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(54) **TOROIDAL FLUID SWIVEL FOR TRANSFER OF FLUID ACROSS A ROTARY INTERFACE**

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B63B 21/50	(2006.01)

(52) **U.S. Cl.**

CPC ***E21B 17/05*** (2013.01); ***B63B 21/507*** (2013.01); ***F16L 39/04*** (2013.01)

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CPC F16L 27/08; F16L 27/0804; F16L 27/093; F16L 39/00; F16L 39/06; F16L 39/04; F16L 41/001; F16L 41/02; E21B 17/05; B63B 21/507

USPC 285/121.3, 106, 98, 121.6; 269/309, 310

See application file for complete search history.

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(57) **ABSTRACT**

A swivel for transfer of fluid across a rotary interface around a swivel rotation axis between an incoming fluid line and an outgoing product piping includes a fixed annular element and a rotating annular element, each arranged around a common rotation axis and having a substantially equal diameter. One selected element from the fixed annular and rotating annular elements includes an annular disk provided with a toroidal cavity in a first of its circular end surfaces, and the other selected element is arranged with a flat circular end surface adjacent to and in close proximity above the first circular end surface to close the toroidal cavity and form a toroidal chamber with the annular disk. The rotary interface is perpendicular to the rotation axis, and is formed by the flat circular end surface of the other selected element and the adjacent first circular surface of the one selected element.

