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(54) **HYDRAULIC AXIAL PISTON UNIT AND METHOD FOR CONTROLLING OF A HYDRAULIC AXIAL PISTON UNIT**

HYDRAULISCHE AXIALKOLBENEINHEIT UND VERFAHREN ZUR STEUERUNG EINER HYDRAULISCHEN AXIALKOLBENEINHEIT

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Description

[0001] The present invention relates to hydraulic axial piston units and a method for controlling hydraulic axial piston units. More specifically, the invention relates to hydraulic axial piston units of the swashplate type as well as hydraulic axial piston units of the bent-axis type of construction. The invention also relates to a method for controlling both types of hydraulic axial piston units. The hydraulic axial piston units to which the invention refers to can be used in open hydraulic circuits as well as in closed hydraulic circuits and can comprise a fixed displacement volume or a variable displacement volume.

[0002] Hydraulic axial piston units of the swashplate or the bent-axis type of construction are widely known in the state of the art and are used as fixed or variable displacements units. All of them can be operated in pumping or motoring mode. The displacement volume of the hydraulic axial piston units can be set/controlled by means of setting/changing the tilt angle of a displacement element, i.e. the swashplate or the yoke. In order to transform mechanical power into hydraulic power and vice versa hydraulic axial piston units comprise a rotational group. This rotational group has a rotatable cylinder block with cylinder bores in which working pistons are arranged reciprocally movable for conveying hydraulic fluid from a kidney-shaped inlet port to a kidney-shaped outlet port located on a valve segment of the hydraulic axial piston unit. When the displacement element is inclined with respect to the drive shaft axis of the hydraulic unit, the working pistons are forced to reciprocate between their inner dead centre (IDC) and their outer dead centre (ODC), when the cylinder block is turning. Thereby, a piston is at its inner dead centre when the direction of motion of the piston changes from a movement towards the valve segment to a movement towards the displacement element. A piston is at its outer dead centre when its direction of movement changes from a movement towards the displacement element to a movement towards the valve segment. As known, one of the inlet port or the outlet port is serving as a high pressure port and the respective other port serves as a low pressure port. It depends on the operational mode of the hydraulic unit and the hydraulic flow direction, which port serves as high pressure port and which port serves as low pressure port.

[0003] For setting the tilt angle of a displacement element of a hydraulic axial piston unit manual, hydraulic or electronic control units are used. To set/adjust the displacement volume of the hydraulic axial piston unit these control units frequently control the movement of servo pistons in servo units by selectively directing hydraulic pressure into pressure chambers of the servo unit by means of shifting a control spool. These control and servo arrangements are complex due to the high level of demand in manufacturing and operation precision and are prone to errors. Thus, they are costly in manufacturing and installation work. Furthermore, control and servo units known in the art, and - due their amount of parts - are bulky and space consuming so that the overall size of hydraulic axial piston units is increased. The known controls of hydraulic axial piston units are developed for specific applications and require a specific adaptation of the control parts for each and every application, like specific valve plates and/or valve segments as well as specifically adapted servo and control spools and springs, which all require narrow tolerances. The components of the displacement control units are exposed to wear and therefore require continuous maintenance or replacement. Furthermore, these specific components are not suitable to be changed on the fly, i.e. once installed they cannot be adapted to individual load situations, and moreover they often cannot be used in different hydraulic axial piston units of different volumetric size/ cubic capacity.

[0004] US 2020/0040867 discloses a hydraulic piston unit having a tiltable displacement element for adjusting the displacement volume of the rotational group. On a valve segment between a kidney-shaped inlet port and a kidney-shaped outlet port at respective dead end positions of reciprocally moveable working pistons first and second control ports are located in fluid connection with cylinder bores in the cylinder block, for controlling the position of the displacement element. The hydraulic piston unit further includes a control valve connected via a high pressure port to a high pressure side of the hydraulic piston unit. The control valve is configured to conduct hydraulic fluid from the high pressure side to one of the first or the second control port.

[0005] It is therefore an objective of the invention to provide a hydraulic axial piston unit with a control system for setting and controlling the displacement volume of hydraulic axial piston units, which compared to the solutions in prior art, comprises a lower amount of components or at least components with a simpler design, but which is capable of reliably setting and controlling the displacement volume of hydraulic axial piston unit. In consequence, the hydraulic axial piston unit according to the invention shall be less costly and shall require less construction space compared to the solutions known in the art. The control system for a hydraulic axial piston unit according to invention is intended to be adaptable to different hydraulic axial piston units, even on-the-fly, i.e. without having to disassemble the hydraulic axial piston unit.

[0006] The objective is solved by a hydraulic axial piston unit according to Claim 1 and a method for controlling the displacement volume of a hydraulic rotation group according to Claim 20.

[0007] Preferred embodiments are presented in the subclaims dependent thereon.

[0008] A hydraulic axial piston unit according to the invention comprises a rotating group whose displacement volume is set by means of a displacement element. The rotating group comprises a rotatable cylinder block with cylinder bores in which working pistons are mounted reciprocally moveable. When the cylinder block rotates and the displacement element is inclined with respect to the rotational axis of the cylinder block, the pistons perform a fore-and-aft movement in the corresponding cylinder bores. When one full rotation of a cylinder bore and of the working piston arranged in the cylinder

bore is observed, the piston changes its direction of motion two times. At the inner dead centre (IDC), the working piston changes its direction of motion from travelling towards fluid exchange opening of the cylinder bore to travelling away from the fluid exchange opening of the cylinder bore. Accordingly, within one revolution, the inner dead centre is the position in which the working piston is closest to the fluid exchange openings of the cylinder bore, that is, it is inserted furthest into the cylinder bore, and the fluid volume in the cylinder bore is minimum. At the outer dead centre (ODC), the movement of the working piston is changed from travelling away from the fluid exchange opening of the cylinder bore to a movement towards the fluid exchange openings of the cylinder bore. In consequence, when one full revolution of the cylinder block is considered, at the outer dead centre the working piston is at the position most distant from the fluid exchange opening of the corresponding cylinder bore, i.e. where the working piston is furthest extracted out of the cylinder bore, and the fluid volume in cylinder bore is the largest the set tilt angle permits.

[0009] For example, when a working piston of a hydraulic axial piston pump is at the ODC, the pressure in the corresponding cylinder bore changes from low inlet pressure to high outlet pressure, whereas for a piston at the IDC the cylinder bore pressure changes from high outlet pressure to low inlet pressure. For a hydraulic motor, the situation is inverted: At the ODC, the pressure on a working piston and in the corresponding cylinder bore pressure change from high inlet pressure to low outlet pressure, whereas at the IDC, the pressure on the piston and in the corresponding cylinder bore accommodating the piston change from low outlet pressure to high inlet pressure.

[0010] In consequence and known in the art, the adjustable longitudinal position of the inner dead centre and of the outer dead centre of the working pistons, i.e., the position seen along the rotational axis of the rotational group, depends on the inclination angle/tilt angle of the displacement element. However, the angular position of the inner and the outer dead centre is set fixedly by the rotational group design as long as the orientation and the position of the tilt axis of the displacement element is not changed, i.e. independent of the tilt angle of the displacement element.

[0011] The hydraulic axial piston unit according to the invention further comprises a valve segment with a kidney-shaped first pressure port and a kidney-shaped second pressure port. Hydraulic fluid can be conducted to and drained from the cylinder bores when a cylinder bore overlaps with the first or the second pressure port. Further, according to the invention, an IDC control port and an ODC control port are located on the valve segment in circumferential direction between the respective circumferential ends of the kidney-shaped first pressure port and the kidney-shaped second pressure port. In other words, the pressure and the control ports are arranged alternately in circumferential direction, e.g. ODC control port, first pressure port, IDC control port, second pressure port.

