring with the annular surface of the inner ring can cause friction and scoring problems during operation.

U.S. Pat. No. 4,819,966 to Gibb, at FIGS. 2, 3, and 4, shows an annular ring having an annular groove which registers with the inlet of an inner housing. An annular chamber is formed outwardly in the annular ring such that upper and lower lips are created in the annular ring that face the exterior surface of the inner housing. The lips carry dynamic seals and are forced into sealing engagement about the cylindrical surface of the inner housing above and below the inlet when pressure is in the chamber. A constant seal gap is maintained as a function of pressure by proper shaping of the chamber and the ring and the lip. A lubricating system may also be provided for injecting a controlled fluid.

U.S. Pat. 6,450,546 to Montgomery and Roy shows a sealed fluid joint for a fluid swivel in which a pressure balanced middle housing ring is mounted between an inner housing and outer housing ring. Pressure balance is achieved by providing an inner annulus chamber or cavity between the inner housing and middle housing ring and an outer annulus chamber or cavity between the middle and outer housing ring. Holes or passages through the middle housing ring fluidly connect the inner and outer chambers. Dynamic seals are placed in seal glands between the inner housing and middle housing ring. Static seals are placed in seal glands between the middle and outer housing rings. The arrangement transfers component deformation due to product fluid pressure from the dynamic seal interface to the static seal interface by exposing fluid product pressure to a smaller effective area at the dynamic seals on the inner side of the middle housing ring than an effective area at the static seals on the outer side of the middle housing ring. The counter forces generated by the product fluid pressure over two different effective areas on the middle housing ring deforms

the middle housing ring radially in a predetermined direction and amount as a function of increasing pressure. Control of radial deformation of the middle housing ring is passive, because it depends on a geometrical arrangement of dynamic and static seals on both sides of the middle housing ring and is proportional to the product fluid pressure.

3. Identification of Objects of the Invention

A primary object of the invention is to provide a fluid swivel arrangement that is capable of flowing high pressure product through it while minimizing product leaking past dynamic seal grooves formed between inner and outer housings.

Another object of the invention is to provide a fluid swivel arrangement for a predetermined high pressure rating, path diameter, and arrangement and shape of the components that minimizes the swivel outside diameter, height, and weight.

Another object of the invention is to provide shapes and arrangements of inner and outer housings with seals between them that minimize relative internal deflections so as to assume proper function and long life of the seals.

Another object of the invention is to provide a fluid swivel arrangement with inner and outer housings arranged so that internal areas subjected to high fluid pressure are minimized, thereby allowing the parts to be reduced in size and weight.

Another object of the invention is to provide dynamic upper and lower seal grooves in the outer housing with face seals placed therein where the seal grooves are oriented radially outwardly from the center line of the fluid swivel, with the shape of a radial groove cavity in the outer housing compensating for the tendency of clearances behind the seals to open wider as pressure acts inside the swivel.

Another object of the invention is to match the bending stiffness of the inner housing with the bending stiffness of the outer housing such that elastic matching occurs with the inner and outer housings expanding about the same amount in the same direction when high

pressure fluid is carried by the swivel, so that the inner and outer housings effectively move together with increasing pressure and the clearance between the parts remains almost the same.

Another object of the invention is to provide upper and lower dynamic seals where the upper dynamic seals are characterized by a slightly larger diameter than the opposing lower dynamic seals, thereby providing a positive downward force to prevent the outer housing from floating upwardly, thereby preventing excessive vertical force of the seals against the surfaces of the outer housing.

SUMMARY OF THE INVENTION

The objects identified above, as well as other advantages and features of the invention, are incorporated in a sealed fluid joint for a rotatable fluid swivel having inner and outer housings with a fluid pressure carrying radial annular groove cavity in the annular outer housing that faces upper and lower radial annular seal grooves, with face seals disposed therein which seal against surfaces of the inner housing. The areas in the radial annular groove cavity are designed and arranged with respect to the areas of the upper and lower radial annular seal grooves so that the outer housing deflects outwardly with increasing pressure to compensate for inner deflections of said face seals inwardly.