8 Claims, 5 Drawing Sheets

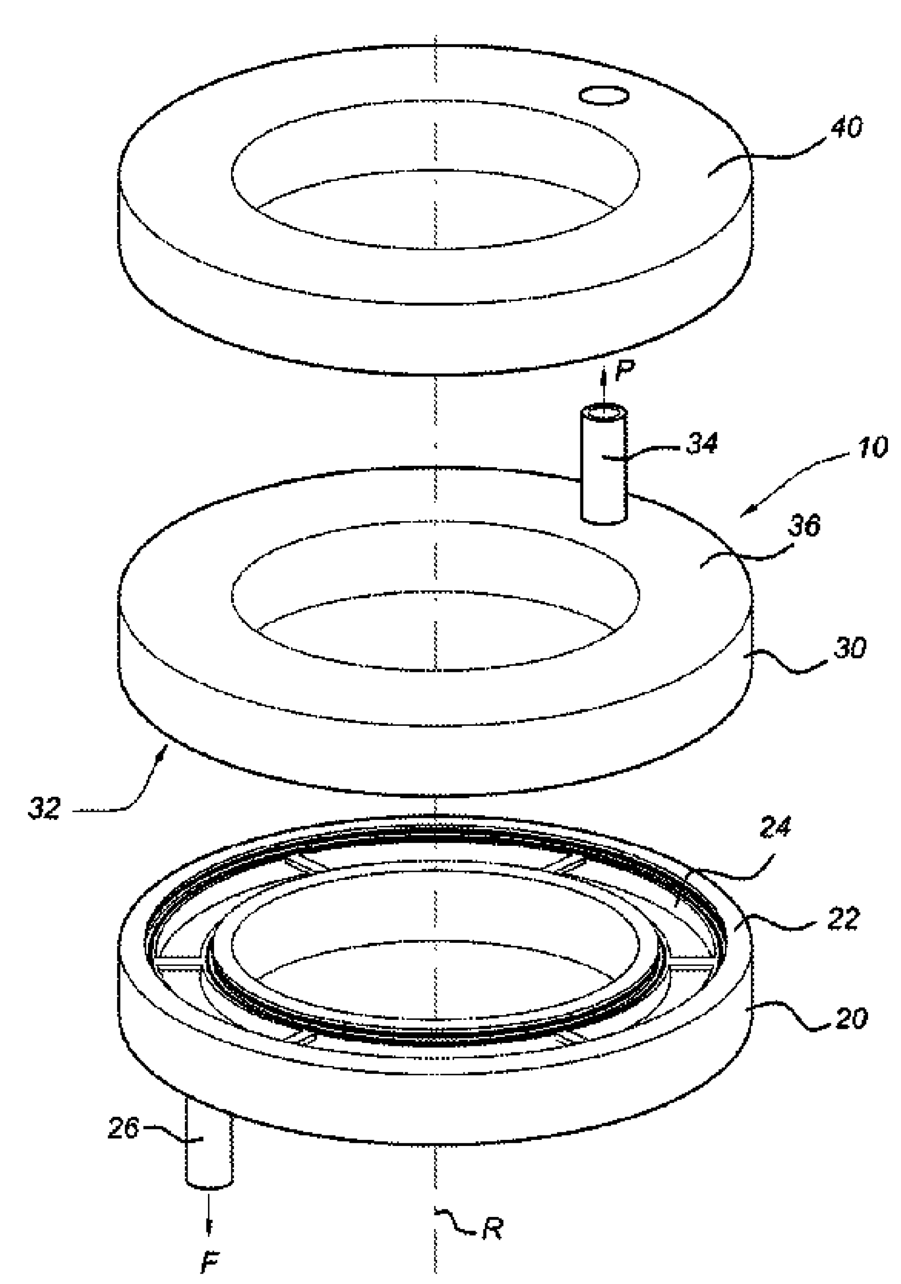

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Fig. 1A

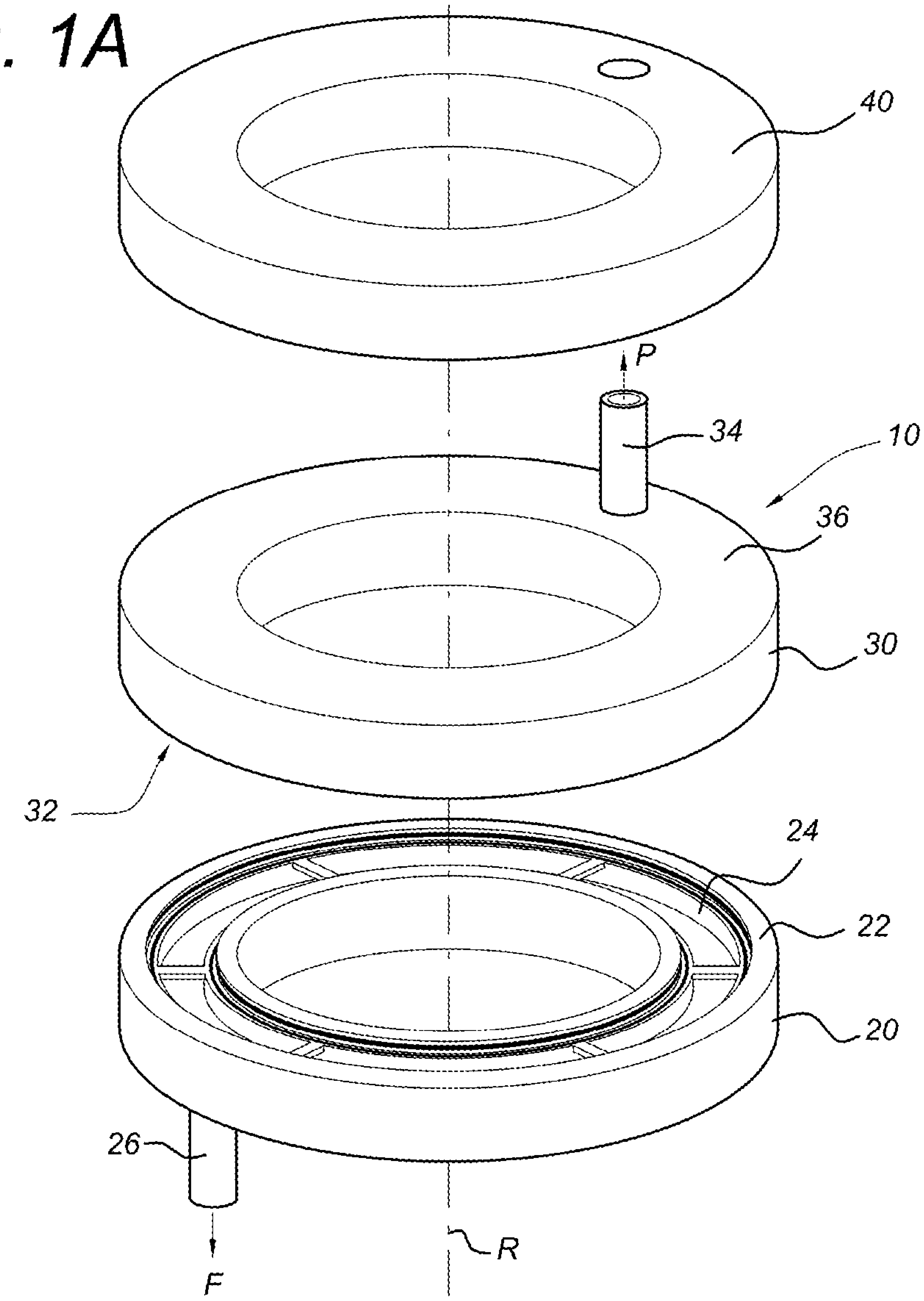


