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(54) Title: A FLUID INLET/OUTLET INTERFACE FOR AN AXIAL PISTON MOTOR OR PUMP

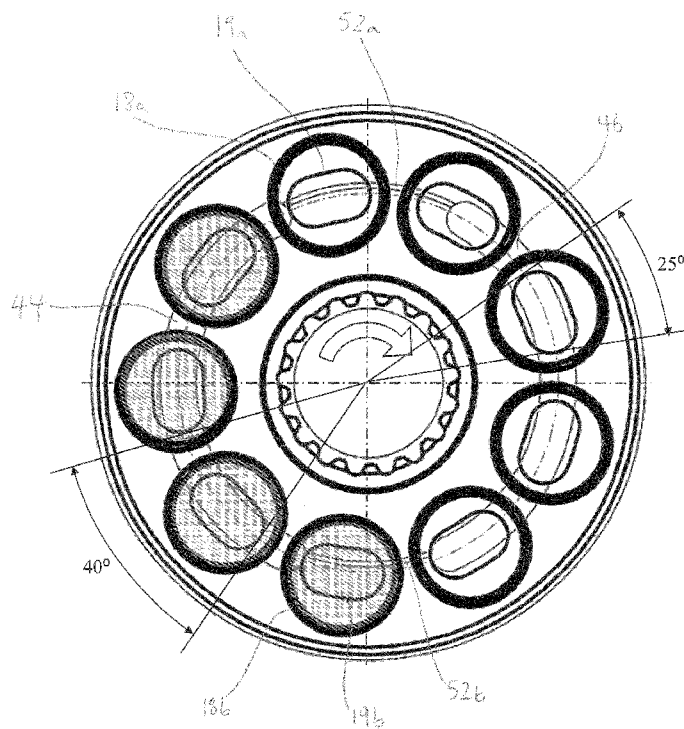


Figure 6a

(57) Abstract: A fluid inlet/outlet interface for an axial piston motor or pump comprising a rotatable cylinder block defining a plurality of cylinder bores each having a respective piston mounted for reciprocal movement therein, the interface comprising: a first slot and a second slot arranged so that, in use, fluid is input to the cylinder bores via the first slot and output from the cylinder bores via the second slot as the cylinder block rotates; and a first conduit fluidically connecting the first slot and the second slot, the first conduit arranged so that, in use, as each cylinder bore sweeps between the first slot and the second slot it is exposed to the first conduit.



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5 **A FLUID INLET/OUTLET INTERFACE FOR AN AXIAL PISTON**
 MOTOR OR PUMP

Technical Field

10 The present invention relates to a fluid inlet/outlet interface for an axial piston motor or pump, and an axial piston motor or pump comprising the same.

Background

15 Hydraulic axial piston pumps transform rotational movement of a drive shaft into a hydraulic flow, resistance to which develops a hydraulic pressure, which may be used to power hydraulic actuators. Conversely, hydraulic motors transform hydraulic pressure into rotation of a drive shaft. Fundamentally, the structure and principles of operation of hydraulic motors and hydraulic pumps are the same. Each comprises a circumferential array of pistons housed in respective bores (cylinders) of a cylinder block. Each cylinder is filled with hydraulic fluid, which is allowed to enter or leave
20 the cylinder at different points in the cycle of the pump or motor via inlet and outlet kidney slots of a wafer plate. The inlet and outlet kidney slots form part of a path for hydraulic fluid arriving at or leaving the pump or motor. The pistons are able to reciprocate within the cylinders, and each piston has an end that projects from the cylinder block that is provided with a piston shoe. Through the piston shoe, the piston
25 engages an inclined bearing surface supported by a yoke. The yoke and bearing surface are commonly referred to as a swash plate. The cylinder block is connected to a drive shaft, which provides the rotational output, in the case of a hydraulic motor, or the rotational input, in the case of a hydraulic pump. The inclined yoke causes each of the pistons to reciprocate with a phased timing. The timing is typically arranged
30 such that as a given piston is compressing, the cylinder is exposed to the outlet kidney slot and hydraulic fluid is able to leave the cylinder. Conversely, as the piston is decompressing, the cylinder is exposed to the inlet kidney slot and hydraulic fluid is able to enter the cylinder.

In the case of hydraulic motors, in which hydraulic power is used to generate mechanical power, high-pressure hydraulic fluid is provided to the inlet kidney slot, which causes extension of the pistons in a portion of the cycle of rotation where they are exposed to the inlet kidney slot. This in turn causes the cylinder block and drive shaft to rotate. Pistons in a portion of the cycle of rotation exposed to the outlet kidney slot are forced to compress by the inclined yoke. As the pistons begin to retract, low-pressure hydraulic fluid is expelled from the chamber through the outlet kidney slot.

10 In the case of hydraulic pumps, in which mechanical power is used to generate hydraulic power, the drive shaft may be driven by an external motor, for example an electric motor, which in turn causes the cylinder block to rotate. The cylinder block in turn carries the pistons, which are forced to reciprocate by the inclined yoke. In portions of the cycle where the pistons are compressing, the cylinders are exposed to the outlet kidney slot and high-pressure hydraulic fluid is forced out of the outlet kidney slot. In portions of the cycle of rotation where the cylinders are decompressing, the cylinders are exposed to the inlet kidney slot and low-pressure hydraulic fluid is drawn into the cylinders through the inlet kidney slot.

20 Hydraulic motors and hydraulic pumps have applications such as powering the control surfaces of aircraft.

In both hydraulic pumps and motors, there are portions of the cycle where the cylinders are not exposed to either the inlet or outlet kidney slots. In these portions of the cycle the cylinder occupies a 'dead space' where movement of fluid into or out of the cylinder is restricted as the cylinder moves from a low-pressure portion of the cycle to a high-pressure portion of the cycle, or vice versa. As the cylinder moves from the dead space to a portion of the cycle where it is open to one or other of the kidney slots, the pressure in the cylinder can change abruptly. This in turn, causes a momentary force to be transmitted through the piston and causes the yoke to experience a moment where the force applied to one side of the yoke is not balanced by an opposing force. As successive cylinders are exposed to an abrupt change in

pressure, the pressure pulsation causes vibration, cavitation erosion, damage to seals, and subsequent leakage. Conventionally, techniques for pre-compressing the piston as it travels through the dead space are employed. However, these techniques still result in pressure pulsations as the cylinders experience a change in pressure, and they do not provide a non-varying moment applied to the yoke.

It is desirable to provide hydraulic pumps and motors with a reduced level of pressure pulsation and associated vibration.

10 Summary

In accordance with a first aspect of the present invention, there is provided a fluid inlet/outlet interface for an axial piston motor or pump comprising a rotatable cylinder block defining a plurality of cylinder bores each having a respective piston mounted for reciprocal movement therein, the interface comprising:

15 a first slot and a second slot arranged so that, in use, fluid is input to the cylinder bores via the first slot and output from the cylinder bores via the second slot as the cylinder block rotates; and

a first conduit fluidically connecting the first slot and the second slot, the first conduit arranged so that, in use, as each cylinder bore sweeps between the first slot and the second slot it is exposed to the first conduit.

The first conduit enables a pressure gradient to be supported, to which, in use, the cylinder are exposed as they sweep from one slot to the other slot during a cycle. This in turn provides a smooth transition of each cylinder between the fluid pressures, which reduces pressure pulsations and vibration of the motor or pump. In turn, cavitation erosion, seal damage, and leakage of hydraulic fluid are all reduced. Furthermore, since the fluid pressure in cylinders at positions between the first and second slots are able to change because of the pressure gradient, the pistons are able to move with a greater degree of freedom. This avoids fluid being trapped in the pistons when they are between slots when the drive shaft is not rotating.

In some embodiments, in use, the first conduit supports a fluid pressure gradient between the first and second slots. Preferably, the pressure gradient supported by the conduit is substantially linear.

5 In some embodiments, the first conduit connects a first pair of opposing ends of the first and second slots, and the interface further comprises a second conduit fluidically connecting a second pair of opposing ends of the first and second slots, the first conduit and second conduit arranged so that, in use, as each cylinder bore sweeps from the first slot to the second slot it is exposed to the first conduit and as each
10 cylinder bore sweeps from the second slot to the first slot it is exposed to the second conduit. By exposing the cylinders to grooves as the cylinders sweep from the first slot to the second slot, and as they sweep from the second slot to the first slot, the cylinders benefit from smooth variation in pressure throughout the whole cycle of rotation.