The rotatable fluid swivel is further characterized by an inner fluid manifold in the inner housing that communicates with the radial annular groove cavity in the annular outer housing. The inner fluid manifold has a diameter D_{in} , while the annular groove cavity is characterized by an internal height and a width.

The internal height of the annular groove cavity is sized to be from 50% to 60% of the internal diameter of the inner fluid manifold. The width of the annular groove cavity is sized to be about twice the internal height of the annular groove cavity. So sized and arranged, the height of pressure area acting on the primary seal in the lateral annular seal groove is such

that the diameter and weight of the outer housing is minimized, while also reducing the compressive load and stresses in the inner housing.

BRIEF DESCRIPTION OF THE DRAWINGS

The objects, advantages, and features of the invention will become more apparent by reference to the drawings which are appended hereto, wherein like reference numbers indicate like parts, and wherein an illustrative embodiment of the invention is shown, of which:

Figure 1 is a cross section of an illustrative swivel stack assembly with two swivels, each according to the invention, stacked on a swivel stack base with one inlet of the base fluidly coupled to an outlet of one swivel and a second inlet of the base fluidly coupled to an outlet of a second swivel;

Figure 2 is a top view of the swivel stack assembly of Figure 1 with section line 1-1 indicating the cross section view of the top swivel of the assembly of Figure 1;

Figure 3 is an enlarged sectional view of a swivel according to the invention;

Figure 4 is an enlarged sectional view showing stair stepped dynamic face seals between inner and outer housings with a radial groove in the outer housing, with arrows showing forces on the swivel parts caused by pressure in the swivel; and

Figure 5 is another diagrammatic illustration of Figure 4 showing effective pressure height area in the swivel according to the invention.

DESCRIPTION OF THE INVENTION

The aspects, features, and advantages of the invention mentioned above are described in more detail by reference to the drawings wherein like reference numerals represent like elements. The following table provides a list of reference numerals used throughout the specification and the features that they represent:

Reference Numeral	Feature	Figures where Reference Numeral Appears
5	Longitudinal axis	1
10A	Upper swivel	1, 3, 4, 5
10B	Lower swivel	1
16A	Upper swivel inner housing	1, 3, 4, 5
16B	Lower swivel inner housing	1
17A	Upper swivel seal plate	1, 3, 4, 5
17B	Lower swivel seal plate	1
18	Upper ring portion	4
18A	threaded bolts	1
19	Lower ring portion	4
20A	Upper swivel outer housing	1, 3, 4, 5
20B	Lower swivel outer housing	1
21A	Upper swivel upper bearing	1, 3, 4
21B	Lower swivel upper bearing	1
22A	Upper swivel lower bearing	1, 3, 4
22B	Lower swivel lower bearing	1
23A	Upper swivel radial bearing	1, 3, 4
23B	Lower swivel radial bearing	1
26A	Upper inner housing inlet	1
26B	Lower inner housing inlet	1
30	Radial groove	1, 3, 4
30A	Radial flow outlet	2
40	Upper dynamic seal	3, 4, 5
41	Lower dynamic seal	3, 4, 5
42	Backup upper dynamic seal	3, 4, 5
43	Backup lower dynamic seal	3, 4, 5
44	Upper secondary dynamic seal	3, 4, 5
45	Lower secondary dynamic seal	3, 4, 5
46	Backup secondary upper dynamic seal	3, 4, 5
47	Backup secondary lower dynamic seal	3, 4, 5
52	Swivel connectors	1
52A	Upper shoulder	4, 5
52B	Lower shoulder	4, 5
54	Base housing	1
56	Fixed spools	1
58A	Upper swivel base inlet	1
58B	Lower swivel base inlet	1
60A	Upper spool	1, 2
60B	Lower Spool	1, 2
61	First upper annular slot	4
62	First lower annular slot	4
63	Second upper annular slot	4
64	Second lower annular slot	4
70	bolts	1
98	Primary static seal	4