Fig. 1B

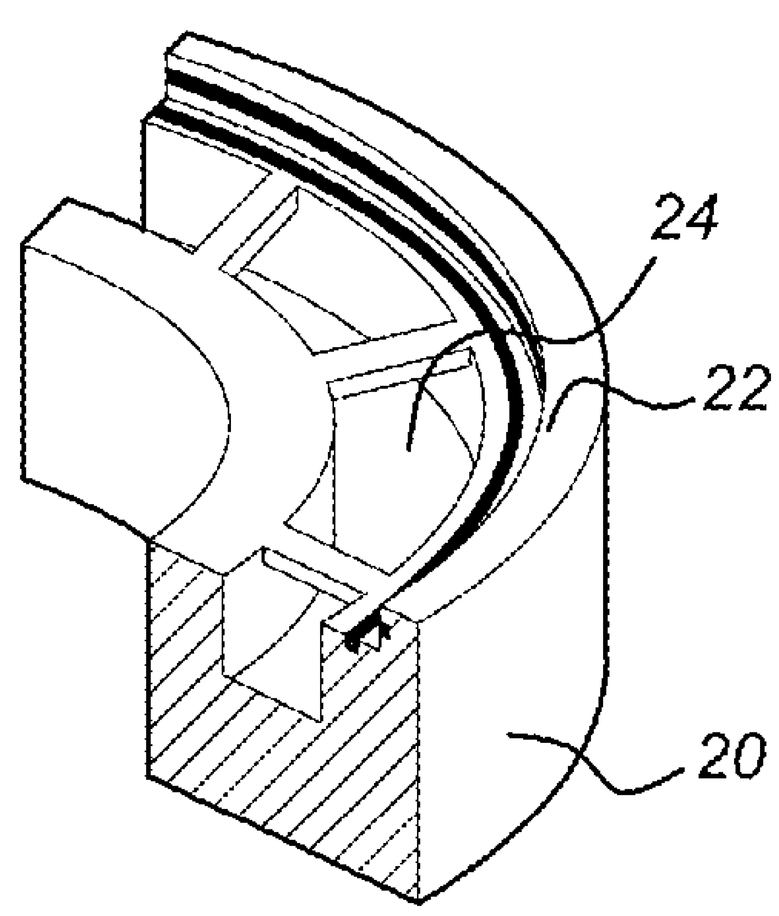
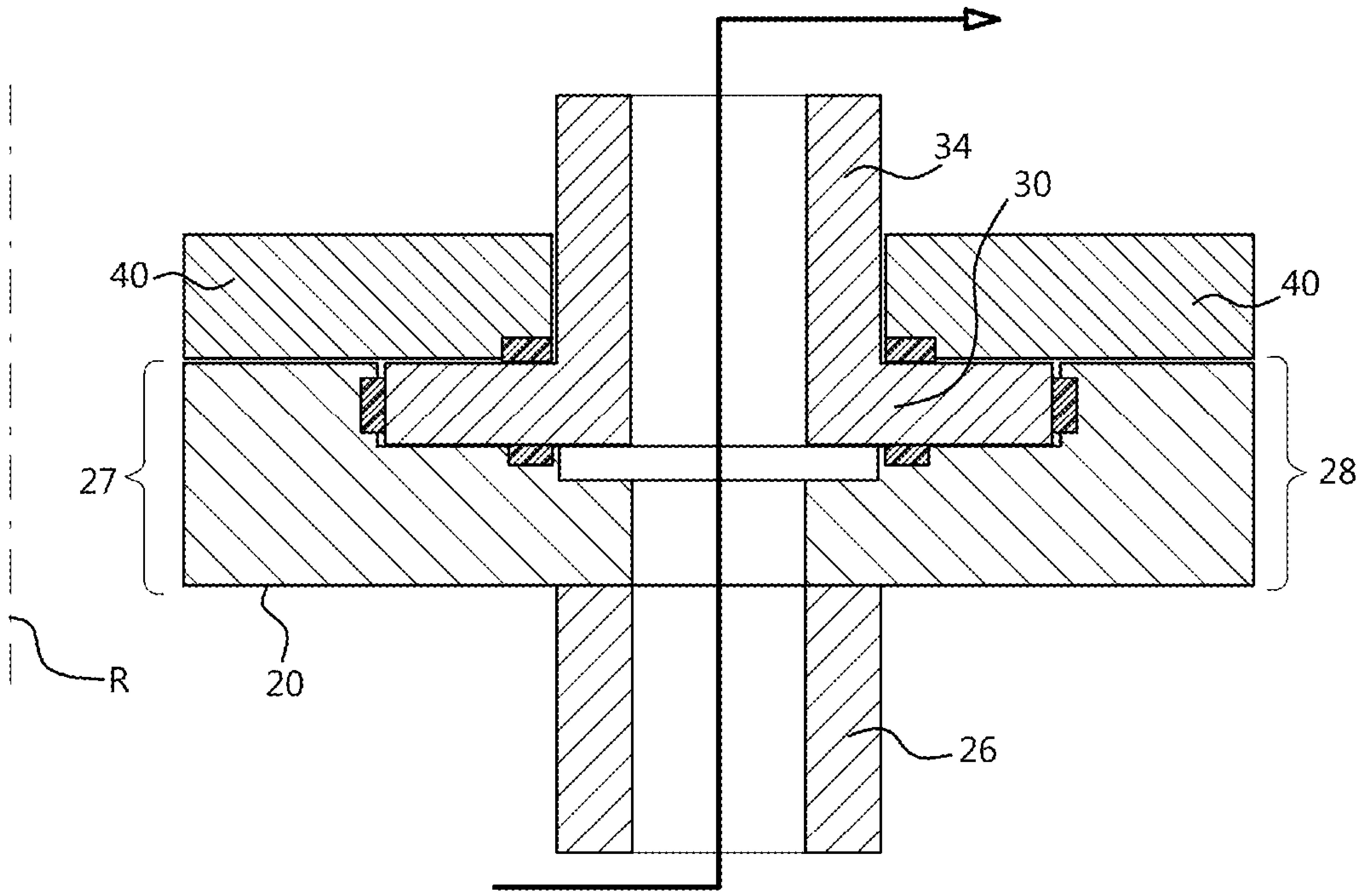
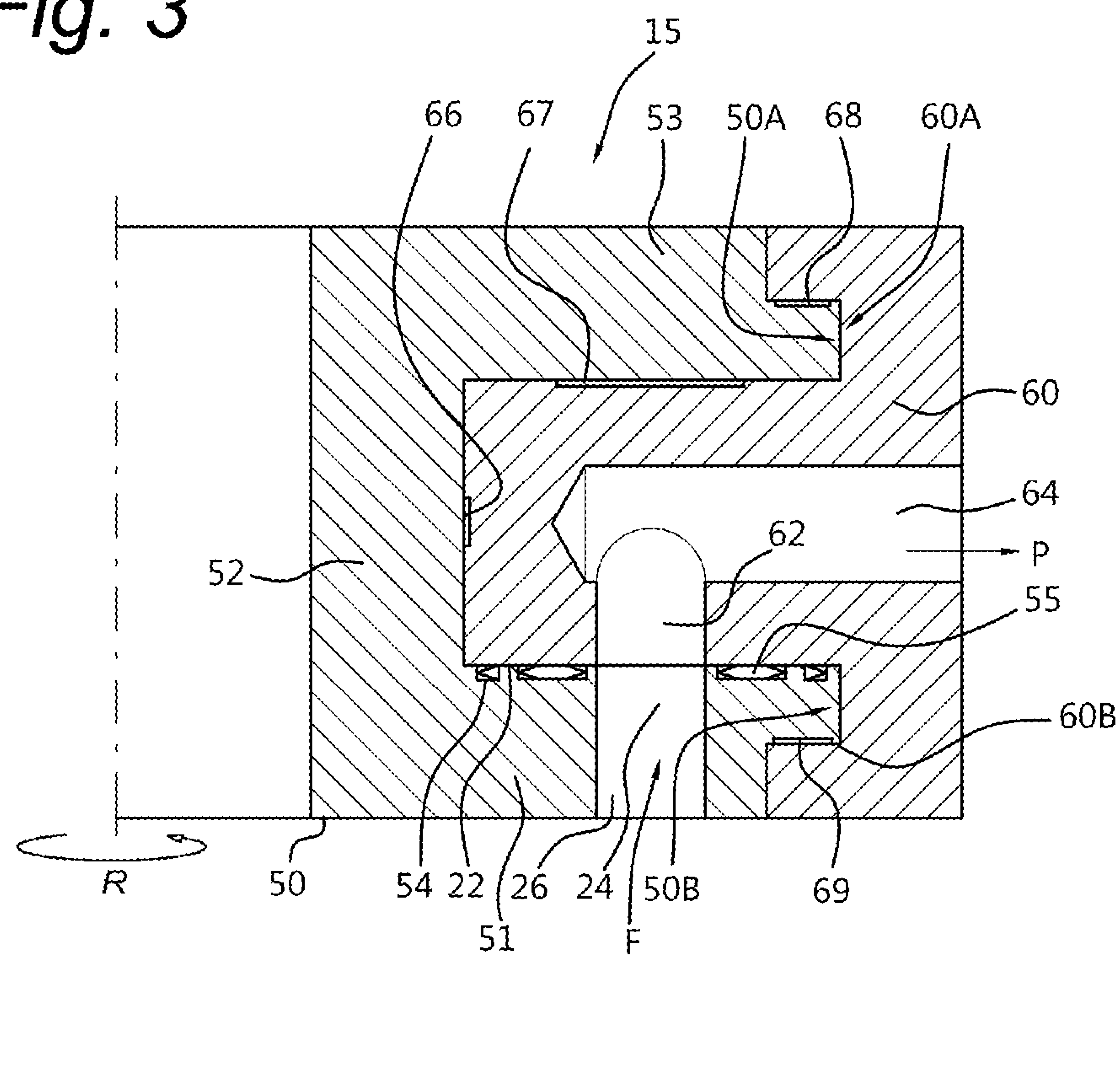