[0012] The IDC and ODC control ports are arranged on the valve segment in such a way that a cylinder bore can be fluidly connected to the IDC control port or the ODC control port when the associated working piston is at or close to its inner dead centre (IDC) or is at or close to its outer dead centre (ODC), respectively. As mentioned above, the circumferential position of the IDC and the ODC of the working pistons is constant. In consequence, according to the invention and independently of the tilt angle, the circumferential position of the IDC control port on the valve segment is always at or near the IDC of the working pistons and analogously the ODC control port on the valve segment is always at or near the circumferential position of the ODC of the working pistons.

[0013] According to the invention the circumferential distance of the IDC control port to the first and second pressure ports and analogously the circumferential distance of the ODC control port to the first and second pressure ports is smaller than the circumferential extension of the cylinder bores or their openings towards the valve segment. When, during the rotational motion of the cylinder block, a cylinder bore leaves the circumferential area in which the cylinder bore overlaps with the first or second pressure port, hydraulic fluid which remains in the cylinder bore can be compressed further due to an ongoing motion of the piston. This effect can for example occur in a hydraulic pump when the piston is close to its inner dead centre but has not yet reached its inner dead centre. Further compressing of the hydraulic fluid in the cylinder bore leads to a pressure shock or pressure peak in the cylinder bore and consequently on the valve segment, as the hydraulic fluid in the cylinder bore cannot be drained via the first or second kidney shaped pressure port. Also in other scenarios and situations pressure peaks, shocks, or a non-uniform distribution of pressure over the valve segment might occur, e.g. a kind of cavitation near ODC. In order to weaken these effects, circumferentially oriented pressure elongation grooves (also called: "fishtails") are often provided in the valve segment in prolongation of the pressure kidneys.

[0014] Further according to the invention, a cylinder bore is simultaneously in contact with the IDC or with the ODC control port, when it stops overlapping with the first or second pressure ports, e.g. in case of a hydraulic axial piston pump, overpressure or excess hydraulic fluid can be drained via the IDC control port or cavitation can be avoided by additional hydraulic fluid supply via the ODC control port. In case of a hydraulic axial piston motor cavitation may occur at the ODC of the working piston, therefore, in this case, hydraulic fluid supply over the ODC control port can avoid or at least can reduce the cavitation effect. As a result according to the invention, pressure peaks and a disadvantageous pressure distribution over the valve segment is avoided as well as elongation grooves (fishtails) mentioned before.

[0015] Further according to the invention, a first bypass line and a second bypass line are provided each connecting one of the control ports, i.e. the IDC control port or the ODC control port, with one of the first or the second pressure port or with a pressure compensation chamber. In the first bypass line an adjustable orifice is arranged capable of continuously and variably opening and closing the first bypass line in order to enable an adjustable fluid flow connection between the

connected pressure port and the passing cylinder bore via the first bypass line and the allocated control port. A second bypass line is connected to the respective other control port. The orifice in the first bypass line can be provided as an additional part, e.g. in form of a flow valve or similar, especially preferred an adjustable flow opening. However, non-adjustable orifices can be formed also integrally with the first and/or second bypass line, in which they are arranged.

5 **[0016]** The opening of the at least one orifice and its magnitude of opening influences the sum of static pressure forces which are present at the displacement element. The pressures which are present at the IDC control port and at the ODC control port each generate a force which acts on the displacement element via the working pistons. The ODC and the IDC control ports are arranged on the valve segment on opposite sides with respect to the tilt axis of the displacement element each with a lateral offset to the tilt axis. These offsets can be the same but does not have to be. Therefore, each pressure
10 force at the ODC and the IDC control ports generate a kit moment/torque with respect to the tilt axis on the displacement element, wherein the moment at the ODC control port comprises a different algebraic sign than the moment at the IDC control port. The resulting kit moment - including the kit moments generated by the pressure ports - sets the tilt angle of the displacement element and therefore - depending on the direction of tilt - cause a corresponding displacement of the displacement element. If the pressure level at the ODC control port is adjusted with respect to the pressure level at the IDC
15 control port, the resulting kit moment changes. The resulting kit moment is also influenced by other parameters and forces, which are explained later.

[0017] By controlling the opening size of the at least one variable orifice or the ratio of the opening sizes of more than one orifice in the bypass lines the tilt angle of the displacement element of the hydraulic unit can be adjusted and set. The magnitude of the opening of the orifice(s) can e.g. be controlled by an electronic control unit. Thereby, it is not required that
20 hydraulic fluid is injected into a passing cylinder bore in a short time interval, e.g. in the range of milliseconds. Quite to the contrary, static pressure is used to control and set the pressure profile, which is encountered by a cylinder bore, when passing one of the control ports. The tilt angle of the displacement element and the opening of an adjustable orifice do not regularly change with a high frequency. Especially not every time when a cylinder bore passes the IDC or the ODC control port. As static pressure is used to influence the pressure profile along the valve segment for controlling the tilt angle of the displacement element, the frequency with which the opening of orifice(s) has to be adjusted is relatively low.
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[0018] The hydraulic axial piston unit according to the invention can comprise a variable displacement volume whose displacement volume is controlled by means of adjusting the opening size of the adjustable orifice, i.e. its opening magnitude. The adjustable orifice is arranged at least in the first bypass line in order to adjust the pressure at one control port in relation to the pressure at the other control port. Therewith the pressure profile, during a transition of a cylinder bore
30 from one pressure port to the other pressure port, can be modified and therewith the kit moments acting on the displacement element can be changed/varied.

[0019] A hydraulic axial piston unit according to the invention can alternatively comprise a fixed displacement volume. In this embodiment of the invention, the displacement volume is set by means of setting the opening of the adjustable orifice in the first bypass line in order to adjust the pressure at one control port in relation to the pressure at the other control port. The fixed displacement volume is maintained throughout the operation of the hydraulic unit. Even though the displacement
35 volume of the hydraulic unit is maintained constant, the opening of the adjustable orifice can be adjusted or controlled, during the operation of the hydraulic unit. In consequence, the pressure profile in a cylinder bore which overlaps with the control port connected to the bypass line with the adjustable orifice can be adjusted. Therewith vibrations of the displacement element as well as pressure peaks, oscillations or cavitation can be reduced or even eliminated. As a result, noise generated during operation of the hydraulic unit can be reduced and the running behaviour of the hydraulic unit according to the invention can be enhanced and therewith the lifetime of the hydrostatic unit can be extended.
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[0020] According to the invention the second bypass line which is connected to the other control port can be connected to a pressure compensation chamber. In such an embodiment, the second bypass line establishes a fluid connection between the other control port and the pressure compensation chamber. The pressure compensation chamber can be
45 adapted to dampen pressure peaks and cavitation in the passing cylinder bores, respectively on the valve segment, and thereby avoid pressure oscillations.

[0021] In one embodiment of the invention, the second bypass line is connected with the first pressure port or the second pressure port in order to establish a fluid flow connection between the connected pressure port and the passing cylinder bore via one of the control ports. Preferably, the first bypass line with the adjustable orifice connects either the IDC control
50 port or the ODC control port with the first or second pressure port and the second bypass line connects the other respective control port with the respective other pressure port.

[0022] Preferably according to the invention, the first bypass line and the second bypass line each connects the next pressure port after the connected control port seen in rotational direction of the cylinder block. E.g., in an open circuit pump, the control port at IDC is preferably connected via the allocated bypass line to the pressure port at low system pressure and
55 the control port at ODC is connected via the allocated bypass line to the pressure port at the higher system pressure. As a closed circuit pump contrary to an open circuit pump is often operated also in motoring mode, the invention may provide additionally for a possibility to switchable connecting the ODC control port with the respective high system pressure port, for instance by the help of a switching or shuttle valve. As known by a person with skills in the relevant art, the system

pressure port at the valve segment changes sides when the hydrostatic unit changes from pumping mode to motoring mode and vice versa.