15 In some embodiments, the first and second slots are arcuate slots. Since the path followed by the cylinders is circular, this enables the cylinders to remain central to the slots as they rotate with the cylinder block, and to be exposed to a substantially constant fluid pressure for predetermined portions of the cycle, dependent on the
20 angular extent of the respective arcuate slots.

In some embodiments, a radius of curvature of the first arcuate slot is substantially equal to a radius of curvature of the second arcuate slot.

25 In some embodiments, the fluid conduit comprises an elongate arcuate groove.

In some embodiments, the arcuate groove has a radial cross-section that is substantially constant along its length. By providing grooves with a radial cross-section that is substantially constant along its length, the groove is able to support a
30 fluid pressure gradient that varies linearly between each of the first and second slots. This further reduces variation in the moment exerted by the hydraulic fluid as a given cylinder passes from one slot to another.

In some embodiments, the first conduit comprises a first arcuate groove and the second conduit comprises a second arcuate groove and a radius of curvature of the first arcuate groove is different to a radius of curvature of the second arcuate groove.

5 By offsetting the radii of the first and second grooves, wear of the face of the cylinder block adjacent to the fluid inlet/outlet interface is more evenly distributed since, in use, all of the top face of the cylinder block is exposed to mechanical contact with the fluid inlet/outlet interface for at least part of the cycle.

10 In some embodiments, the radius of curvature of the first and second grooves is different to a radius of curvature of a path swept by each of the cylinders.

In accordance with a second aspect of the invention, there is provided an axial piston motor or pump comprising a rotatable cylinder block defining a plurality of cylinder bores each having a respective piston mounted for reciprocal movement therein and a fluid inlet/outlet interface in accordance with the first aspect.

15 bores each having a respective piston mounted for reciprocal movement therein and a fluid inlet/outlet interface in accordance with the first aspect.

In some embodiments, the axial piston motor or pump comprises:

20 a drive shaft connected to the cylinder block defining a central rotational axis;
and
a yoke inclinable with respect to the central rotational axis;
wherein the fluid inlet/outlet interface is arranged to form a hydraulic seal with a first surface of the cylinder block and, in use, as each cylinder bore sweeps between the first slot and the second slot it is exposed to the fluid conduit.

25 The axial piston motor or pump of the second aspect may be adapted to provide features, and advantages, corresponding to those of the first aspect.

In some embodiments, the cylinder block comprises a first number of cylinders, the first number being an odd number.

30 first number being an odd number.

In some embodiments, , in use, a second number of cylinder are exposed to neither of the first and second slots at any given time, the second number being an odd number lower than the first number.

- 5 In some embodiments, in use, one cylinder is exposed to neither of the first and second slots at any given time. This enables the total number of cylinders exposed to the first and second slots to remain substantially equal throughout the cycle, and provides a greatly reduced variation of moment acting on the yoke.
- 10 Further features and advantages of the invention will become apparent from the following description of preferred embodiments of the invention, given by way of example only, which is made with reference to the accompanying drawings.

Brief Description of the Drawings

- 15 Figure 1 shows a perspective view of a typical hydraulic pump or hydraulic motor with a partial cutaway of the motor casing, valve block, and fluid inlet/outlet interface, according to an embodiment of the present invention;

- Figure 2 shows a section view of a piston and piston shoe suitable for use in a hydraulic pump or hydraulic motor according to an embodiment of the present invention;
- 20

- Figure 3 shows a cross section view of a variable displacement hydraulic pump or hydraulic motor according to an embodiment of the present invention;
- 25

- Figure 4a shows a cross section view of a variable displacement hydraulic pump or hydraulic motor according to an embodiment of the present invention, set for maximum displacement;

- 30 Figure 4b shows a cross section view of a variable displacement hydraulic pump or hydraulic motor according to an embodiment of the present invention, set for intermediate displacement;

Figure 4c shows a cross section view of a variable displacement hydraulic pump or hydraulic motor according to an embodiment of the present invention, set for low displacement;

- 5 Figure 5 shows a face of a fluid inlet/outlet interface according to an embodiment of the present invention;

Figure 6a shows a cross-section across the axis of rotation of a hydraulic pump or hydraulic motor at the interface between a cylinder block and a cylinder block
10 interface according to an embodiment of the invention;

Figure 6b shows a cross-section across the axis of rotation of a hydraulic pump or hydraulic motor at the interface between a cylinder block and a cylinder block
15 interface according to an embodiment of the invention;

Detailed Description

Although throughout the following description reference is made to hydraulic motors, it will be understood that embodiments of the invention are equally suited for use in hydraulic pumps.

20 Figure 1 shows a partial cutaway perspective view of a typical hydraulic motor 10 in which embodiments of the present invention might be used. The hydraulic motor 10 comprises a motor casing 12, in which a cylinder block 14 is located. The cylinder block 14 is free to rotate within motor casing 12.

25 The cylinder block 14 has a central bore, which extends along the length of the cylinder block 14. The central bore has a central longitudinal axis L. A drive shaft 16 extends through the central bore of the cylinder block 14 and the axis of rotation of the drive shaft 16 is aligned with the central longitudinal axis L of the central bore of
30 the cylinder block 14. The drive shaft 16 is mated to the cylinder block 14, for example by splines (not shown), such that the drive shaft 16 rotates with the cylinder block 14. The drive shaft 16 extends through an opening in the motor casing 12 to

enable the motor 10 to drive an external device (not shown). The drive shaft 16 is supported in the opening by a bearing (not shown). The drive shaft 16 and the cylinder block 14 are free to rotate relative to the motor casing 12 about the central longitudinal axis L.

5

An array of cylinders 18 are positioned circumferentially about the central longitudinal axis L. Pistons 20 are located in each of the cylinders 18. Hydraulic fluid 22 fills the space in each cylinder 18 not occupied by its respective piston 20 at any given time. Each of the cylinders has a cylinder opening 19, through which
10 hydraulic fluid 22 can enter or leave the cylinder 18. In some embodiments, the cylinder openings 19 are arcuate slots arranged about the central longitudinal axis L, with a radius of curvature centred on the central longitudinal axis L and substantially equal to the separation between the centres of each cylinder 18 and the central longitudinal axis L. Each of the pistons 20 has an external diameter that is smaller
15 than the internal diameter of its corresponding cylinder 18, and the diameters of the pistons 20 and cylinders 18 are chosen to provide a clearance fit, such that the pistons 20 can each reciprocate freely in their respective cylinders 18.

Each of the pistons 20 projects from one end of its respective cylinder 18. As shown
20 in figure 2, at the projecting end of each piston 20 is a ball projection 24 arranged to engage with a socket 26 on one side of a piston shoe 28. The ball projection 24 and socket 26 together form a ball and socket joint that enable the piston shoe 28 to rotate about the ball projection 24 in three axes of rotation.

25 Each piston shoe 28 comprises a bearing surface 30a, which is in contact with a bearing surface 30b of a yoke 32. The portion of the piston shoes 28 supporting the bearing surface is wider than the socket portion and therefore forms a lip around the edge of the piston shoe 28. A retainer plate 34 having apertures with positions corresponding to the positions of the pistons 20 and piston shoes 28, holds the piston
30 shoes 28 in contact with the yoke 32.

The yoke 32 is attached to the motor casing 12 by pintles 36 that are supported by respective pintle bearings (not shown) in the motor casing 12. The pintles 36 enable the yoke 32 to incline with respect to the central longitudinal axis L. The yoke 32 has a central bore aligned with the central longitudinal axis L and through which the drive shaft 16 passes. The diameter of the central bore is larger than the diameter of the drive shaft 16 in order that the drive shaft 16 is free to rotate.

As is known in the art, control pistons are positioned within the motor casing symmetrically about an axis defined by the pintles 36, and each piston selectively acts on a respective control piston pad on the yoke. Actuation of the control pistons causes pivoting of the yoke 32 about this axis defined by the pintles 36.