Fig. 2



34
30
40
40
27
28
R
20
26

Fig. 3



15
66
67
53
50A
68
60A
60
64
62
P
52
55
60B
R
50
54
22
26
24
50B
69
51
F

Fig. 4

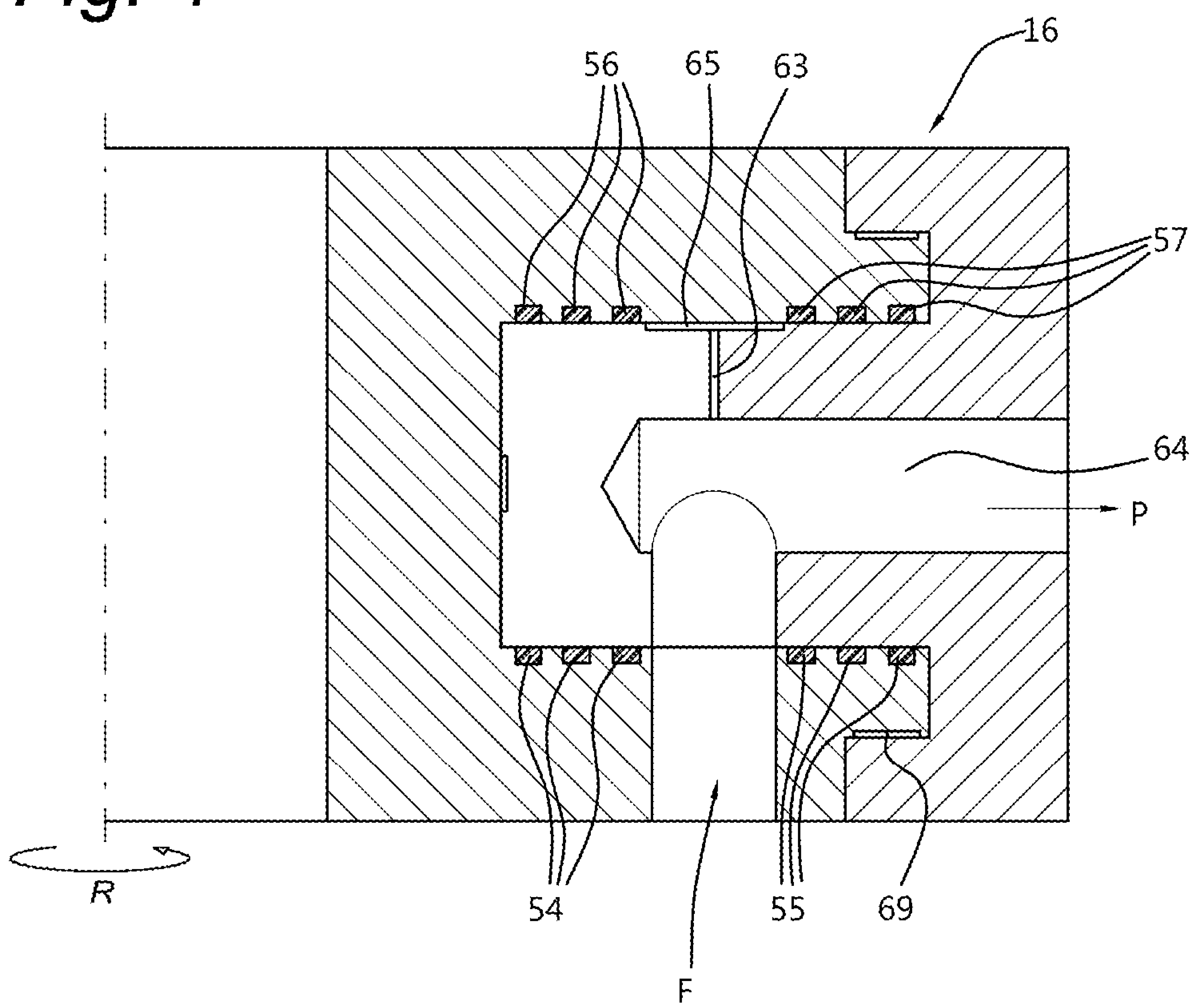


Fig. 5

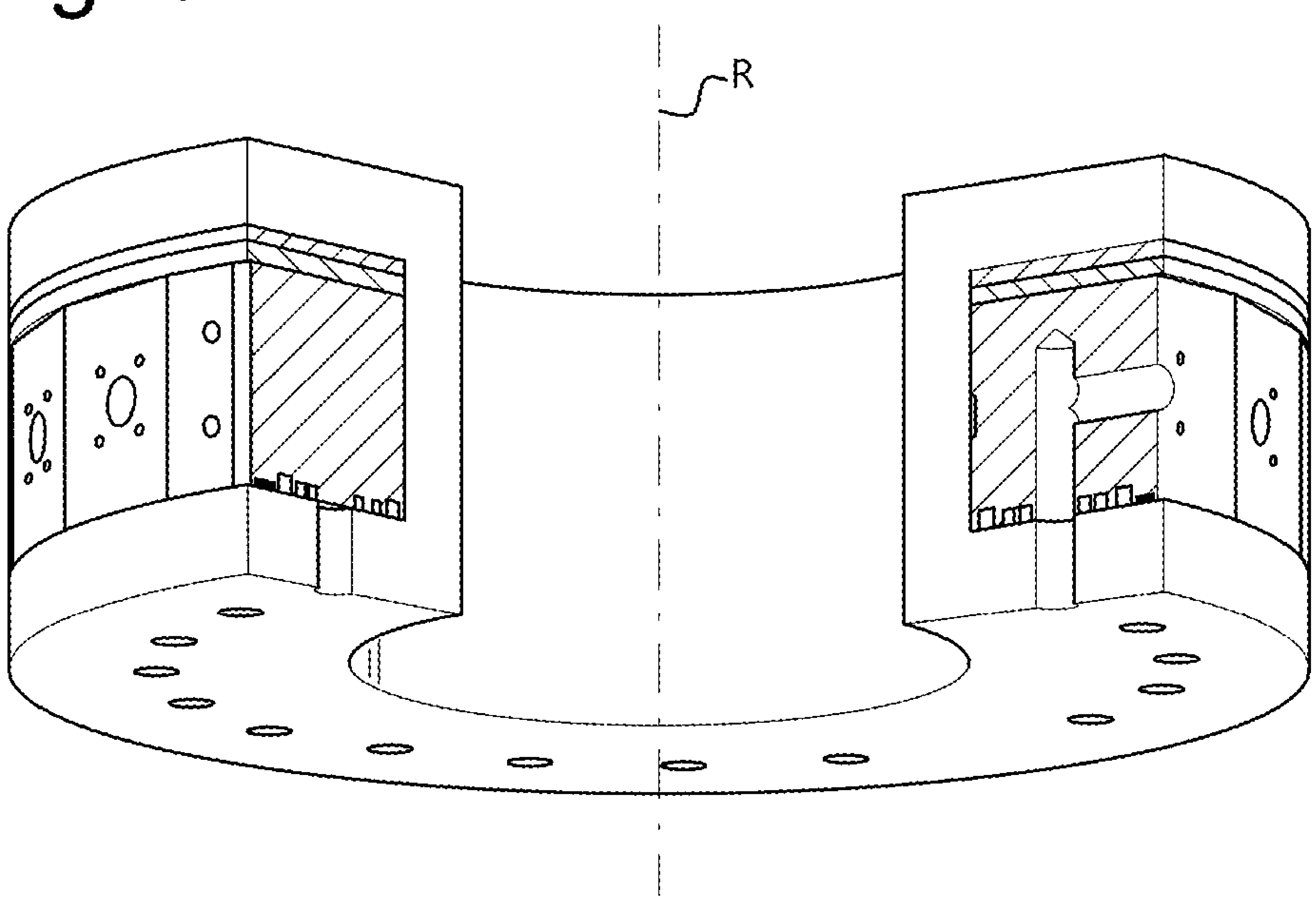


Fig. 6a

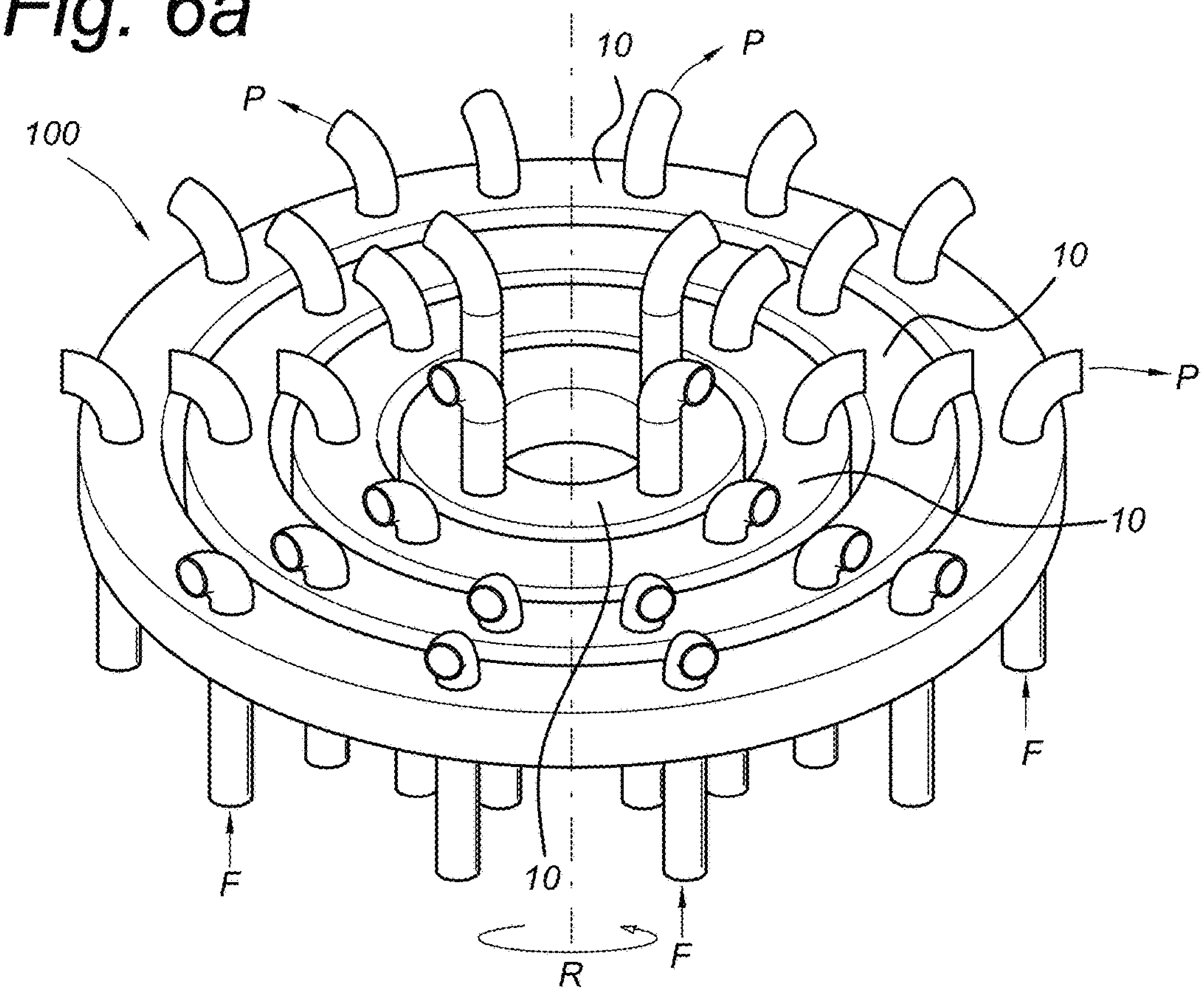


Fig. 6b

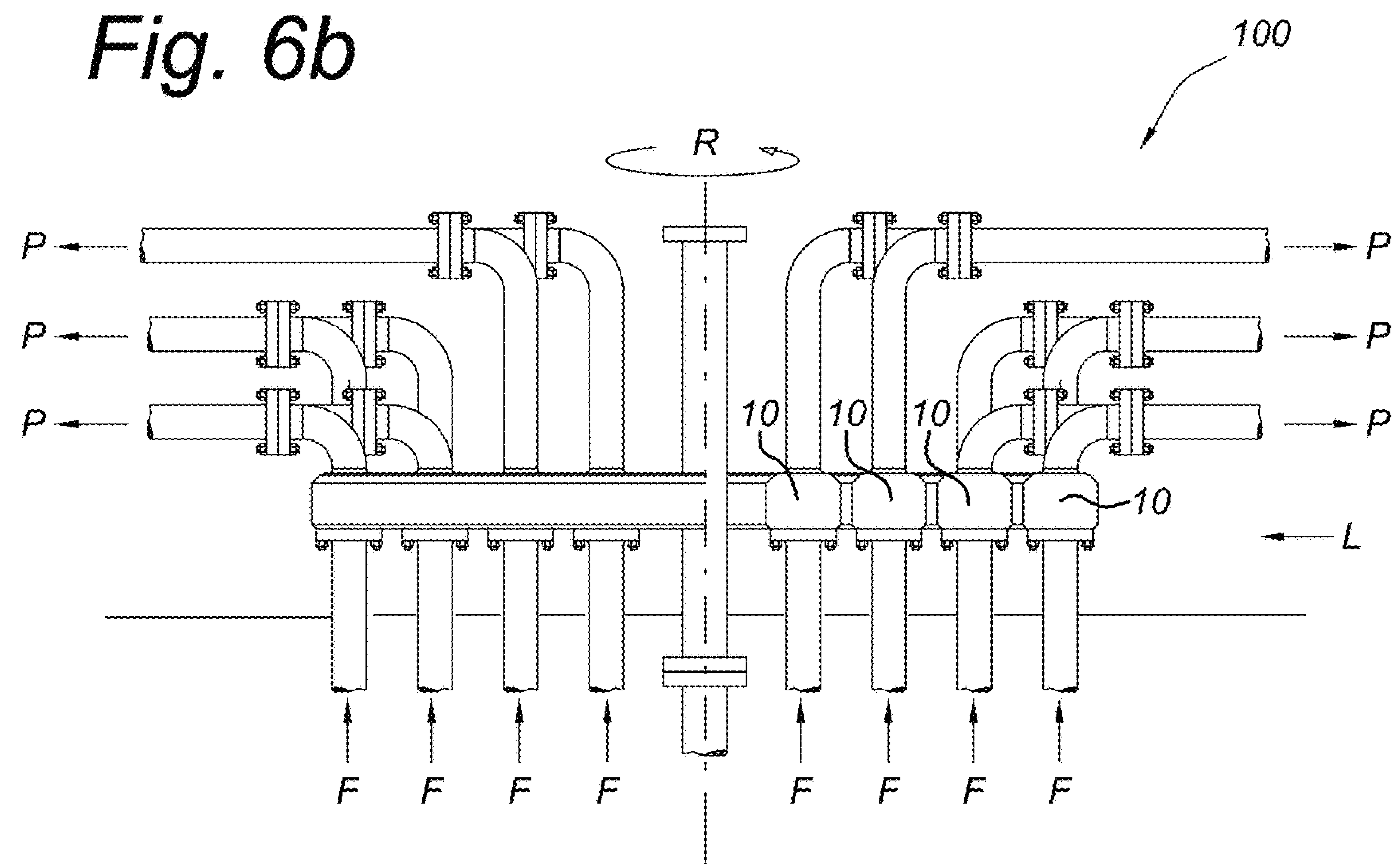
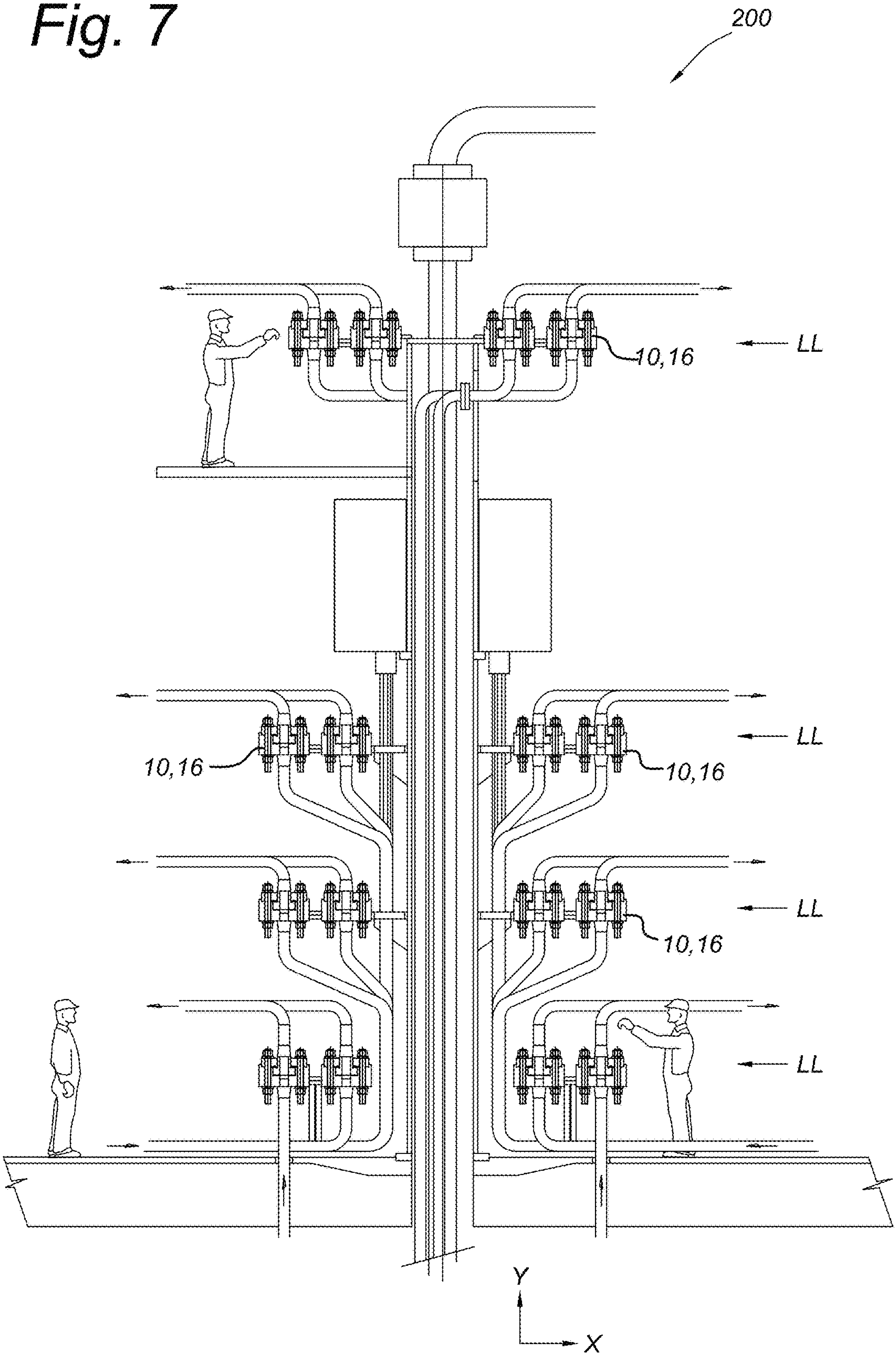


Fig. 7



TOROIDAL FLUID SWIVEL FOR TRANSFER OF FLUID ACROSS A ROTARY INTERFACE

FIELD OF THE INVENTION

The present invention relates to a toroidal fluid swivel for transfer of fluid across a rotary interface. Also, the invention relates to a vessel equipped with a turret mooring system that comprises such a swivel.

BACKGROUND

Toroidal fluid swivels are known in the art for transfer of high-pressure fluids across a rotary interface between an incoming fluid line and an outgoing product piping. Applications for such a swivel include for example offshore oil and gas explorations where high-pressure flows of oil and/or gas are transferred from a (deep-sea) offshore well to a floating vessel such as a Floating Production Storage and Offloading (FPSO) vessel. Typically such a floating vessel is equipped with a turret mooring system that can couple a mooring buoy or a "mooring structure" and that holds one or more riser lines from the well, to product piping ducts on the vessel. Since the turret mooring system should allow some rotation between the vessel and the buoy, the swivel is likewise adapted to provide rotation between the incoming fluid line and the product piping.

In particular for deep-sea applications there is a need for swivels that can withstand design pressures well over 500 atm (50.6 MPa) for incoming fluid while at the same time, a high flow of the fluid should be transferred.

Typically, a prior art swivel comprises a fixed (or static) annular element that is coupled to an incoming fluid line on the turret, and a rotating annular element that is coupled to the outgoing product piping on the vessel. The fixed and rotating annular elements each have a shell shape that form a closed toroidal volume between them in which a radial interface (a basically cylindrical surface area) is present between the rotating element as outer shell and the fixed element as inner shell. The radial interface allows the rotating element to rotate with respect to the fixed element, but in the same time is detrimental to swivel shell design by adding further surfaces exposed to the fluid pressure, calling thus for thicker shell wall.