99	Secondary static seal	4
100	Swivel Base	1
105	Space	4
120	Pick-up arms	2
200	Swivel stack	1
A_1	Lateral component of the circumferential sealed area of the outer housing	4
D_p	Internal diameter of upper spool	1
F_H	Horizontal force	4
F_{v1}	Inward vertical force	4
F_{v2}	Outward vertical force	4
H_{eff}	Effective height	5
P	Pressure in radial groove	4, 5

The invention is for a novel high pressure swivel where two of the novel swivels are illustrated in Figure 1 stacked on top of each other. Two swivels, including upper swivel 10A and lower swivel 10B of swivel stack 200 are shown stacked on top of a fixed swivel base 100. Two swivels are shown for illustrative purposes in Figure 1, but a single swivel could be provided or more inner housing bases may be provided to accommodate several swivels. As shown in Figure 1, an upper swivel inner housing 16A, and a lower swivel inner housing 16B are secured by bolts 70 extending from the top of upper swivel 10A through lower swivel 10B, through swivel connector 52 and into base housing 54.

The swivel base 100 is fixed to a substantially geostationary point (not shown) of an offshore mooring terminal. Fixed spools 56, arranged and designed to carry high pressure fluids, enter upper and lower swivel base inlets 58A, 58B of base housing 54. Of course other spools can be provided about the circumference of the base housing 54 to provide fluid communication to other swivels in a stack. An upper spool 60A provides fluid communication between base inlet 58A and upper inner housing inlet 26A of upper swivel 10A. Lower spool 60B provides fluid communication between base inlet 58B and lower inner housing inlet 26B of lower swivel 10B. Spools 60A, 60B are spaced about a longitudinal axis 5 of the stack of swivels.

Upper swivel 10A is constructed with an upper swivel inner housing 16A having an upper swivel seal plate 17A attached to its top by means of threaded bolts 18A. Upper swivel outer housing 20A is rotatively carried on inner housing components 16A, 17A by means of upper swivel upper and lower bearings 21A, 22A and upper swivel radial bearing 23A.

As illustrated in Figure 1, the lower swivel 10B may be constructed similarly to upper swivel 10A, with the two swivel assemblies bolted together. Lower swivel 10B may be constructed much like upper swivel 10A with lower swivel upper and lower bearings 21B and 22B, and lower swivel radial bearing 23B, providing rotational support of the lower swivel outer housing 20B to the lower swivel inner housing 16B and a lower swivel seal plate 17B. As mentioned above, upper swivel 10A and lower swivel 10B are coupled together, and to the base housing 54, by threaded bolts 70. Although much of the following disclosure references upper swivel 10A and its parts, it is to be understood that the features and principles discussed apply equally to the lower swivel 10B. In addition, a swivel stack according to the present invention may have additional swivels, each sharing features and characteristics in common with those discussed herein.

In the upper swivel 10A, a radial flow outlet 30A in the upper swivel outer housing 20A is radially aligned with a radial groove 30, which extends circumferentially about the upper swivel outer housing 20A. When upper swivel outer housing 20A turns about upper swivel inner housing members 16A/17A, radial groove 30 is always in fluid communication with the upper inner housing inlet 26A, which fluidly connects to spool 60A and base inlet 58A.

Figure 2 is a top view of the swivel stack of an embodiment of the present invention. Spools 60A, 60B positioned 180° degrees from each other. A single radial flow outlet 30A is illustrated for fluid communication with spool 60A, but multiple radial outlet passages can be

provided about the outer housing. Pick-up arms 120 may be mounted to the top of the swivel stack assembly.