5 **[0023]** If the hydraulic unit is configured as a hydraulic pump, one bypass line can for instance connect the ODC control port with the pressure port at higher system pressure and the other bypass line can connect the IDC control port with the pressure port at lower system pressure. If the hydraulic unit is operated as hydraulic motor the situation can be inverted and one bypass line can, for example, connect the IDC control port with the high pressure port, wherein the other bypass line connects the ODC control port with the low pressure port.

10 **[0024]** The connection of the control port with the next, coming pressure port - seen in direction of the intended rotation of the rotational group - helps to avoid "fishtails" in the valve segment, as described above, as the next/coming pressure is guided back to the control port located in direction of rotation before on the valve segment. Hence pressure peaks or cavitation as described above can at least be reduced or even avoided, as the circumferential way/distance for a cylinder bore opening from the end of one pressure port to the beginning of a control pressure port with the other system pressure is shortened. For this, it is preferred by the invention that the circumferential extension of the cylinder bore opening is dimensioned such that the opening intersects on its way leaving a pressure port overlaps with both ports, the control port and the next coming pressure port at least partially. According to invention when the cylinder bore opening overlaps with the control port connected to the next system pressure, the pressure level in the cylinder bore can be adjusted/tuned/-trimmed with the aim to reduce noise and vibrations caused by steps in the pressure profile. Preferably these small adjustments are done during constant tilt angle operation of the hydrostatic unit, wherein these small adjustments may not lead to a change in displacement volume, however the running behaviour of the hydrostatic unit is improved.

20 **[0025]** In one embodiment of the invention, the openings of the cylinder bores facing the valve segment show a kidney-shaped cross section. According to the prior art, cylinder bores often comprise round openings, the diameter of which being substantially equal to the radial extension of the kidney shaped pressure ports on the valve segment. If the openings of the cylinder bores comprise a kidney-shaped cross section and the longer dimension of the kidney-shape opening is oriented in circumferential direction, a bigger area is covered by the opening in circumferential direction compared to a round opening. Therefore, given the requirement that the opening of a cylinder bore shall be capable of simultaneously overlapping with a leaving pressure port and a coming control port, also the distance between a control port and its adjacent pressure ports can be increased, which improves the robustness of the valve segment.

25 **[0026]** Further preferred, the circumferential extension of the kidney-shaped openings of the cylinder bores is smaller than the circumferential distance between the adjacent ends of the first and second kidney-shaped pressure ports. Otherwise, there would be a rotational position of the cylinder bore, in which the cylinder bore could fluidly short circuit the first and the second pressure port.

30 **[0027]** According to the invention, an orifice with adjustable magnitude of opening (in the following just "adjustable orifice") can be arranged in each of the two or more bypass lines, i.e., in the first bypass line and in the second bypass line as well as in potentially existing additional bypass lines. Alternatively, a non-adjustable orifice can be arranged in any of the bypass lines if this bypass line does not comprise an adjustable orifice. In consequence, either both the first and the second bypass line can comprise an adjustable orifice or only the first bypass line can comprise an adjustable orifice. In this case, the other, second bypass line preferably comprises a non-adjustable orifice, in order to provide a constant hydraulic resistance to the hydraulic flow in that bypass line. Depending on the selected arrangement, the tilt angle of the displacement element can be adjusted or set by influencing the ratio of the opening of the orifice in the first bypass line with respect to the opening of the orifice in the second bypass line, or by influencing the ratio between the opening of the adjustable orifice in one bypass line with respect to the opening of the non-adjustable orifice in the other bypass-line. In case of adjustable orifices, for example proportional flow valves, the pressure at the allocated control port can be adjusted variably, such that the pressure difference between the two control ports and consequently the force and kit moment situation on the valve segment is controllably influenced.

35 **[0028]** In one embodiment of the invention, one or two further, parallel bypass lines comprising an adjustable orifice, or a non-adjustable orifice can establish an additional fluid flow connection parallel to the fluid flow connection between the pressure port and the control port connected by the first bypass line or between the pressure port and the control port connected by the second bypass line. When providing two parallel connections between the same pressure port and the same control port allows splitting of the operating range of an adjustable orifice that is required for operating the hydraulic unit into two fractions is possible. The design of the orifices in the parallel bypass lines can be chosen accordingly. For example, one non-adjustable orifice providing a small, constant pressure drop could be combined with an adjustable orifice providing an adjustable pressure drop in addition to the constant pressure drop. This enables a cost efficient design of the orifices which are arranged in the bypass lines. In comparison to one single orifice with a wide operating range each operating range of parallel orifices can be reduced maintaining the total operating range of the orifice arrangement, as the control range of both orifices is summed up.

40 **[0029]** According to the invention, various arrangements of the bypass lines are covered by the present disclosure. For example, both control ports can be connected to the same pressure port via the first and second bypass lines. Additionally, each control port can be connected to the other pressure port via third and fourth bypass lines, wherein adjustable orifices

can be arranged in each of the four bypass lines.

[0030] As known in the art, the displacement element can be biased into an initial position by means of an elastic force, in which the displacement volume of the rotational group is at maximum, minimum or at zero. The displacement element can also be biased into an initial position by means of an offset of the tilt axis of the displacement element with respect to the rotational axis of the cylinder block. As a result, the pistons on either side of the tilt axis comprise different lever arms with respect to the tilt axis. Even if a small pressure, e.g. charge pressure, is provided to the pressure ports/cylinder bores and the pressure force is the same on all pistons, the pistons generate a kit moment on the valve segment with respect to the tilt axis due to the different lever arms. Therefore, as soon as pressure is supplied to the cylinder bores, the displacement element starts to tilt and a pressure difference is present at the first and second pressure ports, which can be conducted to the IDC control port and to the ODC control port via the first and second bypass line.

[0031] According to the invention, the hydraulic axial piston unit can further comprise a return mechanism capable of generating a restoring force on the displacement element, when the displacement element is pivoted out of its initial position. The restoring force can generate a torque which is directed opposite to the resulting torque generated by the pressure forces at the IDC and the ODC control port. For example, the return mechanism can comprise an elastic component which provides a restoring force/torque which increases when the tilt angle of the displacement element increases. For every tilt angle of the displacement element, the equilibrium of moments between the pressure forces at the IDC control port and at the ODC control port and the restoring force of the return mechanism determines the movement of the displacement element and therewith the tilt angle of the displacement element. By arranging control ports on the valve segment circumferentially located between the pressure ports, the kit moments on the valve segment can be influenced/varied such that a restoring torque from the return mechanism can be traversed and the displacement element can be on-stroked, that is, its angle of tilt increases. Thus, for each angle of tilt a balance/equilibrium of forces/torques can be adjusted and the displacement volume of the hydrostatic unit can be controlled. So, in increasing or lowering the pressure difference present at the control ports the displacement element can be on- or de-stroked only by adjusting the opening size of the at least one variable orifice arranged in one or in both bypass lines connecting the control port with the pressure level coming next in direction of rotation.

[0032] The valve segment can be formed integrally with the housing of the hydraulic axial piston unit, or with an end cap of the hydraulic axial piston unit, or with a housing lid or with another component within the housing of hydraulic unit. Alternatively, the valve segment can be provided as a separate part.

[0033] The first pressure port at the valve segment can comprise more than one kidney-shaped pressure port opening, and/or the second pressure port of the valve segment can comprise more than one kidney-shaped pressure port opening. This can improve the mechanical stability of the valve segment in the region of the first and/or second pressure port, while negative impacts on the flow of hydraulic fluid to the cylinder bores which overlap with the first and/or second pressure port are minimised.