In the swivel according to the prior art the outer shell of the swivel (i.e., the rotating annular element) will have the property of expanding under the pressure in the flow path between the inner and outer shell parts. Counteracting this expansion and associated stress imposes heavy wall thickness, and complex face seal design. This strategy is not indefinitely sustainable when the swivel diameter increases, since the radial force on the radial interface increases with increasing diameter. Especially for high pressure applications this will lead to unmanageable wall thicknesses and excessive weight of parts of the swivel. These issues have an adverse effect on the design and size of the swivel construction, but also on maintenance and repair, and of course have an important impact on the cost and on manufacturing limitations.

A further issue relates to the operation mode of prior art swivels which involves avoiding rubbing contact between the fixed and rotating parts. The load path across the various swivel parts is often a long loop passing by a deported roller bearing and which is sealed by seals that can only operate with a very small extrusion gap having very little variation. Again, a proper functioning of this known swivel can be obtained only via massive swivel parts.

It is an object of the present invention to overcome these disadvantages from the prior art.

SUMMARY OF THE INVENTION

The object of the invention is achieved by a toroidal fluid swivel for transfer of fluid across a rotary interface around a swivel rotation axis between an incoming fluid line and an outgoing product piping,

the swivel comprising a fixed annular element and a rotating annular element, each arranged around a common rotation axis and having a substantially equal diameter;

one selected element from the fixed annular element and the rotating annular element comprising an annular disk being provided with a toroidal cavity in a first of its circular end surfaces, and the other selected element from the fixed annular element and the rotating annular element being arranged with a flat circular end surface that is adjacent to and in close proximity above said first circular end surface of said annular disk so as to close the toroidal cavity and form a toroidal chamber within the annular disk,

the rotary interface being formed by the flat circular end surface of the other selected element and the adjacent first circular surface of the one selected element, the rotary interface being perpendicular to the common rotation axis.

According to the invention, the rotary interface between the fixed annular element and the rotating annular element is arranged perpendicular to the rotation axis, of the swivel, in contrast to the radial interface of the toroidal chamber of the prior art shell type swivel. Moreover, the toroidal chamber consists of a toroidal cavity formed in only one the fixed annular element covered by a flat contact surface of the rotating annular element or vice versa: a toroidal cavity formed only in the rotating annular element covered by a flat contact surface of the fixed element. This provides a relatively simple rotary interface perpendicular to the rotation axis.