Figure 3 is a perspective view of the upper swivel 10A illustrating the upper swivel inner housing 16A and upper swivel seal plate 17A in registration with the upper swivel outer housing 20A and rotatively supported thereto by bearings 21A, and 22A, as well as lower radial bearing 23A. An upper radial bearing (not shown) can be provided corresponding to bearing 23A. Dynamic seal pairs 40, 42; 41, 43; 44, 46; 45, 47 provide sealing of the inner and outer housing in response to high pressure fluid in inner fluid manifold 26A and radial groove 30.

Figure 4 shows an enlarged partial cross section of the upper swivel 10A, including upper swivel inner housing components 16A and 17A, and upper swivel outer housing 20A rotatively supported by upper swivel upper and lower bearings 21A, 22A, and upper swivel radial bearing 23A. Static seals 98, 99 are positioned between inner housing 16A and seal plate 17A to prevent high pressure fluid in radial groove 30 from passing therebetween. Components 16A and 17A are static; they are bolted together and move together as one unit. A first set of upper and lower annular dynamic face seals 40, 41 are placed in first upper and lower annular slots 61, 62. A backup secondary set of upper and lower annular dynamic face seals 42, 43 are placed in second upper and lower annular slots 63, 64, which are of greater diameter than the first upper and lower annular slots 61, 62.

Figure 4 further illustrates the forces on the upper swivel outer housing 20A caused by high fluid pressure in radial groove 30, as well as the space 105 between upper swivel inner components 16A, 17A and upper swivel outer housing 20A. Figure 4 exaggerates space 105 to illustrate that high pressure acts behind dynamic seals 40 and 41, including over upper and lower shoulders 52A and 52B, to force dynamic seal 40 into face seal slot 61 and to force dynamic seal 41 into face seal slot 62. In other words, an inward vertical force F_{v1} is

applied behind dynamic seals 40 and 41 toward the upper swivel outer housing 20A by virtue of the fluid pressure. The total inward force F_{v1} is equal to the fluid pressure P times the circumferential sealed area of the outer housing, the lateral component of which is identified as A_1 in Fig. 4.

The radial groove 30 is shaped so as to cause upper and lower ring portions 18, 19, which face opposite to the dynamic seals 40, 41, to deflect outward and spread apart under the force of pressure P in the radial groove 30. See the arrows labeled "DEFLECTION DIRECTION" of Figure 4. These deflections partially compensate for any detrimental deflections of the upper swivel seal plate 17A above and the upper swivel inner housing 16A below.

The outward deflections of upper and lower ring portions 18, 19 are caused by pressure P acting on the surfaces of radial groove 30. The circumferential area of the surfaces of the groove on which the pressure P acts, or circumferential groove area, is designed to be greater than the circumferential seal area discussed above. The outward vertical force F_{v2} , which is generated by pressure P , acts to deflect the upper and lower ring portions 18, 19 in opposition to inward force F_{v1} . The force F_{v2} is greater than F_{v1} . The net force $F_{v2} - F_{v1}$ deflects the upper ring portion 18 outward and upward and the lower ring portion 19 outward and downward. As a result, the clearances of the seal slots 61, 63 and 62, 64 remain substantially constant with pressure increasing to very high levels.

A horizontal force F_H causes upper swivel outer housing 20A to deflect outwardly but has little effect on the clearances of the seal slots 61, 63 and 62, 64.

Figure 5 is the same cross section of a portion of a swivel, but illustrates the shortened radial internal pressure height, or effective height H_{eff} , on which fluid pressure in the swivel is acting. This tends to force upper swivel outer housing 20A outwardly from the upper swivel inner housing members 16A, 17A. The effective height H_{eff} of the pressure area on

which pressure P is acting is the height acting around the groove of the outer housing and upper and lower shoulders 52A and 52B. The area may be reduced by the placement of seals 40, 41 in a stair-step arrangement, bringing them as close together as practical. A reduction in the pressure area results in a reduction of the compressive load and stresses in the inner housing. Further, the reduced effective height H_{eff} reduces the radial force applied to the upper swivel outer housing 20A so that its diameter and weight can be reduced, resulting in a lighter, smaller swivel.