As shown in figures 4a to 4c, variation of the angle of inclination of the yoke 32 with respect to the central longitudinal axis L causes variation of the volume of hydraulic fluid 22 passing through motor 10 during each cycle i.e. variation of the speed and torque outlet of the motor 10. Figure 4a shows the yoke 32 inclined at a maximum angle with respect to the direction of rotation of the cylinder block 14. This corresponds to maximum displacement $d_{\max}$ of the pistons and therefore maximum torque applied to the drive shaft 16. As the angle of inclination of the yoke 32 is reduced, as shown in figures 4b and 4c, the displacement d of the pistons 20 reduces and therefore so does the torque applied to the drive shaft 16. The yoke 32 may be inclined either negatively or positively with respect to the zero displacement position; varying the inclination of the yoke to be 'over-centre' in this way, changes the direction of rotation and enables the motor 10 to be bi-directional.

Returning to figure 1, each cylinder 18 is terminated at one end by its respective piston 20, and at the other end by a wafer plate 42. The wafer plate 42 has two kidney slots, an inlet kidney slot 44 and an outlet kidney slot 46. The inlet kidney slot 44 and outlet kidney slot 46 are arcuate slots arranged about the central longitudinal axis L, each arcuate slot 44, 46 having a radius of curvature centred on the central longitudinal axis L and substantially equal to the separation between the centres of each cylinder 18 and the central longitudinal axis L, such that as the drive shaft 16 and

cylinder block 14 rotate, the cylinders 18 sequentially sweep over both kidney slots 44, 46 during a cycle. The wafer plate 42 is described in detail below.

The cylinder block 14, pistons 20, and wafer plate 42 are enclosed in the motor casing 12 by a valve block 48. A high-pressure inlet port 50h and a low-pressure outlet port 50l within the valve block 48 provide a path for hydraulic fluid 22 to enter and leave the cylinders 18. The wafer plate 42 therefore acts as an inlet/outlet interface between the inlet and outlet ports 50h, 50l, and the cylinder block 14.

Figure 5 shows a schematic illustration of a wafer plate 42 according to an embodiment of the present invention. A pair of conduits 52a, 52b formed as grooves on the surface of the wafer plate 42 fluidically connects the inlet kidney slot 44 with the outlet kidney slot 46. The conduit 52a connects a first pair 44a, 46a of opposing ends of the inlet and outlet kidney slots 44, 46 and the conduit 52b connects a second pair 44b, 46b of opposing ends of the inlet and outlet kidney slots 44, 46. The conduits 52a, 52b are arcuate about the central longitudinal axis L of the hydraulic motor 10.

During operation of the hydraulic motor 10, hydraulic fluid 22 is supplied to the motor 10 from the inlet port 50h through the inlet kidney slot 44. Cylinders 18 exposed to high-pressure hydraulic fluid at the inlet kidney slot 44 become pressurised causing their respective pistons 20 to extend. The piston shoes 28 bear onto the yoke 32, and the inclination of the yoke 32 causes the piston shoes 28 to sweep across the bearing surface 30b of the yoke 32; the cylinder block 14, in which the pistons 20 are carried, then rotates with respect to the yoke 32.

Since the yoke 32 is inclined, as the cylinder block 14 rotates, the degree of extension of the pistons 20 varies with the degree of rotation of the cylinder block 14. In one full rotation of the cylinder block 14, each piston 20 revolves once about the central longitudinal axis L and completes one cycle of compression and decompression i.e. moves in and out of its respective cylinder 20 once.

During one cycle of rotation each cylinder sweeps around the wafer plate 42 and is sequentially exposed to the inlet and outlet kidney slots 44, 46. The wafer plate 42 is orientated with respect to the yoke 32 such that during portions of the cycle where the pistons 20 are compressing, the cylinder openings 19 of the cylinders 18 are exposed to the outlet kidney slot 46, and during portions of the cycle where the pistons 20 are extending, the cylinder openings 19 of the cylinders 18 are exposed to the inlet kidney slot 44. For hydraulic motors 10, the outlet kidney slot 46 is the low-pressure kidney slot, and the inlet kidney slot 44 is the high-pressure kidney slot. Conversely, for hydraulic pumps, the inlet kidney slot 44 is the low-pressure kidney slot, and the outlet kidney slot 46 is the high-pressure kidney slot.

The positions of the inlet and outlet kidney slots 44, 46 are such that the cylinder openings 19 of the cylinders 18 are exposed to one or other of the kidney slots 44, 46 in the portions of the cycle where the piston position is changing at the highest rate. The angular extent of the inlet and outlet kidney slots 44, 46 about the central longitudinal axis L is such that by the time a kidney slot 44, 46 is 'closed' to a given cylinder opening 19, the respective piston 20 is near the end of its stroke. This ensures that catastrophically high pressures are not able to build up in the cylinders 18.

During parts of the cycle where a given cylinder opening 19 is between the inlet and outlet kidney slots 44, 46, the cylinder opening 19 is exposed to one of the conduits 52a, 52b. Since the conduits 52a, 52b are fluidically coupled to each of the kidney slots 44, 46, hydraulic fluid 22 can traverse the conduits 52a, 52b. Each of the conduits 52a, 52b is formed as a groove in the face of the wafer plate 42. The dimensions of the grooves are such that an impedance of the conduits 52a, 52b to flow of hydraulic fluid 22 is sufficiently high to prevent high parasitic flows of hydraulic fluid 22 through the conduits 52a, 52b, and to maintain a pressure gradient between the inlet and outlet kidney slots 44, 46. The grooves have a constant radial cross-section along their lengths to provide a pressure gradient that varies substantially linearly between the inlet and outlet kidney slots 44, 46. Furthermore, since the grooves are circumferential and overlap with the trajectory swept by the cylinders 18

as the cylinder block 14 rotates, the cylinder openings 19 sweep along the grooves and are exposed to the linearly varying pressure as they move between the kidney slots 44, 46. The result of this is that the pressure in each cylinder 18 does not change abruptly, but varies smoothly as the cylinder opening 19 moves between kidney slots 44, 46. This gradually changing pressure applies a moment to the yoke 32 that is almost exactly counteracted by the changing moments applied to other pistons 20 exposed to pressurised hydraulic fluid 22 from the kidney slots 44, 46.

Exposing the cylinder slots 19 to the grooves during the portion of the cycle of rotation where the cylinders pass from the inlet kidney slot 44 to the output kidney slot 46 and during the portion of the cycle where the cylinders 18 pass from the outlet kidney slot 46 to the inlet kidney slot 44, not only provides a less abrupt overall variation in cylinder pressure and moment applied to the yoke, but enables this advantage in both directions of rotation in bi-directional motors and pumps.

Advantageously, when the drive shaft 16 is not rotating (or rotating very slowly) the conduits 52a, 52b also provide a route for hydraulic fluid 22 to flow into or out of those cylinders 18 that are in the closed regions between the kidney slots 44, 46. This prevents trapping of a volume of hydraulic fluid 22 in the cylinders 18, which would otherwise inhibit movement of the pistons 20, and thus enables the inclination of the yoke 32 to be varied by the control pistons 38 without there being created an excessive amount of fluid pressure in these cylinders. As the inclination of the yoke 32 is varied, cylinders 18 on one side of the motor 10 will, on average, be losing volume, while cylinders 18 on the opposite side of the motor 10 will, on average, be increasing in volume. Cylinders 18 in which the volume reduces are able to drain hydraulic fluid 22 via the conduits 52a, 52b, and cylinders in which the volume increases are able to draw in hydraulic fluid 22 (or air if the motor 10 is not operating) via the conduits 52a, 52b. Furthermore, when the motor is turned off following a period of use, the conduits 52a, 52b enable pressurised hydraulic fluid 22 to drain more easily from those cylinders that are in the closed regions between the kidney slots 44, 46 to prevent those cylinders 18 from remaining pressurised.

In the embodiment shown in figure 5, the radius of curvature of each of the conduits 52a, 52b are different, and neither is coincident with the radius of curvature of the inlet and outlet kidney slots 44, 46. Advantageously, this ensures that as the cylinder block 14 rotates no portion of the surface of the cylinder block 14 that sweeps across the wafer plate 42 is only exposed to portions of the wafer plate 42 that are occupied by the kidney slots 44, 46 or the conduits 52a, 52b i.e. not exposed to any solid part of the wafer plate 42. This in turn minimises uneven wear patterns forming on the face of the cylinder block 14.