The invention has the effect that forces in the swivel created by the high pressure fluid are substantially in axial direction. In a specific embodiment the radial forces applied to the inner and outer diameters of the toroidal chamber substantially counterbalance each other, being oriented in opposite radial directions, and exerted on the same swivel body part. Therefore, the hoop stresses and deformations in any of the swivel parts are greatly reduced, as a result of the respective surface difference between the toroidal inner and outer diameter subject to the pressure. Furthermore, this respective surface difference may be reduced by the multiple inlets and outlets serving the toroidal chamber, allowing to have a toroidal cavity to be only a corresponding fraction of the effective swivel overall throughput. This leads to a requirement for enforcement predominantly in axial direction. Additionally, since the rotary interfaces between the toroidal cavity and the sealing arrangement are a ring shaped area perpendicular or substantially perpendicular (for example a tapered or diagonal interface) to the rotation axis and not a cylindrical surface area, stresses (force per unit area) on the fixed annular element and the rotating annular element do not significantly increase for larger diameters of the swivel. This allows relative freedom of design (as compared to the prior art) with respect to the diameter of the swivel.

According to an aspect, the invention relates to a swivel as described above, wherein the one selected element is the fixed annular element and the other selected element is the rotating annular element; the toroidal cavity being provided in the fixed annular element and the flat circular end surface being provided in the rotating annular element.

According to an aspect, the invention relates to a swivel as described above, wherein the one selected element is the rotating annular element and the other selected element is the fixed annular element; the toroidal cavity being provided in the rotating annular element and the flat circular end surface being provided in the fixed annular element.

According to an aspect, the invention relates to a swivel as described above, wherein the annular disk is provided with at least one inlet aperture that couples the incoming fluid line to the toroidal cavity, the rotating annular element being provided with at least one passing through outlet aperture that provides a fluid communication between the toroidal chamber and the outgoing product piping.

According to an aspect, the invention relates to a swivel as described above, wherein the fixed annular element comprises an inner wall and an outer wall; the inner wall at one end connected to the annular disk, and the outer wall at one end connected to the fixed annular disk so as to form a "U-shaped" fixed annular element, and the rotary interface between the rotating annular element and the fixed annular element is arranged in between the inner and outer walls of the fixed annular element.

According to an aspect, the invention relates to a swivel as described above, wherein the rotary annular element is rotatingly clamped to the fixed annular element by retaining rings; the retaining rings being attached to the fixed annular element by bolts.

According to an aspect, the invention relates to a swivel as described above, wherein the fixed annular element comprises an annular disk which is provided with an inner wall at its inner edge and a circular wall parallel to the annular disk; the inner wall at one end is connected to the annular disk and at the other end is connected to the circular wall so as to form a "C-shaped" fixed annular element, and the rotating annular element is arranged in between the annular disk and the circular wall.

According to an aspect, the invention relates to a swivel as described above, wherein the at least one inlet aperture extends from a second circular end surface to the first circular end surface perpendicularly through the annular disk into the toroidal cavity, parallel to the common rotation axis.

According to an aspect, the invention relates to a swivel as described above, wherein the at least one outlet aperture extend perpendicular through the rotating annular element, parallel to the common rotation axis.

According to an aspect, the invention relates to a swivel as described above, wherein the at least one outlet aperture is provided internal of the rotation annular element with a right angle, has at the side of the toroidal chamber an inlet portion parallel to the common rotation axis and at the side of the outgoing product piping an outlet portion transverse to common rotation axis directed radially outward with respect to the common rotation axis.

According to an aspect, the invention relates to a swivel as described above, wherein the swivel further comprises retaining elements for retaining the rotating annular element between the inner and outer walls, the retaining elements being fixed to the inner and outer walls and holding the rotating annular element in position over the toroidal cavity.

According to an aspect, the invention relates to a swivel as described above, wherein the swivel comprises sealing means i.e., a seal or seals adjacent to the edges of the toroidal cavity between the annular disk and the rotating annular element.

According to an aspect, the invention relates to a swivel as described above, wherein the rotating annular element is provided with a bore hole extending between the inlet opening and a surface of the rotating annular element facing the circular wall of the fixed annular element.

According to an aspect, the invention relates to a swivel as described above, wherein the at least one inlet aperture comprises a plurality of externally interconnected inlet apertures distributed over the circle of the toroidal cavity, and the at least one outlet aperture comprises a plurality of externally interconnected outlet apertures distributed over the circle of the toroidal chamber.

According to an aspect, the invention relates to a swivel as described above, wherein in a top region of the toroidal cavity crossbars are fixedly arranged in radial direction over the cavity.

According to an aspect, the invention relates to a swivel as described above, wherein the crossbars are distributed on the toroidal cavity at constant intermediate angle.

According to an aspect, the invention relates to a swivel as described above, wherein the at least one inlet aperture and/or the at least one outlet aperture has an elongated shape along the toroidal cavity.

According to an aspect, the invention relates to a swivel as described above, wherein the toroidal cavity extends over 360° around the common rotation axis.

According to an aspect, the invention relates to a swivel as described above, wherein the fixed annular element and/or the rotating annular element comprises a plurality of annular segments, the annular segments being interconnected at their ends to form the circular shape of the respective annular element.

According to an aspect, the invention relates to a swivel as described above, wherein the toroidal cavity is segmented as a series of cavity segments embodied as an homogeneous array of arc-shaped cavity segments, each cavity segment being provided with an inlet aperture, and the swivel comprises on the rotating annular element a corresponding number of outlet apertures that are distributed in accordance with the layout of said array, the cavity segments being designed with an overlapping passage between at least one of the inlet aperture(s) and at least one of the outlet aperture (s) in a manner that whatever angular orientation between the rotating and the fixed annular element a flow path through the swivel is present.

The invention also relates to a swivel stack comprising at least one swivel as described above.

Moreover, the invention relates to a vessel for offshore operations and comprising a turret mooring system, wherein the turret mooring system is equipped with a swivel as described above.

Advantageous embodiments are further defined by the dependent claims.

BRIEF DESCRIPTION OF DRAWINGS

The invention will be explained in more detail below with reference to drawings in which illustrative embodiments thereof are shown. The drawings are intended exclusively for illustrative purposes and not as a restriction of the inventive concept. The scope of the invention is only limited by the definitions presented in the appended claims.

FIG. **1**A shows a perspective drawing of a rotary interface of a swivel in accordance with an embodiment of the invention;

FIG. **1**B shows a perspective cross-sectional view of a rotary interface of a swivel;

FIG. **2** shows a cross-section of the rotary interface of FIG. **1**A in accordance with an embodiment of the invention;

FIG. **3** shows a cross-section of a swivel in accordance with an embodiment of the invention;

FIG. **4** shows a cross-section of a swivel in accordance with a further embodiment of the invention;

FIG. **5** shows a perspective cross-sectional view of a swivel in accordance with an embodiment of the invention;

FIGS. **6**A and **6**B show a perspective view and a side view of a number of concentric swivels in accordance with an embodiment of the invention;

FIG. **7** shows a swivel stack comprising swivels in accordance with an embodiment of the invention.

DETAILED DESCRIPTION OF EMBODIMENTS

FIG. **1**A shows a perspective drawing of a rotary interface of a swivel in accordance with an embodiment of the invention.

On a FPSO vessel (not shown) a turret mooring system (not shown) is provided that can couple a mooring buoy that holds one or more riser lines from the well, to product piping ducts on the vessel.

During operation the FPSO should be allowed to weathervane which can be achieved the turret mooring system allowing some rotation between the vessel and the buoy. Correspondingly, the swivel is adapted to provide rotation between the incoming fluid line and the product piping.

The swivel **10** according to the invention comprises a rotary interface **20**, **30** for transfer of fluid from the incoming fluid line to the outgoing product piping.

The rotary interface comprises two annular elements: a fixed annular element **20** that in use is coupled to the turret mooring system and a rotating annular element **30** that is coupled to the outgoing product piping that is attached to the vessel.

The two annular elements **20**, **30** are arranged to have a common rotation axis R and to have a substantially same diameter.

The fixed annular element **20** consist of an annular disk which a first circular end surface **22**, in which a toroidal cavity **24** or groove is arranged.

According to an embodiment, the toroidal cavity has been machined into the annular disk with inner and outer sidewalls of the cavity that is arranged to contain the high pressure fluid being perpendicular in respect of the direction of the rotation axis.

The fixed annular element additionally comprises at least one inlet aperture **26** for coupling the incoming fluid line (indicated by arrow F) to the groove.