[0034] According to the invention, the opening of the orifice(s) can be controlled mechanically or by an electronic control unit (ECU). The electronic control unit can comprise a micro-controller and can be connected to at least one sensor selected from a group of sensors comprising a tilt angle sensor, a shaft position sensor, a pressure sensor, a flow sensor, a rotational speed sensor, a temperature sensor, a direction sensor, a torque sensor, an acceleration sensor, or any other sensor capable of monitoring at least one operational parameter of the hydraulic unit. The control unit can be capable of controlling the opening of the orifices based on measurements provided by the at least one sensor. For this purpose, the control unit can be capable of performing calculations, e.g. of calculating an error signal, and of adjusting the opening of the orifice(s), such that the error signal is reduced, e.g. by applying a PID control rule. The opening of the orifice(s) can be calculated based on the circumferential position of the first and second kidney shaped pressure ports, the circumferential position of the IDC and the ODC control ports, the diameter of the orifice(s), the restoring force of the return mechanism, the angular velocity of a shaft of the hydraulic unit, the pressure at the first and second kidney shaped pressure ports, the operating temperatures, and/or other parameters.

[0035] According to the invention, the adjustable orifice can be a rotary spool valve or a linear spool valve which is accommodated in a valve bore. The rotary or linear spool of the valve can comprise recesses or openings which overlap with channels in the valve bore, i.e. valve ports, wherein the magnitude of overlapping can be continuously adjusted by rotating the rotary spool or by longitudinal moving the linear spool. The orifice can be a linear operating valve/orifice, a rotary valve/orifice, or a flow valve. Flow valves are generally less costly than linear or rotationally operating orifices. Here, a person skilled in the relevant art will find plenty of solutions how to provide an adjustable orifice, i.e. an orifice whose magnitude of opening is adjustable.

[0036] As mentioned above, a hydraulic axial piston unit according to the invention can comprise two adjustable orifices, one provided in the first bypass line and another one provided in the second bypass line. The openings of the two adjustable orifices can be adjustable by means of a shared mechanism, which can be mechanical, electromechanical, hydraulic, or pneumatic. For example, a common, i.e. shared, spool can be provided, which serves as a shared valve spool for the adjustable orifice in the first bypass line as well as for the adjustable orifice in the second bypass line. Such a single spool can for example comprise one recess for adjusting the fluid flow in the first bypass line, and another recess for

adjusting the fluid flow in the second bypass line.

[0037] According to the invention the shape of the control ports is relevant for achieving a good controllability of the tilt angle of the displacement element. A round/circular shape of the control ports requires low manufacturing effort and therefore represents a solution causing low costs. However, the shape of the control ports can also be adapted to the shape of the opening of the cylinder bores. Basically, the control ports can comprise any desired shape. For example, the control ports can show an elongated shape in circumferential direction of the valve segment with a radial extension that matches the radial extension of the cylinder bores. This design provides an increased overlap between the opening of the cylinder bore and the control port. The control port can also comprise a kidney shape, wherein the longer side of the kidney preferably extends in circumferential direction. The control port can also comprise an ellipse shape, a triangle shape, or any other shape, wherein even the manufacturing direction must not coincide with rotational axis of the valve segment.

[0038] Not only the shape of the IDC and the ODC control port is considered to be relevant for setting and adjusting the displacement of a hydraulic axial piston unit, but also the position of the IDC and the ODC control port on the valve segment. According to the invention, the IDC control port and/or the ODC control port can be located on the valve segment in circumferential direction with an angular offset to the rotational position at which the working pistons are at their inner dead centre and/or outer dead centre, respectively. This arrangement is often referred to as "indexing" and is especially preferable for hydraulic pumps. The specific location of the IDC and/or the ODC control port is selected based on the type of use of the hydraulic unit and the requirements derived therefrom. In one exemplary embodiment, the IDC control port and/or the ODC control port can be located clockwise slightly behind the actual rotational/circumferential position of the IDC or the ODC.

[0039] As a result, to continue the example of a hydraulic pump, the pressure at the ODC control port influences the motion of the working pistons when the pistons are entering the cylinder bore, that is at the start of the pressure phase, and the pressure at the IDC control port influences the motion of the piston, when the piston is withdrawn from the cylinder bore, i.e. at the start of the suction phase. In an exemplary case, the ODC port can be connected to the high pressure line, wherein the IDC port can be connected to the low pressure line. Increasing the opening of an orifice in the bypass line connected to the ODC control port generates a higher pressure in the pressure chamber which is enclosed by the working piston in the cylinder bore. As the higher pressure has to be supported by the displacement element, the tilt angle of the displacement element is increased. Increasing the opening size of an orifice arranged in that bypass line which is connected to the IDC control port reduces the hydraulic resistance which has to be overcome when hydraulic fluid is sucked into the above mentioned pressure chamber when passing the IDC control port. The resulting reaction force acting on the displacement element in the area of the inner dead centre (IDC) is reduced and the tilt angle of the displacement element is increased.

[0040] In another embodiment of the invention, the IDC control port and/or the ODC control port can be located on the valve segment exactly at that rotational position at which the working pistons are at their inner dead centre (IDC) and/or their outer dead centre (ODC), respectively. This arrangement can for example be preferable for hydraulic units, especially hydraulic motors, which are operated with changing directions of fluid flow, but whose displacement element can be tilted only in one direction. As the algebraic sign of the tilt angle does not change, the rotational position of the inner dead centre and the outer dead centre remains the same, even if the direction of fluid flow is changed. However, when the direction of the fluid flow is inverted and the direction of tilt remains constant, the direction of rotation of a hydraulic motor is inverted. If the IDC pressure port and the ODC pressure port on the valve segment does not coincide with the IDC or the ODC but shows an angular offset to the IDC and to the ODC position, the behaviour of the hydraulic unit would be different depending on the rotational direction of the cylinder block, as - considering exemplarily only one of the control ports - the control port would be in one direction of rotation before the respective dead centre position and in the other rotational direction after the respective dead centre position.

[0041] In another embodiment of the invention, a first ODC control port can be located on the valve segment with an angular offset to the rotational position at the valve segment at which the working pistons are at their outer dead centre, and a second ODC control port can be located on the valve segment such that the first and second ODC control ports are located on both sides of the rotational position on the valve segment, which corresponds to the outer dead centre position of the working pistons. This arrangement increases the options for controlling the tilt angle of a displacement element of a hydraulic unit, as the pressure in a cylinder bore can be influenced before reaching as well as after leaving the outer dead centre position, i.e. when the working piston is moving outwards, as well as after leaving the inner dead centre, i.e. when the working piston is moving inwards. This increases the angular range within which the tilt angle can be influenced by the displacement control according to the invention.

[0042] Similar to the above mentioned embodiment, according to the invention, a second IDC control port can be located on the valve segment. If the first IDC control port is located on the valve segment with an angular offset to the rotational position at the valve plate at which the working pistons are at their inner dead centre the first and second IDC control ports can be located on both sides of the rotational position on the valve plate which corresponds to the inner dead centre position of the working pistons. This can be done either as an additional feature or as an alternative to providing a second ODC control port on the valve segment.

[0043] Providing a second IDC control port as well as a second ODC control port can be especially useful when the direction of fluid flow which is conveyed/supplied by another hydrostatic unit can be inverted. In this case, the rotational direction of the cylinder block and therewith the direction in which the cylinder bores move from to the ODC to the IDC interchanges. When four control ports are arranged symmetrically on the valve plate/segment, the control possibilities remain the same regardless of the direction of fluid flow.

[0044] According to the invention, the second ODC control port and/or the second IDC control port can correspondingly be connected to a fourth bypass line and/or to a third bypass line, wherein at least one of the third and fourth bypass lines comprises an adjustable orifice capable of continuously and variably opening and closing the associated bypass line. Providing additional orifices with adjustable openings in separate, additional bypass lines increases the possibilities of adjusting the pressure ratio at the control ports and enhances the possibilities of influencing/controlling/adapting the pressure profile of hydraulic pressure acting on a working piston during one revolution of the cylinder block, and thus further enhances the controllability of the hydraulic unit.