The result is that the conduits 52a, 52b remove the abrupt change in pressure that would be experienced by each of the cylinders 18 in the absence of the conduit 52a, 52b. This in turn greatly reduces the abrupt changes in pressure experienced by the cylinders 18 and greatly reduces the abrupt change in moment experienced by the yoke 32. This is particularly important in variable displacement motors and pumps, in which the moment is transmitted to the control pistons 36. With a conduit 52a, 52b that supports a linear pressure gradient between kidney slots 44, 46 the net effect is firstly to reduce the overall maximum magnitude of yoke moment in either sense, and secondly to smooth out the yoke moment variation, such that there are no abrupt changes in yoke moment. Typically, the yoke moment oscillates between maximum and minimum values with an amplitude that is significantly less than that of an equivalent motor with a wafer plate 42 that does not have the conduits 52a, 52b.

In the embodiment shown in figure 5, the angular extents of the conduits 52a, 52b are unequal. The conduit 52a has an angular extent of 50° , and the conduit 52b has an angular extent of 40° .

Figures 6a and 6b show section views across the cylinder block 14 and the corresponding central axis of rotation L, showing the positions of the cylinders 18, and cylinder openings 19 relative to the inlet and outlet kidney slots 44, 46 at two points in the cycle.

14

Figure 6a shows the cylinder block 14 at the instant in time that cylinder 18a has just moved from a position where its cylinder opening 19a is exposed to the inlet kidney slot 44 to a position where it is not exposed to the inlet kidney slot 44 and, at the same instant, a second cylinder 18b has just moved from a position where its cylinder opening 19b is not exposed to the inlet kidney slot 44 to a position where it is exposed to the inlet kidney slot 44. At this instant, the three cylinders 18 between cylinders 18a and 18b in the clockwise sense are also exposed to the inlet kidney slot 44 (the four cylinders 18 exposed to the inlet kidney slot 44 are represented by the cross-hatching in figure 6a).

10

Figure 6b shows the cylinder block 14 at the instant in time that cylinder 18a has just moved from a position where its cylinder opening 19a is not exposed to the outlet kidney slot 46 to a position where it is exposed to the outlet kidney slot 46 and, at the same instant, a third cylinder 18c has just moved from a position where its cylinder opening 19c is exposed to the outlet kidney slot 46 to a position where it is not exposed to the outlet kidney slot 46. At this instant, the three cylinders 18 between cylinders 18a and 18c in the clockwise sense are also exposed to the outlet kidney slot 46 (the four cylinders 18 exposed to the outlet kidney slot 46 are represented by the cross-hatching in figure 6b).

20

In this example, at any given time, only one of the cylinders 18 is not exposed to either of the inlet and outlet kidney slots 44, 46. Since there are an odd number of cylinders in total, nine in this example, an equal number of cylinders 18, four in this example, are exposed to each of the inlet and outlet kidney slots 44, 46 at any given time, and the total number of cylinders 18 exposed to the kidney slots 44, 46 remains substantially equal throughout the cycle. Consequently, as the cylinder block 14 rotates, the net moment acting on the yoke 32 varies by only a small amount, since the increasing moment applied in one sense, in almost exactly counteracted by an increased moment develop in the opposite sense.

30

In the particular embodiment shown in figures 6a and 6b, the angular extent of each cylinder opening 19 is 25° and since there are 9 cylinders 18, the repeat angle of the

cylinders 18 is 40° . The conduit 52a has an angular extent of 50° , and the conduit 52b has an angular extent of 40° . However, it will be understood that this geometry is exemplary and that other combinations of angles will have the same effect.

5 It will also be understood that cylinder blocks 14 having different numbers of cylinders 18 are possible, though typically an odd number of cylinders 18 will be used to minimise symmetry. In some embodiments, it may be the case that, at any given time, an odd number of cylinders 18, the number being greater than 1, are not exposed to either of the inlet and outlet kidney slots 44, 46 whilst an equal number of cylinders
10 18 are exposed to each of the inlet and outlet kidney slots and the total number of cylinders 18 exposed to the kidney slots 44, 46 remains substantially equal throughout the cycle.

The above embodiments are to be understood as illustrative examples of the
15 invention. Further embodiments of the invention are envisaged. For example, although the inlet/outlet interface is described as being disposed on a wafer plate 42, which is a discreet component, the inlet and outlet kidney slots 44, 46 and the conduit may be formed on the surface of the valve block itself.

20 The above embodiments are described as having two conduits 52a and 52b, however, it will be understood that in some embodiments there may only be a single one of these conduits, or there may be more than two conduits. Furthermore, the conduits need not necessarily be arcuate; for example in some embodiments, the conduit may be in the form of a linear groove.

25

While the conduits 52a and 52b are described as supporting a substantially linear pressure gradient between the inlet and outlet kidney slots 44, 46, it will be understood that in some applications the pressure change across the conduits 52a, 52b may not vary linearly, and/or may comprise one or more intermediate pressures. In
30 the embodiments described above, the inlet and outlet kidney slots 44, 46 are arcuate, but it will be understood that slots having different configurations are possible.

While it is preferable to have an odd number of cylinders, many of the advantages of the invention are available for pumps or motors having an even number of cylinders.

5 The above embodiments are described in relation to a bi-directional variable displacement motor; however, it will be understood that the invention is equally suited to unidirectional and fixed displacement motors, as well as pumps.

10 It is to be understood that any feature described in relation to any one embodiment may be used alone, or in combination with other features described, and may also be used in combination with one or more features of any other of the embodiments, or any combination of any other of the embodiments. Furthermore, equivalents and modifications not described above may also be employed without departing from the scope of the invention, which is defined in the accompanying claims.

Claims

1. A fluid inlet/outlet interface for an axial piston motor or pump comprising a rotatable cylinder block defining a plurality of cylinder bores each having a respective piston mounted for reciprocal movement therein, the interface comprising:
 - a first slot and a second slot arranged so that, in use, fluid is input to the cylinder bores via the first slot and output from the cylinder bores via the second slot as the cylinder block rotates; and
 - a first conduit fluidically connecting the first slot and the second slot, the first conduit arranged so that, in use, as each cylinder bore sweeps between the first slot and the second slot it is exposed to the first conduit.
2. A fluid inlet/outlet interface for an axial piston motor or pump according to claim 1, wherein, in use, the first conduit supports a fluid pressure gradient between the first and second slots.
3. A fluid inlet/outlet interface according to claim 1 or claim 2, wherein, in use, the first conduit is supports a substantially linear fluid pressure gradient between the first and second slots.
4. A fluid inlet/outlet interface according to any preceding claim, wherein the first conduit connects a first pair of opposing ends of the first and second slots, and the interface further comprises a second conduit fluidically connecting a second pair of opposing ends of the first and second slots, the first conduit and the second conduit arranged so that, in use, as each cylinder bore sweeps from the first slot to the second slot it is exposed to the first conduit and as each cylinder bore sweeps from the second slot to the first slot it is exposed to the second conduit.
5. A fluid inlet/outlet interface according to any preceding claim, wherein the first and second slots are arcuate slots.

6. A fluid inlet/outlet interface according to claim 5, wherein a radius of curvature of the first arcuate slot is substantially equal to a radius of curvature of the second arcuate slot.
- 5 7. A fluid inlet/outlet interface according to any preceding claim, wherein the first conduit comprises an elongate arcuate groove.
8. A fluid inlet/outlet interface for an axial piston motor or pump according to claim 7, wherein the arcuate groove has a radial cross-section that is substantially
10 constant along its length.
9. A fluid inlet/outlet interface according to claim 4, wherein the first conduit comprises a first arcuate groove and the second conduit comprises a second arcuate groove and a radius of curvature of the first arcuate groove is different to a radius of
15 curvature of the second arcuate groove.
10. A fluid inlet/outlet interface according to claim 9, wherein the radius of curvature of the first and second grooves is different to a radius of curvature of a path swept by each of the cylinders.
20
11. An axial piston motor or pump comprising a rotatable cylinder block defining a plurality of cylinder bores each having a respective piston mounted for reciprocal movement therein and a fluid inlet/outlet interface according to any of the preceding claims.
25
12. An axial piston motor or pump according to claim 11, further comprising:
a drive shaft connected to the cylinder block defining a central rotational axis;
and
a yoke inclinable with respect to the central rotational axis;
30 wherein the fluid inlet/outlet interface is arranged to form a hydraulic seal with a first surface of the cylinder block and, in use, as each cylinder bore sweeps between the first slot and the second slot it is exposed to the fluid conduit.