The fixed annular element and the rotating annular element are held in frictional contact or close frictionless proximity by a bearing arrangement provided in each element so that one element can rotate freely in respect of the other element along the common rotation axis while axial displacement of one element in respect of the other element is restricted, or limited by the bearing arrangement. The toroidal chamber formed by the two elements contains at least one dynamic interface surface substantially perpendicular to the direction of the common rotation axis.

In a preferred embodiment, the at least one inlet aperture **26** is extending through the thickness of the annular disk from a second circular end surface opposite to the first circular end surface **22**, into the toroidal cavity **24**.

The rotating annular element **30** is arranged with a substantially flat circular end surface **32**. The rotating annular element **30** is positioned with its flat circular end surface facing, and in close proximity to, the first circular end surface **22** of the fixed annular element, in such a manner that the opening surface of the toroidal cavity **24** is closed and a toroidal chamber is formed.

The rotary interface **20**, **30** is thus defined between the first circular end surface **22** of the annular disk **20** and the facing flat circular end surface **32** of the rotating annular element and extends perpendicular to the common rotation axis R.

The person skilled in the art will appreciate that the toroidal cavity may alternatively be formed in the rotating annular element, while the fixed annular disk is provided with the facing flat circular surface for closing the toroidal cavity and forming the toroidal chamber between the fixed annular and the rotating annular elements.

The rotating annular element **30** additionally comprises at least one outlet aperture **34** for providing a connection from an inlet portion (not shown) at the flat circular surface **32** to an outlet portion coupled to the outgoing product piping (indicated by arrow P).

In an embodiment, the at least one outlet aperture **34** is extending through the thickness of the annulus of the rotating annular element **30** from the flat circular end surface opposite to an opposing circular end surface **36**.

In an alternative embodiment, the outlet portion of the at least one outlet aperture **34** is located at the outer circumference of the rotating annular element as will be explained below in more detail with reference to FIG. **3**.

In case, a high pressure fluid is introduced from the incoming fluid line F, the toroidal chamber will be pressurized, which has the effect that a force is exerted on the rotary interface parallel to the rotation axis.

Of course, the high pressure may also induce some deformation in the plane of rotation but the skilled in the art will appreciate that such effect is highly reduced by the antagonist planar forces being exerted on the same part and greatly cancelling each other effects. Furthermore, those effects can be kept to the minimum by reducing the toroidal cavity section, while optimizing it's shape and wall thickness to avoid excessive stress and stress concentration.

Each swivel annular body can be made of a single annulus or at least two annular segments interconnected at their respective ends to forming thus a single whole body circumference. According to an embodiment, within the swivel the fixed annular disk and/or the rotating annular disk comprises a plurality of annular segments, the annular segments being interconnected at their ends to form the circular shape of the annular disk. It is noted that the circumferential continuity of the toroidal cavity is interrupted at the mating extremity of each annular segment which eliminates the hydrostatic separation force normally exerted on the whole toroidal cavity surface, leaving only the hydrostatic separation force corresponding to the swivel extrusion gap surface exposed to the fluid pressure, which in comparison is negligible.

The person skilled in the art will appreciate that at least one of the fixed and rotating annular elements can be embodied by a massive cylindrical part. For example, a swivel stack according to the invention may comprise one massive cylindrical inner part or inner core with multiple fluid lines (channels) combined with two or more outer (annular) parts.

In the above embodiments, the toroidal cavity is embodied as a circular and continuous channel in between the fixed annular element and the rotating annular element. According to an embodiment, the toroidal cavity is segmented as a series of cavity segments embodied as an homogeneous array of arc-shaped cavity segments, wherein each cavity segment is provided with an inlet aperture. On the rotating annular element a corresponding number of outlet apertures is provided that are distributed in accordance with the layout of the array. The cavity segments are designed in a manner that whatever the angular orientation between the rotating and the fixed annular element an overlapping passage is present between at least one of the inlet aperture(s) and at least one of the outlet aperture(s).

FIG. **2** shows a cross-section of the rotary interface **20**, **30** in accordance with an embodiment of the invention.

In FIG. **2** the rotary interface is shown with inlet aperture **26** and outlet aperture **32** in alignment.

According to the shown embodiment, the annular disk part of the fixed annular element **20** is arranged with side walls **27**, **28**. An inner wall **27** is arranged at the inner circumference of the annular disk, an outer wall **28** is arranged at outer circumference of annular disk **20**. Both inner and outer walls extend in the axial direction parallel to the rotation axis **29**, towards the rotating annular element **30**. In this manner, the fixed annular element has a "U-shape". The rotating annular element is positioned in between the inner and outer walls, with the rotary interface located at the "floor" inbetween the inner and outer walls.

On the distal ends of the walls **27**, **28** away from the rotary interface, the swivel is provided with retaining rings **40** for holding the rotating annular element **30** positioned above and in close proximity to the first circular end surface of the annular disk **20**. The retaining rings **40** are attached to the inner and outer walls **27**, **28** by bolts (not shown here).

The rotary interface between the annular disk and the rotating annular element is further provided with seals **42** to prevent leakage of high pressure fluid from the toroidal chamber **24** along the rotary interface. Various seal type can be used as will be appreciated by the person skilled in the art, for example Zero gap sealing, face sealing, or membrane sealing.

The seals can be located at various positions between the surface of the annular disk **20** and the facing surface of rotating annular element **30** or between the rotating annular element **30** and the inner and/or outer walls **27**, **28** or between the retaining ring(s) **40** and the surface of the rotating annular element that faces away from the rotary interface.

Moreover, the rotary interface is further provided with bearings that can also be positioned at various positions between the surface of the annular disk **20** and the facing surface of rotating annular element **30** or between the rotating annular element **30** and the inner and/or outer walls **27**, **28** or between the retaining ring(s) **40** and the surface of the rotating annular element that faces away from the rotary interface. The bearings may comprise friction bearings and/or hydrostatic bearings, or other bearing types.

FIG. **3** shows a cross-section of a swivel **15** in accordance with an embodiment of the invention.

The swivel comprises a fixed annular element **50** and a rotating annular element **60**.

The fixed annular element **50** in this embodiment comprises a base annular disk **51**, an inner wall **52** at the inner circumference of the base annular disk, and a second annular disk **53**. The base annular disk **51** has a first circular end surface **22** perpendicular to the rotation axis R and is provided with a toroidal cavity **24** in the first circular end surface **22**. At the inner circumference of the base annular disk, the inner wall **52** is provided that extends along the direction of the rotation axis and forms a cylindrical wall. The second annular disk **53** is arranged parallel to the base annular disk **51** and is connected to the cylindrical inner wall in a manner that a "C"-shaped toroid is formed with an opening at the outer circumference.

The rotating annular element **60** is arranged in the C-shaped opening between the base annular disk **51**. and the second annular disk **53**. The lower circular surface facing the first circular end surface of the first annular disk forms a rotary interface and closes the toroidal cavity so as to form a toroidal chamber.

The rotary interface next to the edges of the toroidal chamber **24** is provided with seal arrangements **54**, **55**.

Bearing arrangements are provided at least between the surface of the rotating annular element and the facing surface of the inner wall (vertical bearing **66**), and between surface of the rotating annular element and the facing inner surface of the second annular disk **53** (horizontal bearing **67**).

In particular, when high pressure fluid in the toroidal chamber is present, the rotary interface is subjected to torque along the axial direction. In that case in particular the horizontal bearing **67** needs to provide sufficient wear resistance to facing surfaces of the second annular disk and the rotating annular element as the contacting area of these surfaces is above the toroidal chamber **24**. In FIG. **4** an alternative embodiment will be described.

In FIG. **3** an inlet aperture **26** and an outlet aperture **62**, **64** are shown in alignment below and above the toroidal chamber **24**.

The inlet aperture **26** extends through the thickness of the base annular disk **50** and is coupled with the incoming fluid line F.

The outlet aperture due to the arrangement of the rotating annular element **60** in the C-shaped toroid **51**, **52**, **53** has a right angled shape comprising an inlet portion **62** that is open towards the toroidal chamber and an outlet portion **64** that is perpendicular to the rotation axis direction and directed radially outward for coupling to the outgoing product piping P. The inlet portion and outlet portion of the outlet aperture could be formed by two intersecting drill holes.

In this embodiment, the outer circumferential portion of the rotating annular element **60** is provided with profiled end portions **60**A, **60**B that cooperate with profiled end portions **50**A, **50**B of the base and second annular disks.

Such profiles advantageously enhance the mechanical stability. It is noticed that the skilled in the art will appreciate that various shapes of the end profiles **60**A, **60**B; **50**A, **50**B are conceivable.