[0045] A hydraulic axial piston unit according to the invention can be operated in an open hydraulic circuit or a closed hydraulic circuit. The hydraulic unit can be operated as hydraulic motor or as hydraulic pump. A person with skills in the relevant art is aware of the fact that a hydraulic pump which is arranged in an open hydraulic circuit often comprises only one rotational direction of the cylinder block and consequently shows only one conveying direction. A hydraulic pump arranged in a closed hydraulic circuit typically comprises only one rotational direction, wherein the displacement element of the hydraulic pump can be tilted bidirectional, such that hydraulic fluid can be conveyed in two/both directions through the closed hydraulic circuit. In many embodiments, the cylinder block of a hydraulic motor in a closed hydraulic circuit can be rotated in two directions depending on which of the pressure ports of the hydraulic motor is connected to higher system pressure and which is connected to lower system pressure. In most applications according to the state of the art, the tilt angle of a hydraulic motor in a closed circuit can only be stroked/adjusted in one direction.

[0046] When a hydraulic unit according to the invention is operated in a closed hydraulic circuit and the fluid flow direction is inverted, the pressure at the first and second pressure ports and thus the pressure in the first bypass line and in the second bypass line is changed also. However, depending on the type of use, it can be preferred to always have the same kind of system pressure present in the first bypass line and at the connected control port (e.g. always high system pressure at the IDC control port), as well as in the second bypass line and at the connected control port (e.g. always low system pressure at the ODC control port). This is particularly preferred for hydraulic motors whose displacement element is tiltable only in one direction and whose outer dead centre is not interchanged with its inner dead centre during operation of the hydraulic unit neither in the one nor the other rotational direction.

[0047] In this case, the hydraulic unit can comprise a component capable of always conducting one pressure level to the IDC control port and the other pressure level to the ODC control port regardless of the direction of rotation of the hydraulic unit. This function can e.g. be fulfilled by a shuttle valve having two inlets and one outlet, wherein the inlets of the shuttle valve are in fluid connection with the first and second pressure ports and the outlet is in fluid connection with the IDC control port, the ODC control port, or with a control valve (whose functionality is explained later) or a similar device. E.g. for a hydraulic motor the outlet of the shuttle valve can be connected to the IDC control port. According to this arrangement, the shuttle valve is capable of conducting the higher system pressure from the first or second pressure ports to the IDC control port, or to the ODC control port; or to the control valve. E.g., for a hydraulic motor the IDC control port is connected to a higher pressure, e.g. inlet pressure, and the ODC control port can be connected in this case to a lower pressure, e.g. outlet pressure or to a hydraulic reservoir. In consequence, the one-directional tilt angle of the displacement element can be controlled independently of the direction of rotation of the hydraulic unit, here exemplarily a hydraulic motor. According to the invention, the opening of an orifice in the second bypass line which could - for example - be connected to the ODC control port, could be adjusted in order to influence the tilt angle of the hydraulic unit. Additionally or alternatively, the opening of an orifice in the first bypass line connected to the IDC control port could be adjusted and therewith the pressure level present at the IDC control port can be controlled. This influences the profile of pressures acting on a working piston during one revolution around the cylinder block axis, at least until the working pistons reaches the other control port.

[0048] If the displacement element of a hydraulic unit can be tilted in two directions, the IDC and the ODC can be interchanged depending on the direction of tilt of the displacement element. According to the invention a control valve or a similar device can be provided capable of guiding high system pressure to the ODC control port and low pressure to the IDC control port, or vice versa. The control valve may comprise a first inlet connected to the outlet of a shuttle valve and a second inlet connected to a hydraulic reservoir. In this way, the first inlet of the control valve is connected to a high pressure level and the second inlet is connected to a lower pressure level, wherein a first outlet of the control valve can be connected to the IDC control port or the ODC control port, and a second outlet can be connected to the respective other control port. The control valve is capable of selectively connecting the first inlet with the first outlet and the second inlet with the second outlet or connecting the first inlet with the second outlet and the second inlet with the first outlet or short-circuiting the first outlet with the second outlet. Because of this, and regardless of the actual rotational position of the ODC and the IDC, the higher pressure can always be conducted to the ODC control port (for a hydraulic pump) or to the IDC control port (for a hydraulic motor), and the lower pressure can always be conducted to the respective other control port.

[0049] In order to facilitate the start-up of a hydraulic unit according to the invention, the hydraulic unit can comprise an (additional) charge pump capable of providing an initial start-up pressure which can be conducted to one of the control ports, e.g. by a valve arrangement via one of the bypass lines. For such a start-up the charge pressure provided by the charge pump is sufficient to initially tilt the displacement element towards a start position in which a small pressure difference is generated between the first and second pressure ports. Via the bypass lines this pressure difference is conducted via the bypass lines to the IDC control port and to the ODC control port and can be used to initially tilt the displacement element about a small angle. From thereon, hydraulic fluid flow from the charge pump to one of the control ports is no longer necessary, in particular when the high system pressure at one of the pressure ports exceeds the charge pressure, the pressure difference generated by the started hydraulic unit is sufficient to control the tilt angle by means of the least one variably adjustable orifice.

[0050] According to the invention, at least one of the adjustable orifices can provide a pressure and/or a displacement feedback signal. Displacement or pressure feedback means, that the hydraulic displacement unit comprises a feedback loop in order to mechanically, electrically, or hydraulically transmit the pressure level in the cylinder bores or at the control ports or the tilt angle of the displacement element to the adjustable orifice, or from the adjustable orifice to a control unit of the hydraulic system. According to the invention, a mechanical feedback or an electronic feedback signal could be provided by the orifices to an electronic control unit. Additionally or alternatively, the opening of the at least one adjustable orifice can be influenced by the magnitude of the feedback signal. For example, when the tilt angle of the displacement element is increased, and the increased tilt angle is sent either directly as feedback signal to the adjustable orifice or as feedback signal to an electronic control unit controlling the opening of the adjustable orifice, the opening of the adjustable orifice can be reduced, in order to limit or to stop the movement of the displacement element. Thus the pressure in the cylinder bores and the tilt angle of the displacement element can be controlled by means of the adjustable orifices in the bypass lines. As a result, a servo piston/servo unit according to the state of the art can be omitted, at least in some cases.

[0051] According to the invention, the control ports can pass through the valve segment perpendicular to its front surfaces. However, the control ports can also pass through in a direction inclined with respect to a rotational axis of the valve segment or the hydraulic axial piston unit, respectively. This means, that the orientation and position of the hydraulic bypass lines in which the adjustable or non-adjustable orifices are arranged can be chosen depending on space restrictions imposed by the design of the components of the hydrostatic unit surrounding the rotating group, e.g. For example, the control ports can be drilled, and the drilling direction can be oriented perpendicular to the front surface of the valve segment or can be oriented with an angle to the front surface different to the perpendicular to valve segment plane.

[0052] In one embodiment, the radial position of the control ports can deviate from the pitch diameter defined by the circumferential extension of the first and second pressure ports. In other words, the radial distance of the control ports to the rotational axis of the hydraulic unit must not be equal to the pitch radius of the pressure ports.

[0053] According to the invention, a method for controlling the displacement volume of a hydraulic rotating group driving or being driven by a driving shaft is provided further. The hydraulic rotational group comprises a displacement element which can be tilted in order to adjust the displacement volume of the rotating group. The rotating group comprises a rotatable cylinder block with cylinder bores in which working pistons are mounted reciprocally moveable, and a valve segment with a kidney-shaped first pressure port and with a kidney-shaped second pressure port. An IDC control port and an ODC control port are located on the valve segment in circumferential direction between the respective circumferential ends of the first pressure port and the second pressure port. A cylinder bore can be fluidly connected to the IDC control port or the ODC control port when the associated working piston is at or close to its inner dead centre (IDC) or is at or close to its outer dead centre (ODC), respectively. The circumferential distance from the IDC control port to the first and second pressure ports and the circumferential distance from the ODC control port to the first and second pressure ports is smaller than the circumferential extension of the cylinder bores.