13. An axial piston motor or pump according to claim 12, wherein the cylinder block comprises a first number of cylinders, the first number being an odd number.
14. An axial piston motor or pump according to claim 13, wherein, in use, a
5 second number of cylinder are exposed to neither of the first and second slots at any given time, the second number being an odd number lower than the first number.
15. An axial piston motor or pump according to claim 14, wherein, in use, one cylinder is exposed to neither of the first and second slots at any given time.

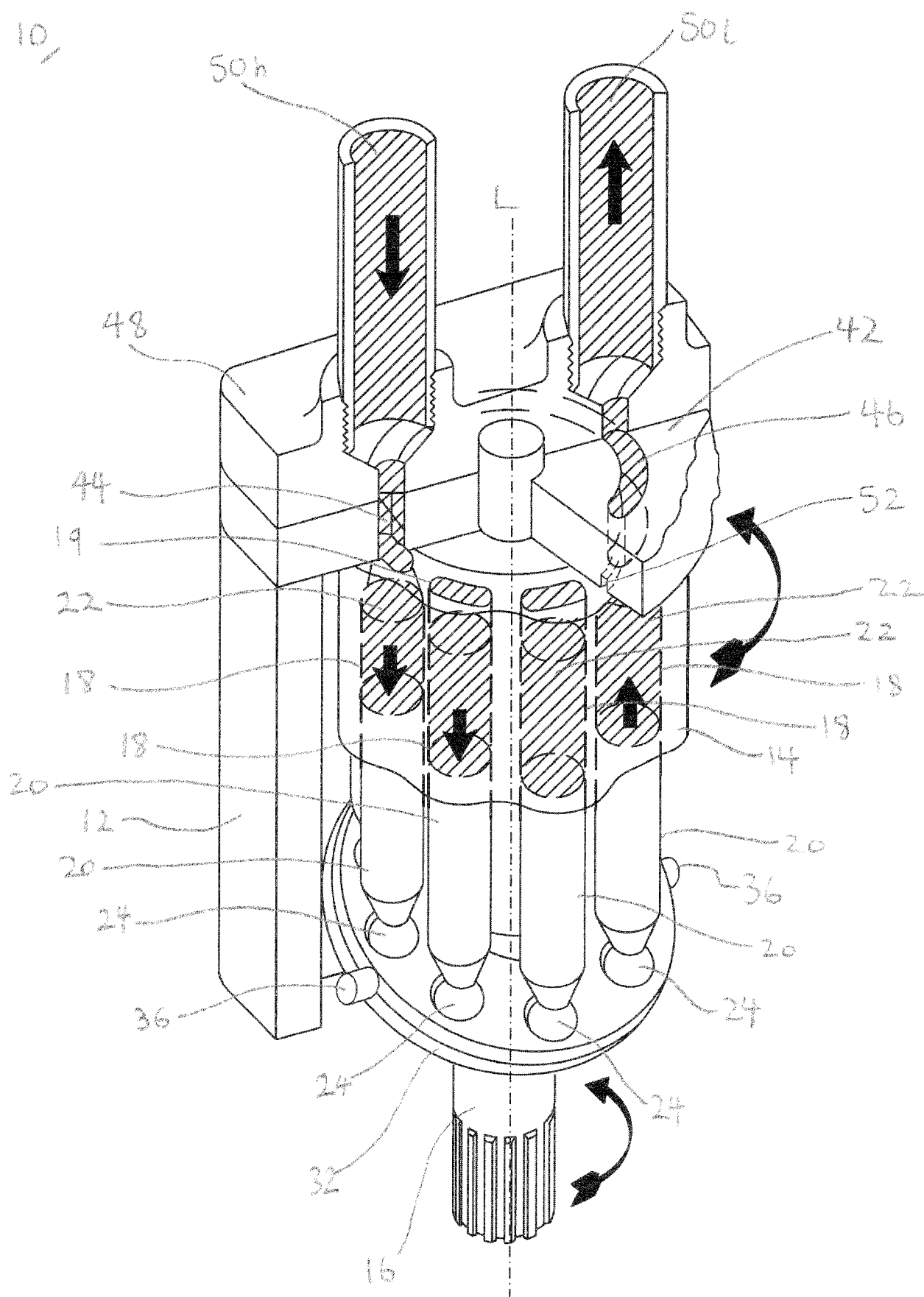


Figure 1

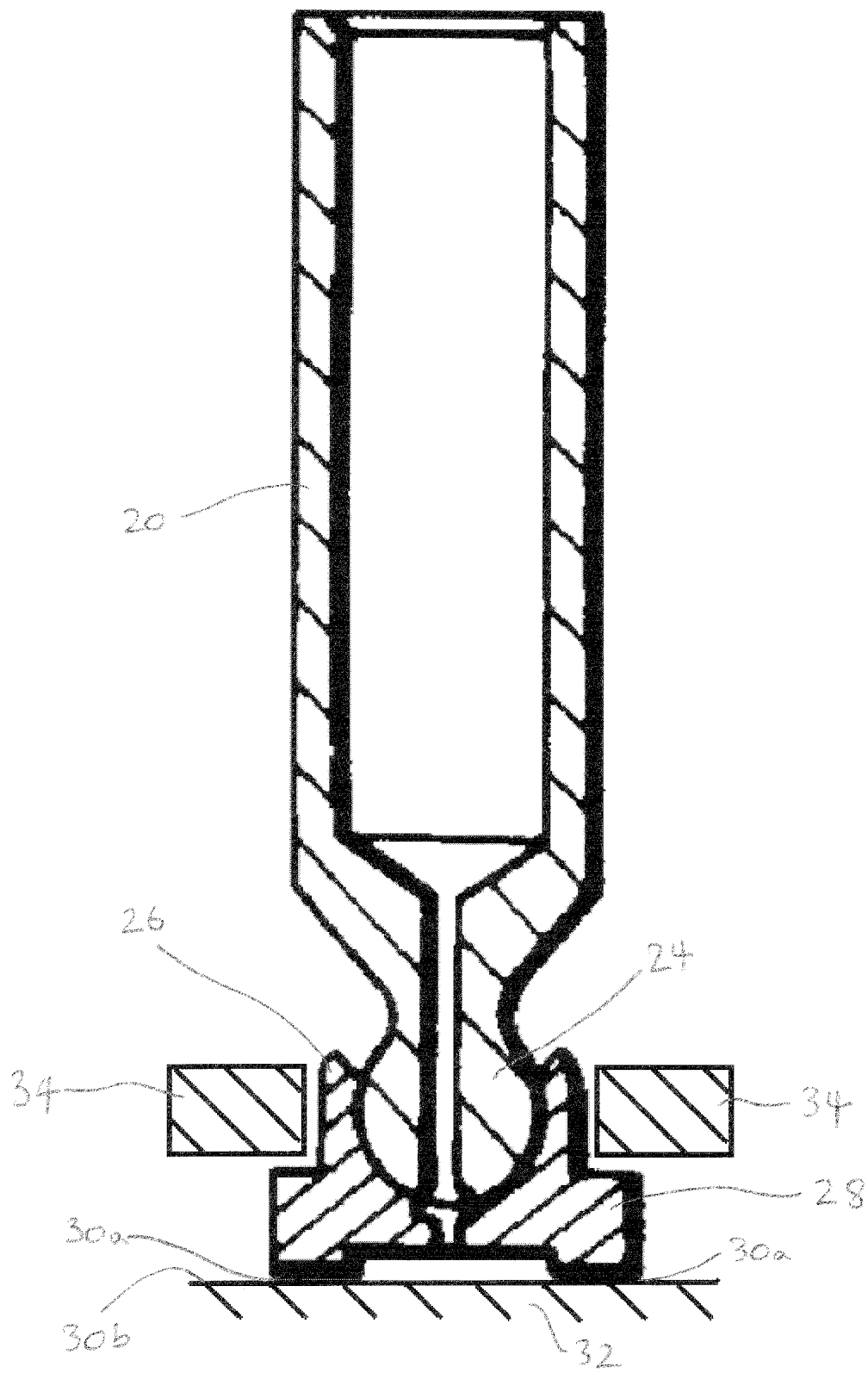


Figure 2

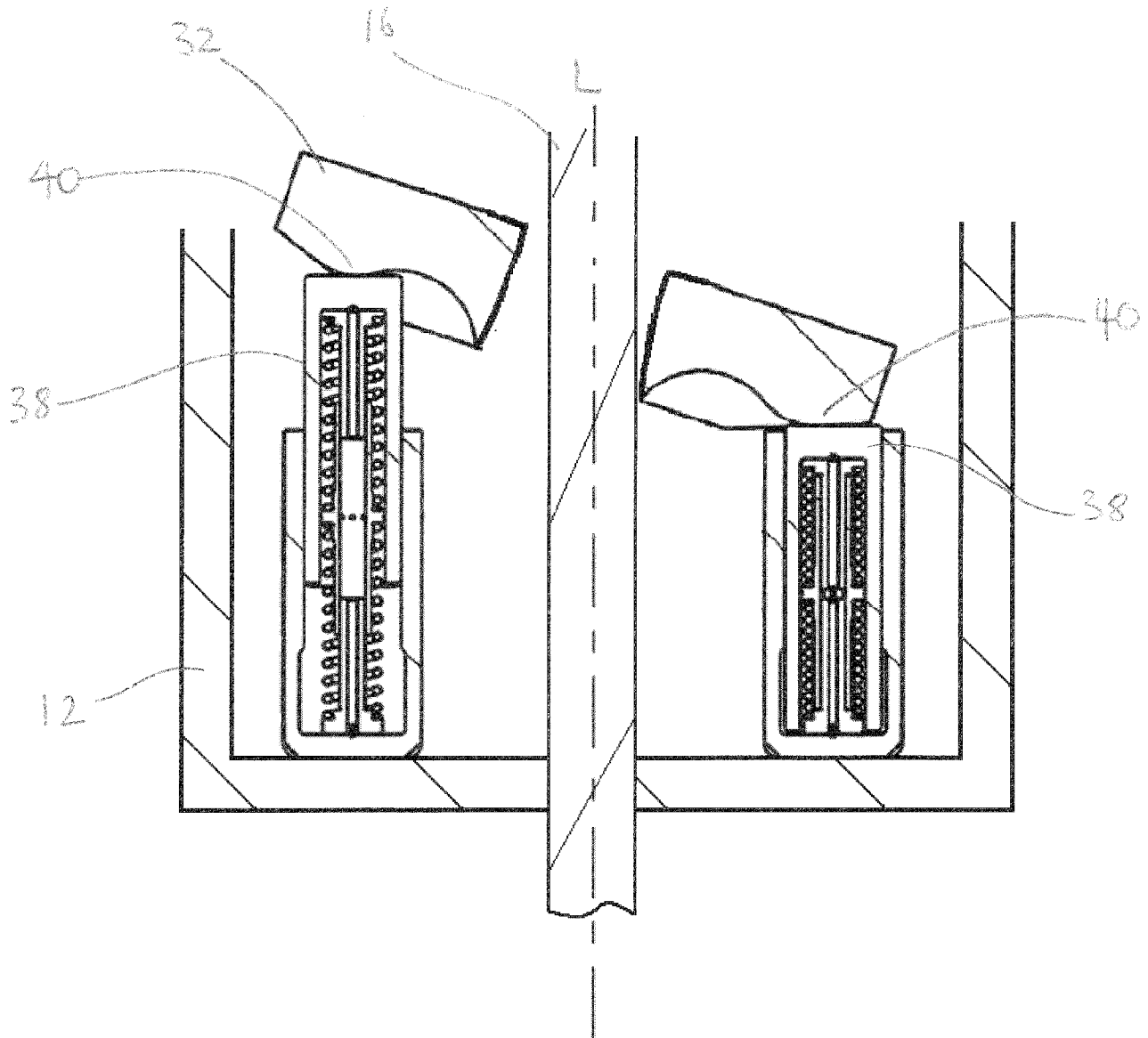


Figure 3

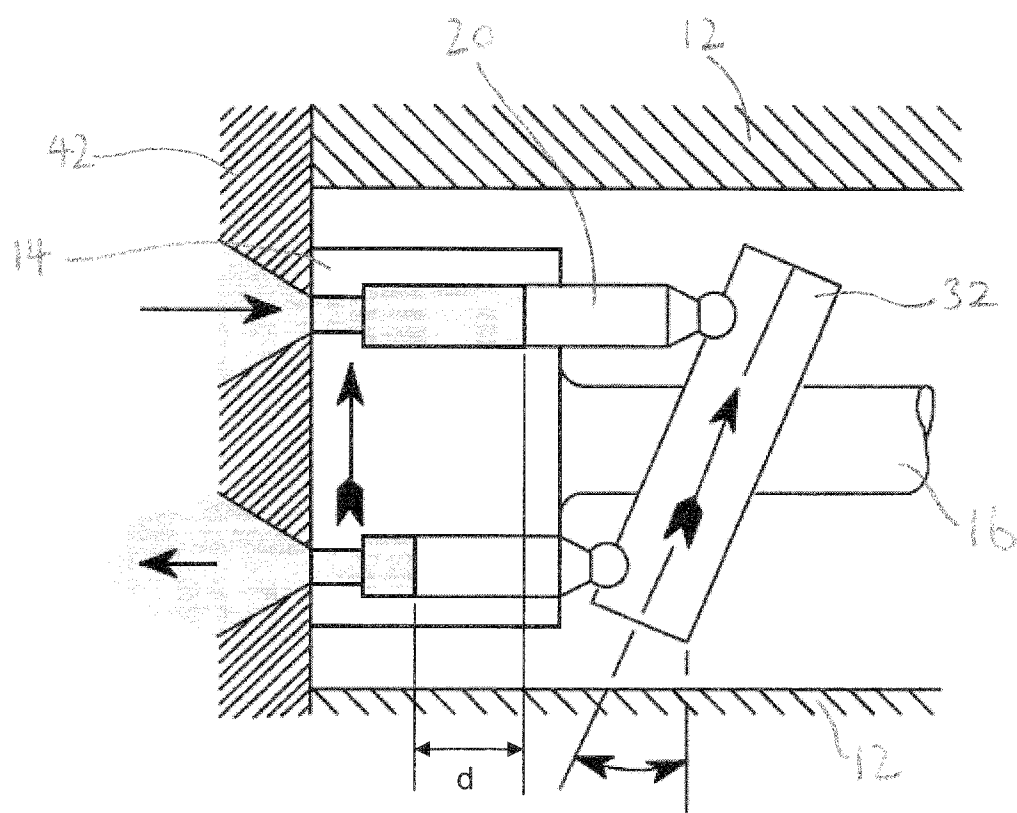


Figure 4a

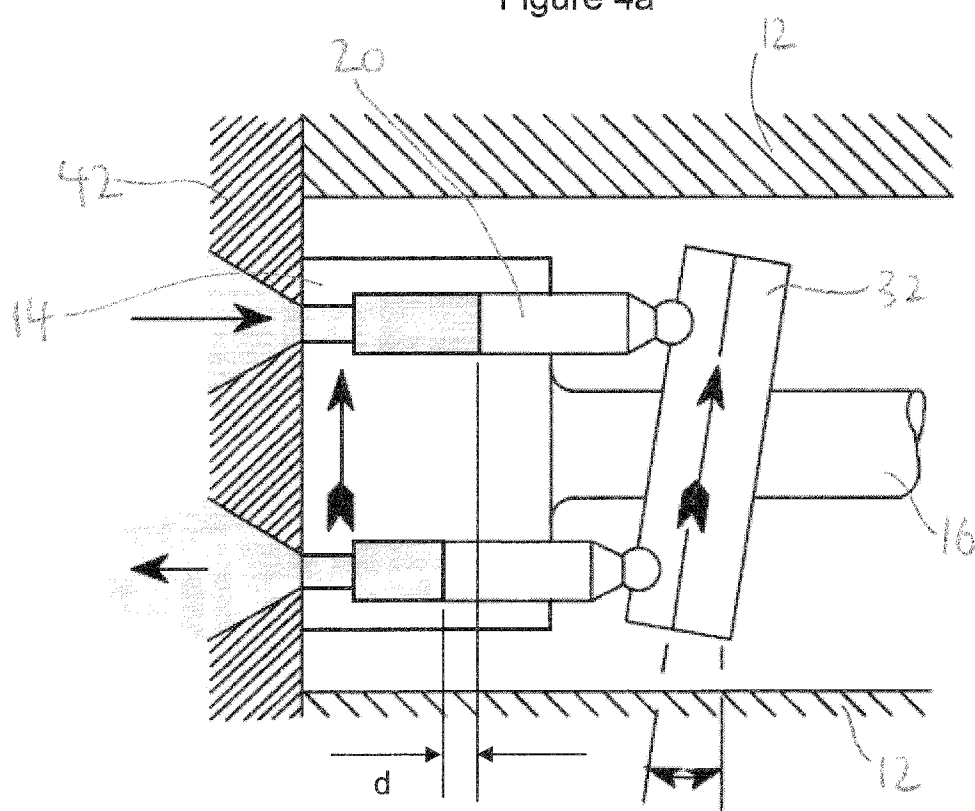


Figure 4b

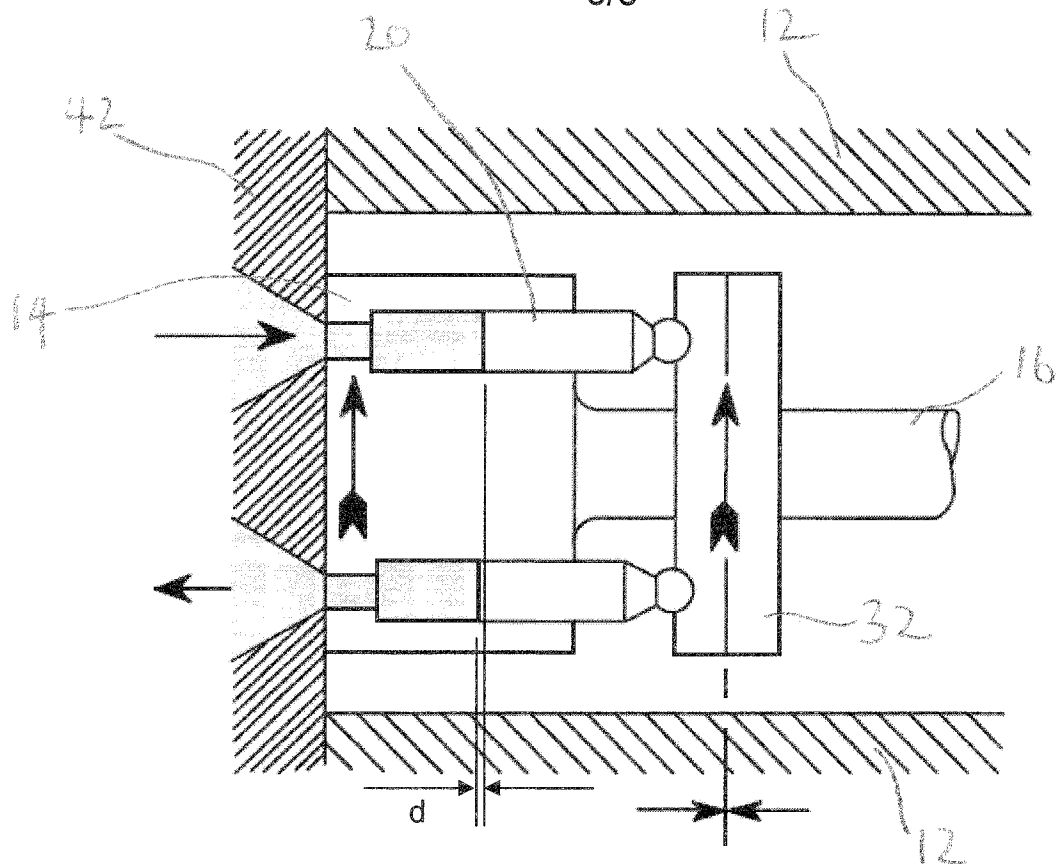


Figure 4c

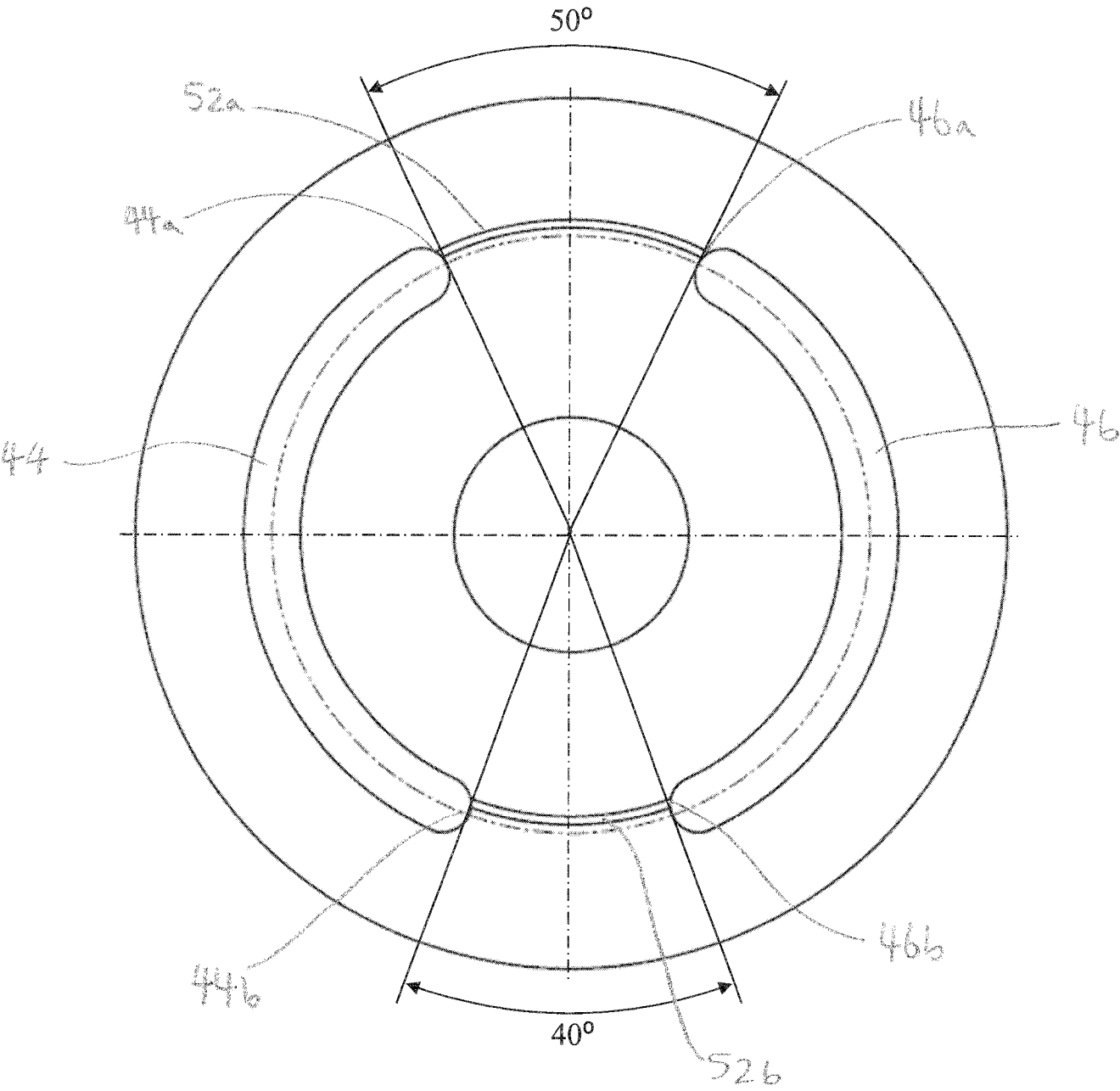


Figure 5

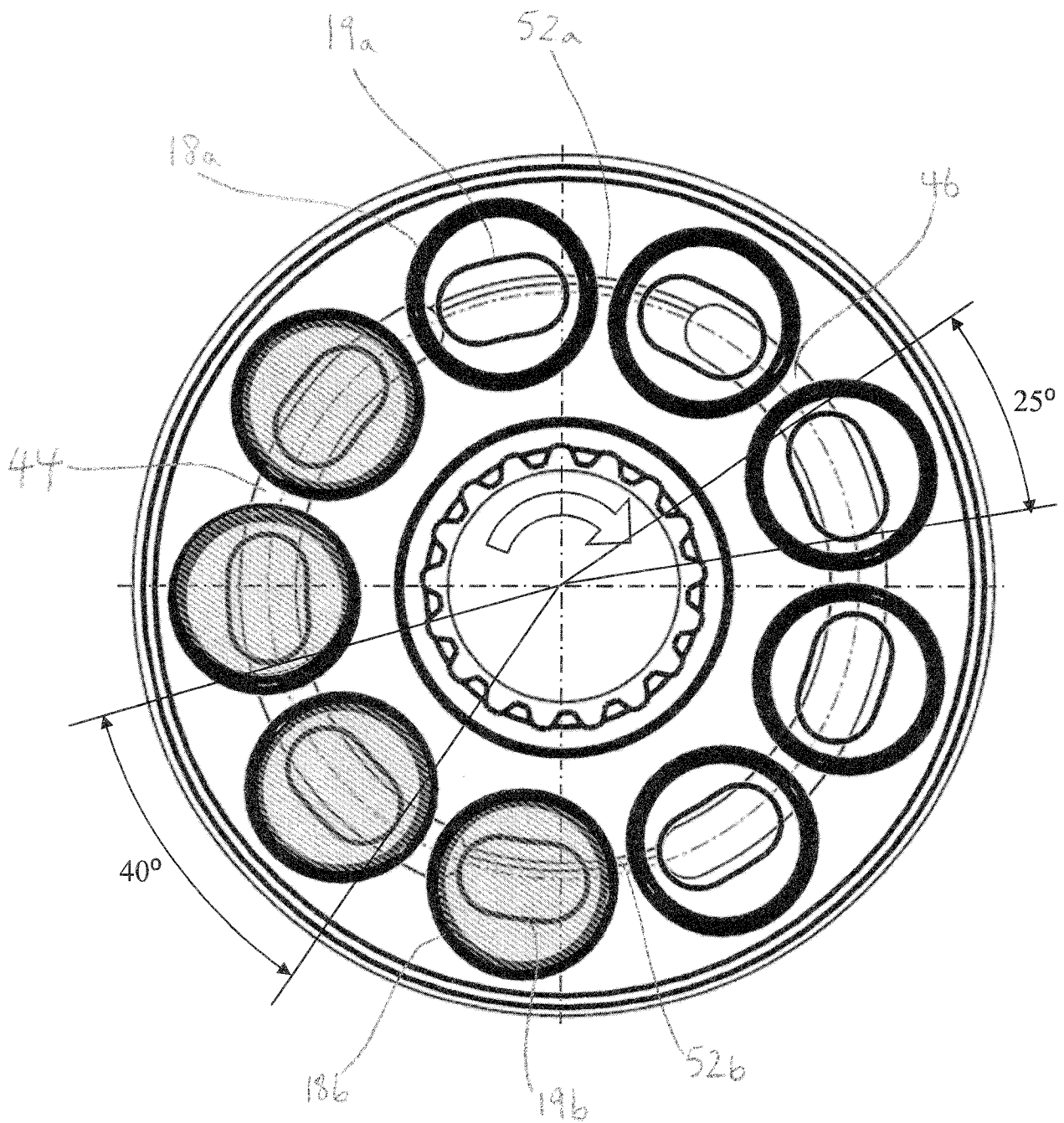


Figure 6a