Additional Features

The invention embodied in the swivel illustrated in Figures 1-5 is characterized by additional features, including:

(1) The dynamic seals discussed above may include as primary seals an upper seal 40, a lower seal 41, a backup upper seal 42, and a backup lower seal 43 to seal between upper swivel inner housing components 16A, 17A and outer housing 20A. See Figs. 4 and 5. A secondary seal system, including an upper secondary seal 44, a lower secondary seal 45, a backup secondary upper seal 46, and a backup secondary lower seal 47 may also be provided.

(2) The static seals of Figs. 4 and 5 may include a primary static seal 98 and a secondary static seal 99.

Separate oil barrier systems may be provided on the primary dynamic seals 40, 42 and 41, 43 and on the secondary dynamic seals 44, 46, and 45, 47.

(3) The upper dynamic seals 40, 42 and 44, 46, that radially surround the inner housing components 16A, 17A, may be of a slightly larger diameter than the corresponding opposing lower dynamic seals 41, 43 and 45, 46. Such larger diameter of the upper dynamic seals as compared to the lower dynamic seals produces a positive downward force that minimizes upper swivel outer housing 20A from "floating" upward and excessively forcing the seals vertically.

(4) The radial groove 30 in the upper swivel outer housing 20A is wide and of short height, as illustrated in Fig. 4, with the height being about 50% to 60% of the internal diameter D_p of the inner housing inlet (26A). As described above, the dynamic seals 40, 42; 41, 43; 44, 46; 45, 47 are preferably placed as close together as practical in a stair step arrangement. Such geometries contribute to the reduction of pressure height in the area acting on the upper swivel outer housing 20A. (See, e.g., effective height H_{eff} in Fig. 5). With a predetermined internal pressure rating, that pressure acts on a smaller pressure area, resulting in a smaller radial force. As a consequence, the diameter and weight of the outer housing is reduced, compared to prior swivels of the same pressure rating. The shorter effective pressure height H_{eff} area also reduces the compressive load and stresses in the upper swivel inner housing components 16A and 17A.

CLAIMS

1. A sealed fluid joint (10A) comprising:
 - inner annular housing components (16A, 17A) positioned coaxially about a
5 central longitudinal axis (5);
 - an outer housing (20A) positioned coaxially about said inner annular housing
components (16A, 17A), said outer housing arranged and designed to rotate relative to
said inner annular housing components (16A, 17A) about said central longitudinal axis
(5), said outer housing defining an annular groove cavity (30) that has upper and lower
10 surfaces;
 - upper and lower annular seals (40, 41) for sealing between said inner annular
housing components (16A, 17A) and said outer housing (20A), wherein the upper and
lower annular seals are disposed in upper and lower annular slots (61, 62) formed in
said inner annular housing components or said outer housing;
 - 15 an inner housing inlet (26A) disposed in at least one of said inner annular
housing components (16A, 17A) and arranged to provide fluid of pressure P to said
annular groove cavity (30), the fluid allowed to fill a small space (105) between the
outer housing and inner annular housing components, and the fluid exerting a first force
(Fv₁) longitudinally inwardly on an outer surface of said outer housing (20A), and a
20 second force (Fv₂) longitudinally outwardly on said upper and lower surfaces of said
annular groove cavity (30), said second force (Fv₂) having a greater magnitude than said
first force (Fv₁) so that said outer housing (20A) deflects longitudinally outwardly.
2. The fluid joint of claim 1, wherein the inner annular housing components
25 are stationary.
3. The fluid joint of claims 1 or 2, further comprising:
 - at least two thrust bearings (21A, 22A) between laterally extending annular
surfaces of the outer housing (20A) and said inner annular housing components (16A,
30 17A); and

at least one radial bearing (23A) between longitudinally facing surfaces of said inner annular housing components (16A, 17A) and said outer housing (20A).