[0054] The method for controlling the displacement volume of a hydraulic rotating group comprises the following steps:

- draining or supplying of hydraulic fluid via the IDC control port from or to the passing cylinder bores by means of a first bypass line having a first orifice,
- supplying or draining of hydraulic fluid via the ODC control port to or from the passing cylinder bores by means of a second bypass line having a second orifice,
- adjusting an opening size of the first orifice, or an opening size of the second orifice or adjusting both opening sizes of the first orifice and the second orifice in order to control the pressure level in the cylinder bores passing the control ports in order to set or adjust the angle of tilt of the displacement element and therewith the displacement volume of the hydraulic rotating group. In some cases, especially when the control ports are arranged symmetrical on the valve segment with respect of the tilt axis a complementary (additional) amount of hydraulic fluid is drained from the other control port to which hydraulic fluid is not supplied. This follows from the incompressibility of hydraulic fluid and the stiffness of the displacement element in order to allow a tilting movement of the displacement element around the tilt axis.

[0055] The pressure in the cylinder bores can be increased when hydraulic fluid under high pressure is supplied to the passing cylinder bores at the ODC control port (for hydraulic pumps) or at the IDC control port (for hydraulic motors). Due to the higher pressure the force on the working piston which seals the cylinder bores increases. This increased force is transferred by the piston to the displacement element and is supported there. According to the principle "actio = reactio", the supporting force influences the balance of forces and torques present at the displacement element. When high pressure is supplied at the ODC control port to the passing cylinder bore an increased tilting force acting on the displacement element is generated. If the tilting (kit) moments at the displacement element are higher than the resetting forces/moments which force the displacement element back to its initial or neutral position, the tilt angle of the displacement element is increased.

[0056] In the exemplary case of a hydraulic pump, increasing the opening of an adjustable orifice in the bypass line which connects the pressure ports with the higher system pressure to the ODC control port, leads to a higher pressure at the ODC control port and in the passing cylinder bore, therewith causing a bigger tilt angle. In short, opening of an adjustable orifice in this bypass line increases the tilt angle of the displacement element. The other way round, closing or reducing the size of the adjustable orifice in the bypass line decreases the tilt angle of the displacement element as the force on the working pistons passing the ODC control port decreases.

[0057] At the IDC control port, there is a similar/analogous situation at low system pressure level. To continue the case of a pump, an increasing pressure in the cylinder bore passing the IDC control port leads due to the aforementioned transmission of forces to a neutralizing/ de-stroking moment which is capable of decreasing the tilt angle of the displacement element. Therefore, the higher the pressure in the cylinder bore passing the IDC control port, the more neutralizing/de-stroking moment is generated that de-strokes/tilts the displacement element back towards zero displacement. In contrast to that when the pressure in the cylinder bore passing the IDC is lowered, the tilt angle of the displacement element can be increased. The pressure at the IDC control port can be influenced by an adjustable orifice arranged in the connected bypass line. Preferably for a hydraulic pump, the bypass line connected to the IDC control port is connected to a low (system) pressure level. An orifice with an adjustable opening size can be arranged in the bypass line. Therewith the flow resistance or a backpressure in the bypass line connecting the IDC control port with the low pressure port can be adjusted. As a result, increasing the opening size of a variable orifice in the bypass line can increase the angle of tilt of the displacement element.

[0058] According to the invention supply or drain of hydraulic fluid is done with the pressure level of the subsequent/ next coming pressure port - seen in direction of rotation of the cylinder block or the rotating group. For instance, in a hydraulic pump the pressure level at the IDC is changing from the high system pressure to the low system pressure such that according to the invention, the IDC control port located between the two pressure kidneys at, or nearby IDC is preferably connected via a bypass line to the low system pressure kidney. Optionally an adjustable orifice is arranged in this bypass line, in particular for hydraulic pumps operable with positive as well as negative tilt angles, as in this case the IDC changes with the ODC by tilting the displacement element over zero, and vice versa, such that the control port can be the IDC control port as well as the ODC control port.

[0059] To summarize, according to the invention, controlling the pressure in the cylinder bores passing the control port at the ODC, and in the cylinder bores passing the control port at the IDC can make an additional servo system for adjusting the tilt angle of the displacement element superfluous, as the tilt angle of the displacement element of the hydraulic unit can be adjusted by means of a controlled opening or closing of variable orifices provided in the first and/or second bypass lines connected to the ODC and IDC control ports for changing in a controlled way the pressure levels in the cylinder bores passing the control ports.

[0060] The invention is also applicable to hydraulic units equipped with a servo system for supporting the adjustment of the displacement volume and/or for tuning and/or balancing the running behaviour of the hydraulic unit as pressure steps during change of pressure in the cylinder bores from the high system pressure to the low system pressure and vice versa. These pressure transitions can be smoothed by the arrangement of control ports on the valve segment, through which a preferable variably adjustable pressure can be supplied via bypass lines connected to the two system pressure ports. For this, preferably at least one adjustable orifice is arranged in one of the two bypass lines. Thereby it is further preferred to arrange two or more bypass lines in such manner that for each rotational direction the next coming system pressure level can be guided back to the control port laying on the valve segment in rotational direction before the pressure port to which the bypass line is connected to.

[0061] The method according to the invention may further comprise the step of processing a command of a control unit or an operator by means of an electronic control unit (ECU). The electronic control unit can comprise a microcontroller for adjusting the size of the openings of the orifices in the first bypass line and/or in the second bypass line, in order to adapt/control the pressure in the cylinder bores for controlling the displacement volume of the hydraulic axial piston unit. According to the invention, any of the adjustable orifices can be controlled by the electronic control unit, regardless of whether the bypass line in which the adjustable orifice is arranged, connects one of the control ports with one of the pressure ports, or with a hydraulic reservoir, or with a pressure compensation chamber or closed cavity.

[0062] The method according to the invention may further comprise the step of sensing of at least one operational

parameter of the hydraulic axial piston unit by means of a sensor. The sensor can be selected from a group of sensors comprising a tilt angle sensor, a shaft position sensor, a pressure sensor, a flow sensor, a rotational speed sensor, a temperature sensor, a direction sensor, a torque sensor, an acceleration sensor, or any other sensor capable of monitoring at least one operational parameter of the hydraulic unit.

5 **[0063]** According to the invention, the method may further comprise the step of continuously monitoring the operational parameters of the hydraulic axial piston unit in order to smoothen pressure transitions between the kidney-shaped first and second pressure ports and vice versa, and/or for controlling the pressure level in the cylinder bores and thus the pressure profile in the cylinder bores on its way around the rotational axis of the hydraulic axial piston unit, i.e. the course of pressure in dependency of the rotational angle of the cylinder block. The method according to the invention further enables adjusting
10 the tilt angle of the displacement element by controlling the pressure level present at the control ports by means of opening and closing the opening size of an adjustable orifice. For this purpose, measured operational parameters of the hydraulic unit can be processed by the electronic control unit.