FIG. **4** shows a cross-section of a swivel **16** in accordance with a further embodiment of the invention. The embodied swivel **16** is substantially identical to the swivel **15** described above with reference to FIG. **3**. In FIG. **4** entities with the same reference number as shown in the preceding FIG. **3** refer to similar or same entities and will not be discussed here.

In the swivel **16** of this embodiment, a horizontal hydrostatic bearing **65** is provided at the horizontal portion of the rotary interface between the second annular disk **53** of the fixed annular element and the upper surface of the rotating annular element **60**. In addition a borehole **63** is provided that extends from the outlet aperture **62**, **64** to the surface of the rotating annular element at the location of the horizontal hydrostatic bearing **65**. By providing high pressure fluid to the hydrostatic bearing during use of the swivel **16**, a same pressure will be present at the rotary interface between the second annular disk **53** of the fixed annular element and the upper surface of the rotating annular element **60** as will be present at the side of the toroidal chamber. In this manner a counter force is present that at least reduces or minimizes the torque on the swivel **16**. As a result, wear on the rotary interface will be significantly reduced.

According to an embodiment, adjacent to the horizontal hydrostatic bearing **65** seal arrangements **56**, **57** are provided to avoid leakage from the hydrostatic bearing **65**.

FIG. **5** shows a perspective partially cut-away view of a swivel in accordance with an embodiment of the invention.

The swivel **17** of this embodiment, is similar to the embodiments **15**, **16** shown in FIGS. **3** and **4**. The swivel comprises a C-shaped toroid **51**, **52**, **53** which is arranged as fixed annular element **50** that can be coupled to the incoming fluid line and a rotating annular element **60** that is positioned within the C-shaped toroid and can be coupled to the outgoing product piping. In between the C-shaped toroid **50** and the rotating annular element **60** the toroidal chamber **24** and the rotary interface are present that allow transfer of high pressure fluid over the rotary interface.

In this embodiment, between the second annular disk **53** and the upper surface **601** of the rotating annular element **60**, a bearing arrangement **70**, **71** (shown here as multiple layers) is provided. The bearing arrangement is a thrust bearing type and comprises either roller bearings or friction bearings.

At the rotary interface adjacent to the toroidal chamber **24**, on each edge of the toroidal chamber an plurality of face seals **72** is arranged. Further, at the vertical interface between the C-shaped toroid **50** and the rotating annular element **60** a vertical bearing is arranged.

FIGS. **6**A and **6**B show a perspective view and a cross-sectional view respectively of a number of concentric swivels in accordance with an embodiment of the invention.

As the diameter of the swivel according to the invention has no significant effect on the vertical stresses on the swivel, the diameter can be chosen arbitrarily to any practical size without the need for excessive reinforcements for larger diameters. This allows to design an arrangement **100** of a series of concentric swivels **10** at substantially a same operational level L. Advantageously, this type of swivel arrangement **100** is more compact than a swivel stack arrangement of prior art swivels, saving space and weight in a turret mooring system.

The swivel arrangement according to the invention can create savings at least of the following order, pending on flow manifolding parameters, which are the smaller pipes size, which affects their required quantity and subsequently affects the swivel toroidal cavity and therefore its overall size.

FIG. **7** shows a schematic side view of a swivel stack comprising swivels in accordance with an embodiment of the invention.

According to an embodiment, a plurality of swivels **10**;**16** can be stacked in a relatively optimized manner. A number of swivels can be arranged concentrically in the horizontal direction X. This horizontal arrangement can be combined with a vertical stacking (Y) of swivels or multiple concentrically arranged swivels.

Swivels according to an embodiment of the invention are arranged at different operational levels LL above each other and also in concentric arrangement. Due to reduced requirements of enforcements and space, the weight and size of the swivel stack is relatively low and the swivel stack can be designed to be compact.

Stacking according to this method, results in a reduction of the overall swivel stack size, weight and cost where the fixed flow line entering the stack is divided into multiple smaller pipes connected to multiple smaller swivel inlets. Multiple swivel outlets connected to smaller pipes are then interconnected to at least one rotating flow line recreating thus the equivalent flow as the fixed flow line entering the stack.

Furthermore, a swivel stack **200** comprising one or more swivels as described above can be used in a swivel stack throughput repair or upgrade method where at least one new swivel in accordance with the invention is assembled concentrically around an existing (not necessarily prior art) swivel stack and connected via flow lines to the fixed and rotating stream lines of the FPSO, insuring thus the flow continuity.

In addition, a swivel according to any embodiment, can be equipped with a manifold header on either the fixed annular element or the rotating annular element in order to reduce the number of inlet or outlet pipes connected to the swivel. The respective header thus provides multiple paths either entering or departing the toroidal cavity.

In an embodiment, a swivel stack made with one or more swivels according to the invention has a header system for the incoming fluid flow which divides the incoming flow line in multiple smaller flow lines before entry of the swivel and has another header system that concentrates outgoing multiple flow lines into at least one larger outgoing flow line downstream of the swivel stack.

In relation to the swivel stack arrangements shown here, a swivel according to an embodiment of the invention may comprise a single input to an inner annular element and multiple outputs on the outer annular element of the rotary interface.

Furthermore, the swivel according to the invention may be designed to have the incoming fluid line pass through the center of the rotary interface, and connect with the swivel on the inner element of the swivel while the outgoing product piping exits through the outer periphery of the swivel. The incoming fluid line then substantially coincides with the rotation axis of the swivel.

Alternatively, the situation may be reversed in that the incoming fluid line(s) connect to the outer element of the swivel, and the outgoing product piping connects with the inner swivel element and passes through the center of the rotary interface. In that case, the outgoing product piping substantially coincides with the rotation axis of the swivel.

The invention has been described with reference to the preferred embodiment. Obvious modifications and alterations will occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims.

The invention claimed is:

1. A swivel for transfer of pressure flows of oil and/or gas across a rotary interface formed around a swivel rotation axis between an incoming fluid line and an outgoing product piping, the swivel comprising:

a fixed annular element; and

a rotating annular element,

each of the fixed annular element and the rotating annular element arranged around a common rotation axis,

the fixed annular element comprising an annular disk provided with circular end surfaces and a toroidal cavity inside a first of said circular end surfaces, and

the rotating annular element having a flat circular end surface that is adjacent to and located in proximity above said first circular end surface of said annular disk of the fixed annular element so as to close the toroidal cavity of the fixed annular element and thereby form a toroidal chamber within said annular disk,

the rotary interface being formed by the flat circular end surface of the rotating annular element and the first circular surface of the fixed annular element located adjacent thereto, the rotary interface being perpendicular to the common rotation axis,

wherein the fixed annular element comprises an inner wall and an outer wall,

a first end of the inner wall connected to an inner portion of the fixed annular disk, and one end of the outer wall connected to an outer portion of the fixed annular disk, such that the fixed annular element forms a "U-shape" in cross-section,

and the rotary interface between the rotating annular element and the fixed annular element being arranged in between the inner and outer walls of the fixed annular element,

wherein the rotating annular element has at least one outlet aperture passing through outlet aperture configured to provide a fluid communication between the toroidal chamber and outgoing product piping,

wherein the at least one outlet aperture extends perpendicularly from the flat circular end surface of the rotating annular element and parallel to the common rotation axis, and

wherein in a top region of the toroidal cavity, crossbars are fixedly arranged in radial direction in the cavity between the inner wall and the outer wall.

2. The swivel according to claim **1**, wherein the annular disk has at least one inlet aperture that couples the incoming fluid line to the toroidal cavity.

3. The swivel according to claim **2**, wherein the at least one inlet aperture comprises a plurality of externally interconnected inlet apertures distributed over the circle of the toroidal cavity, and the at least one outlet aperture comprises a plurality of externally interconnected outlet apertures distributed over the circle of the toroidal chamber.

4. The swivel according to claim **1**, further comprising:

retaining elements that retain the rotating annular element between the inner and outer walls of the fixed annular element, the retaining elements being fixed to the inner and outer walls and configured to hold the rotating annular element in position over the toroidal cavity.

5. The swivel according to claim **1**, wherein the swivel comprises sealing means adjacent to the edges of the toroidal cavity between the annular disk and the rotating annular element.

6. The swivel according to claim **1**, wherein the crossbars are distributed about the toroidal cavity at a constant intermediate angle.

7. The swivel according to claim **1**, wherein the toroidal cavity extends over 360° around the common rotation axis.

8. A vessel for offshore operations comprising a turret mooring system, wherein the turret mooring system is equipped with a swivel according to claim **1**.

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