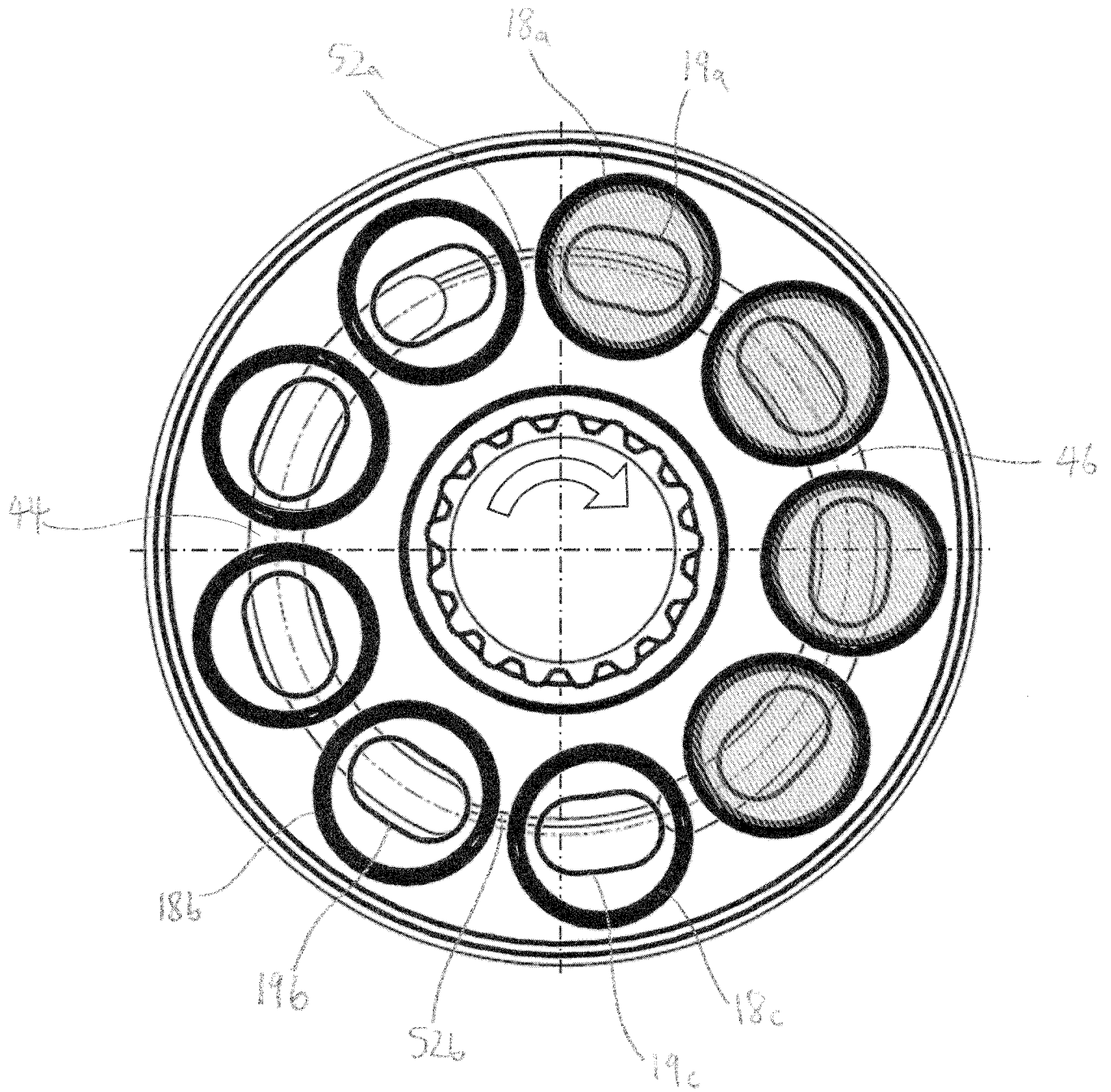


Figure 6b

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/075110

A. CLASSIFICATION OF SUBJECT MATTER

INV. F04B1/20 F01B3/00 F03C1/06
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F04B F01B F03C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP H05 33843 A (KUBOTA KK) 9 February 1993 (1993-02-09) the whole document -----	1-3,5-7, 11-15
X	JP H05 195946 A (KUBOTA KK) 6 August 1993 (1993-08-06) the whole document -----	1-3,5-7, 11,12
X	US 3 910 587 A (HIGGINBOTTOM L C; LOEFFLER R I) 7 October 1975 (1975-10-07) column 17, line 60 - column 19, line 50; figure 12 -----	1-8



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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Date of the actual completion of the international search

26 March 2014

Date of mailing of the international search report

04/04/2014

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2013/075110

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