[0064] With the help of the enclosed Figures preferred embodiments of a hydraulic axial piston unit according to the invention are explained in more detail in order to enhance the understanding of the basic idea of the invention. The present
15 embodiments do not limit the scope of the idea of the invention, but only represent possible design alternatives, to which within the knowledge of a person with skills in the relevant art modifications can be made without leaving the scope of the invention. Therefore all those modifications and changes are covered by the claimed invention. In the Figures it is shown in:

- 20 Figure 1 a design of a first embodiment of a hydraulic axial piston unit according to the invention;
- Figure 2 schematically the first embodiment of a hydraulic axial piston unit according to the invention;
- Figure 3 schematically a valve segment of the first embodiment of a hydraulic axial piston unit according to the invention;
- 25 Figure 4 schematically a valve segment of a second embodiment of a hydraulic axial piston unit according to the invention;
- Figure 5 schematically a valve segment of a third embodiment of a hydraulic axial piston unit according to the invention;
- 30 Figure 6 schematically a valve segment of a fourth embodiment of a hydraulic axial piston unit according to the invention;
- 35 Figure 7 schematically a valve segment of a fifth embodiment of a hydraulic axial piston unit according to the invention;
- Figure 8 schematically a valve segment of a sixth embodiment of a hydraulic axial piston unit according to the invention;
- 40 Figure 9 schematically a valve segment of a seventh embodiment of a hydraulic axial piston unit according to the invention;
- 45 Figure 10a schematically a hydraulic circuit of an eighth embodiment of a hydraulic axial piston unit according to the invention;
- Figure 10b schematically a hydraulic circuit of a ninth embodiment of a hydraulic axial piston unit according to the invention;
- 50 Figure 11 schematically a valve segment of the eighth embodiment of a hydraulic axial piston unit according to the invention;
- Figure 12 schematically a valve segment of a tenth embodiment of a hydraulic axial piston unit according to the invention;
- 55 Figure 13 a first embodiment of an adjustable orifice according to the invention in an open position;
- Figure 14 the first embodiment of an adjustable orifice according to the invention in a closed position;

Figure 15 a second embodiment of an adjustable orifice according to the invention in an open position;

Figure 16 the second embodiment of an adjustable orifice according to the invention in a closed position;

5 **[0065]** In the Figures same reference numerals are used for same components of different embodiments throughout the description to improve readability.

[0066] Figure 1 shows an exemplary design of a first embodiment of a hydraulic axial piston unit according to the invention. The hydraulic pump comprises a displacement element 4 which can be tilted with respect to a tilt axis 9 in order to adjust the displacement volume of a rotating group 2 of the hydraulic unit. The rotating group 2 comprises a cylinder block 3 rotatable around a rotational axis 13, having cylinder bores 5 in which working pistons 6 are mounted reciprocally
10 moveable between an outer dead centre (ODC) and an inner dead centre (IDC). The working pistons 6 abut against the displacement element 4 via gliding shoes. A valve segment 20 is located on the other side of the cylinder block 3 comprising a first pressure port 21 and a second pressure port 22 serving as interfaces for connecting the hydraulic unit to an open or closed hydraulic circuit. The valve segment 20 further comprises an IDC control port 23 arranged near the rotational
15 position of the IDC of the working pistons 6 of the hydraulic unit and an ODC control port 24 arranged near the rotational position of the ODC of the working pistons 6 of the hydraulic unit.

[0067] Figure 2 depicts a hydraulic scheme of the first embodiment of a hydraulic axial piston unit, here exemplarily a hydraulic axial piston pump. The ODC control port 24 is fluidly connected to the second pressure port 22 via a first bypass line 27. The IDC control port 23 is fluidly connected to a hydraulic reservoir 100 via a second bypass line 28.

20 **[0068]** In the embodiment according to Figure 2, the hydraulic unit is operated in an open hydraulic circuit, for example. The first pressure port 21 is connected to a low system pressure, e.g. to the hydraulic reservoir 100. The second pressure port 22 is connected to high pressure line. Thus, at the ODC control port 24 high system pressure is present, whereas at the IDC control port 23 low system pressure is present. An orifice 29 with a variably adjustable opening size is arranged in the first bypass line 27 for adjusting the fluid flow in the bypass line 27 and therewith the pressure level at the ODC control port
25 24. As the first bypass line 27 is connected to the second pressure port 22, i.e. to the outlet of the hydraulic pump and thus to the high pressure side, opening of the adjustable orifice 29 increases the flow and pressure at the ODC control port 24. The second bypass line 28 comprises an orifice 31, whose opening size in this embodiment is not adjustable. Thus, in the embodiment shown with Figure 2, the flow resistance in the second bypass line 28 is not adjustable.

[0069] The hydraulic unit further comprises a return mechanism 10 that forces the displacement element 4 of the hydraulic unit back into its initial position, when the displacement element 4 is tilted out of this initial position. The initial position of the displacement element 4 can be at a tilt angle of zero degrees, e.g. However, especially preferred for hydraulic units operated as a hydraulic pump or motor in an open hydraulic circuit, the displacement element 4 can be initially tilted towards a non-zero tilt angle. For this purpose the rotational axis 12 of the displacement element 4, respectively the rotational axis 12 of the sliding surface for the guiding shoes on the displacement element 4, can comprise
30 in direction of the tilt axis 9 of the displacement element 4 an offset with respect to the rotational axis 13 of a driving shaft or the cylinder block 3 (c.f. Figure 1). Alternatively the displacement element 4 of the hydraulic unit can be biased to a non-zero displacement angle by means of an elastic force, e.g. provided by a spring.

[0070] Figure 3 schematically shows the valve segment 20 of the first embodiment of a hydraulic axial piston unit according to the invention. The valve segment 20 comprises a first pressure port 21 and a second pressure port 22. Both
40 pressure ports show a kidney-shape. As mentioned above, the first pressure port 21, - the suction port of the hydraulic unit in the example of the first embodiment according to Figures 2 and 3 - is connected to a hydraulic reservoir 100. A dash-dot-dot line represents a dead centre plane 7 in which the rotational position of the outer dead centre (ODC) and the inner dead centre (IDC) are located. The dead centre plane 7 represents a plane which is orthogonal to the tilt axis 9 of the displacement element 4 and which contains the rotational axis 13 of the cylinder block 3 in case of a hydraulic axial piston unit of the swashplate type of construction, or in case of a hydraulic axial piston unit of the bent axis type of construction, which contains the rotational axis of a driving shaft.

[0071] The working pistons 6 (c.f. Figure 1) of the hydraulic unit abut with one side against the displacement element 4 via gliding shoes. On the other side, the working pistons 6 seal with a pressure chamber which is formed by the cylinder bores 5 in combination with the valve segment 20. When the cylinder block 3 rotates and the displacement element 4
50 comprises a non-zero angle of tilt, the working pistons 6 move reciprocally in the cylinder bores 5 and the volume of the pressure chambers in the cylinder bores 5 increases, when a piston 6 is moving away from the valve segment 20. The volume of a pressure chamber decreases when a piston 6 is moving towards the valve segment 20. At the outer dead centre (ODC), the volume of a pressure chamber is maximum, as the distance between the piston 6 and the valve segment 20 is maximum. At the inner dead centre (IDC) the distance between piston 6 and valve segment 20 and therewith the
55 volume of the pressure chamber is minimum.

[0072] In the first embodiment, in case an (open circuit) hydraulic pump is considered, at the position of the ODC a working piston 6 transitions from the suction phase, in which the pressure chamber extends, and hydraulic fluid enters the pressure chamber, to a pressure phase, in which hydraulic fluid is pressed out of the pressure chamber. At the IDC the

phases are inverted, i.e. a working piston 6 transitions from a pressure phase to a suction phase.

[0073] According to the invention, an ODC control port 24 is provided at or near the rotational position of the ODC. Similarly, an IDC control port 23 is provided at or near the rotational position of the IDC. In the first embodiment of the invention, both control ports 23 and 24 are arranged in positions, where an offset-angle γ_O / γ_i is provided between the rotational position of the working pistons 6 at ODC and IDC (dead centre plane 17) and the rotational position of the ODC control port 24 and the IDC control port 23, respectively. The position of the ODC and IDC control ports 23, 24 is essential for the functionality of the invention, especially the offset-angle γ_O / γ_i . Depending on the algebraic sign and the magnitude of the angles γ_O / γ_i , the point in time, at which overlap of the control ports 23, 24 with the passing cylinder bores 5 starts and ends, can be influenced. Modifying the position of the ODC and the IDC control ports 23, 24 influences the timing and time span, when the pressure in a cylinder bore 5 passing/overlapping one of the control ports 23, 24 can be changed/adjusted in a controlled manner. According to the invention, e.g. for a hydraulic pump, the IDC and ODC control ports 23, 24 can preferably be arranged - seen in rotational direction of the pump - behind the respective IDC or ODC rotational positions. According to Figure 3 the IDC control port 23 is connected via the second bypass line 28 with a non-adjustable orifice 31 to the hydraulic reservoir 100 and the first pressure port 21, here the low system pressure side (inlet or suction side) of the hydraulic pump. The ODC control port 24 is connected via the first bypass line 27 comprising an adjustable orifice 29 to the second pressure port 22, here the high system pressure side (outlet or pressure side) of the hydraulic pump.