4. The fluid joint of any of the preceding claims, wherein said upper and
5 lower annular seals (40, 41) are dynamic seals.

5. The fluid joint of any of the preceding claims, wherein said upper and lower annular seals (40, 41) are face seals.

10 6. The fluid joint of any of the preceding claims, wherein the outer housing includes said upper and lower annular slots (61, 62) and the upper and lower annular seals (40, 41) are disposed in the upper and lower annular slots (61, 62).

7. The fluid joint of claim 6, wherein the upper annular slot (61) is above
15 the annular groove cavity (30) and the lower annular slot (62) is below the annular groove cavity (30), the annular slots having a slot diameter that is less than an outer diameter of the annular groove cavity (30).

8. The fluid joint of any of the preceding claims, further comprising:
20 second upper and lower annular seal slots (63, 64) which are substantially concentric to said upper and lower annular slots (61, 62) but are formed at an increased diameter in said outer housing (20A); and

backup upper and lower dynamic seals (42, 43) disposed respectively in said second upper and lower annular seal slots (63, 64).
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9. The fluid joint of claim 6, 7, or 8 wherein:
said inner housing inlet (26A) has an internal diameter;
said annular groove cavity (30) in said outer housing (20A) has an internal height and a width;

said internal height of said annular groove cavity (30) being from 50% to 60% of said internal diameter of said inner housing inlet (26A);

said width of said annular groove cavity (30) being about twice said internal height; and

5 wherein said upper and lower annular slots (61, 62) in the outer housing are positioned closely together in an axial direction thereby reducing the height of the pressure area (H_{eff}) acting outwardly on said outer housing (20A).

10 10. The fluid joint of any of the preceding claims, further comprising backup seals (42, 43), secondary seals (44, 45), and backup secondary seals (46, 47), positioned between said outer housing (20A) and said inner annular housing components (16A, 17A).

15 11. The fluid joint according to any of the preceding claims, wherein the annular groove cavity (30) has a radial width defining upper and lower ring portions (18, 19) of the outer housing, and the first axial force (F_{v1}) is exerted on the outer upper surface of the upper ring portion (18), and the second axial force (F_{v2}), having a greater magnitude than the first axial force, causes the upper ring portion to deflect axially upward.

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 12. The fluid joint of any of the preceding claims, wherein:
 the upper annular seal (40) defines a circumferential axially-facing sealed area of the outer housing from an innermost diameter to the upper annular seal;
 the magnitude of the first axial force (F_{v1}) is the product of the circumferential
25 axially-facing sealed area times the fluid pressure (P); and
 the annular groove cavity (30) has an upper circumferential groove area defined by a radial groove width, and the magnitude of the second axial force (F_{v2}) is the product of the upper circumferential groove area times the fluid pressure (P).

13. The fluid joint of any of the preceding claims, wherein the fluid exerts a third axial force (F_{v1}) on an outer lower surface of the outer housing, and a fourth axial force (F_{v2}) on the lower surface of the annular groove cavity (30), the fourth axial force having a greater magnitude than the third axial force so that the outer housing deflects axially downward.

14. The fluid joint of claim 13, wherein the third axial force is equal to the first axial force but in the opposite direction and the fourth axial force is equal to the second axial force but in the opposite direction.

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15. The fluid joint of any of the preceding claims, wherein:
the outer housing includes said upper and lower annular slots (61, 62) having a first slot diameter;

each of the upper and lower annular seals (40, 41) defines a circumferential axially-facing sealed area of the outer housing from the innermost diameter to the annular slot (61, 62), and the annular groove cavity (30) having upper and lower circumferential groove areas defined by a radial groove width, the circumferential groove areas being greater than the circumferential axially-facing sealed areas of the outer housing; and

the fluid pressure acting on the upper and lower circumferential groove areas and the circumferential axially-facing sealed areas of the outer housing results in net forces acting axially outwardly causing a small axial outward deflection of the outer housing.