[0074] The openings of the cylinder bores 5 facing towards the valve segment 20 - illustrated with dashed lines in the Figures - comprise a kidney shape, e.g., with a circumferential extension τ which is, in most applications smaller than the circumferential distance between the first pressure port 21 and the second pressure port 22. The circumferential distance between the first pressure port 21 and the second pressure port 22 is the sum of the circumferential distance between the first pressure port 21 and the position of the ODC/IDC σ_O / σ_i and the circumferential distance between the second pressure port 22 and the position of the ODC/IDC β_O / β_i . If the extension τ would be larger than the sum of $\sigma_O + \beta_O$ or the sum of $\sigma_i + \beta_i$, the first pressure port 21 could be hydraulically short-circuited to the second pressure port 22 via the cylinder bore 5.

[0075] The tilt angle of the displacement element 4 can be adjusted by controlling the magnitude of the opening of the adjustable orifice 29. When the opening of the orifice 29 is increased, high pressure is conducted to the ODC control port 24. Therefore the pressure in the cylinder bore 5 passing the ODC control port 24 can be increased. Increased cylinder bore pressure leads to a higher force on the working piston 6 arranged in the passing cylinder bore 5. As this force is supported/abuted by the displacement element 4, respectively acts on the displacement element 4 via the gliding shoes, the tilt angle of the displacement element 4 can be increased by increasing the pressure in the cylinder bores 5 passing the ODC control port. If the opening size of the variable orifice 29 in the first bypass line 27 is the decreased, the pressure on the working pistons 6 decreases and the force with which the working piston 6 acts on the displacement element 4 decreases also. As a result, the return mechanism 10 (see Figure 2) can exert a returning/neutralizing force which is higher than the on-stroking force on the displacement element 4 and tilts/de-strokes the displacement element 4 back towards its initial position until an equilibrium of the returning forces and the pressure forces acting on the displacement element 4 exerted by the working pistons 6 is established again. To summarize, adjusting the magnitude of the opening of the variable/-adjustable orifice 29 influences the equilibrium of forces/moments with respect to the tilt axis on the displacement element 4, which is established between an on-stroking pressure force on the displacement element 4 and a neutralizing force of the return mechanism 10. The moment generated by the pressure force is maximum at full opening of the adjustable orifice 29.

[0076] A person skilled in the relevant art will appreciate that the inventive concept can be applied in order to set the displacement volume of fixed displacement units as well as in order to set and adjust the displacement volume of variable displacement hydraulic units. Moreover the inventive concept can be used to improve and/or smoothening the running behaviour of a hydraulic unit as pressure transition steps can be lowered making the provision of "fishtails" unnecessary. Thereby the inventive concept can be applied to hydraulic units equipped with a servo unit or to hydraulic units without a servo unit to set/adjust the displacement volume.

[0077] Figure 4 schematically shows a valve segment 20 of a second embodiment of a hydraulic axial piston unit according to the invention. The arrangement according to the second embodiment of the invention is similar to the arrangement shown with Figures 1 and 2. The second embodiment comprises an adjustable orifice 29 in the first bypass line 27, in order to control the pressure at the IDC control port 23. In the second bypass line 28 a non-adjustable orifice 31 is provided. In consequence, the tilt angle of the displacement element 4 in this exemplary embodiment is controlled by means of adjusting the opening/flow resistance in the first bypass line 27 and therewith the pressure at the IDC control port 23. At the rotational area of the IDC control port 23 the pressure in a cylinder bore 5 passing the IDC control port 23 generates a moment with respect to the tilt axis of the displacement element 4, which is capable of decreasing the tilt angle. At the IDC the working piston 6 is at its most introduced point in the passing cylinder bore 5, therefore, increasing the pressure in a cylinder bore 5 passing the IDC will decrease the tilt angle of displacement element 4. On the contrary, decreasing the pressure in a cylinder bore 5 which passes the IDC, can lead to an increased angle of tilt of the displacement element 4, as the reaction force on the displacement element 4 is reduced.

[0078] As mentioned earlier, the first pressure port 21 and therewith the first bypass line 27 are connected to the low pressure side of the hydraulic unit, here to a hydraulic reservoir 100. Therefore, opening of the adjustable orifice 29 provides a reduced (back-) pressure at the IDC control port 23, as hydraulic fluid can be pushed out of the cylinder bores 5 with less resistance, and the pressure in the passing cylinder bore 5 is reduced. In consequence, the tilt angle of the displacement element 4 is increased. Closing the adjustable orifice 24 increases the resistance with hydraulic fluid can be discharged and a higher backpressure is build-up, therewith increasing the pressure in the passing cylinder bore 5 by restricting the pressure relief. Simultaneously, the pressure profile at the ODC pressure port 24 is not actively adjusted due to the non-adjustable orifice 31 in the second bypass line 28.

[0079] Figure 5 schematically shows a valve segment of a third embodiment of a hydraulic axial piston unit according to the invention. The third embodiment can be seen as a combination of the first and second embodiments. Hence, an adjustable orifice 29 is provided in the second bypass line 29 and an adjustable orifice 30 is provided in the first bypass line 27. The working principle of the hydraulic axial piston unit according to the third embodiment is similar to the above explained. Increasing the pressure at the ODC control port 24 leads to an increased tilt angle of the displacement element 4 due to the increased force on the displacement element 4 acting in the direction of tilt. Increasing the pressure at the IDC control port 24 leads to a decreasing tilt angle of the displacement element 4, as the corresponding pressure force acts in a direction which decreases the angle of tilt. Therefore, by providing adjustable orifices 29, 30 in each of the two bypass lines 27, 28, the tilt angle of the displacement element 4 can be adjusted with a high degree of precision. Additionally, vibrations and noises can be reduced by adjusting the opening magnitudes of the orifices 29, 30 in relation to each other in order to smoothen the pressure profile and to reduce or even avoid pressure peaks or cavitation nearby or at the dead centre points IDC and ODC.

[0080] Figure 6 schematically shows a valve segment 20 of a fourth embodiment of a hydraulic axial piston unit according to the invention. The fourth embodiment is a further development of the above mentioned embodiments. In the area of the ODC, the valve segment 20 of the hydraulic unit comprises a second ODC control port 26. Compared to the first ODC control port 24, the second ODC control port 26 is arranged on the opposite side of the ODC/IDC connection line, respectively of the dead centre plane 7, - seen in circumferential direction. This, e.g., means that the first ODC control port 24 is arranged in clockwise direction behind the ODC, whereas the second ODC control port 26 is arranged in clockwise direction before the ODC. The second ODC control port 26 is connected to the second pressure port 22 via an additional bypass line 33, which can comprise, e.g. an adjustable orifice 30 as well as a non-adjustable orifice. This arrangement provides an enhanced possibility to precisely adjust the pressure profile which is provided to a cylinder bore 5 via the first and second ODC control ports 24, 26, when the cylinder bore 5 is travelling on its circular path due to the rotation of the cylinder block 3. Therewith it is further possible to reducing noises and vibrations when operating the hydraulic unit and provides for a shorter reaction time to control signals due to the higher flow rate which can pass through the two ODC control ports 24, 26.

[0081] Figure 7 schematically shows a valve segment 20 of a fifth embodiment of a hydraulic axial piston unit according to the invention. The fifth embodiment of the hydraulic unit can for example represent a hydraulic motor which can be arranged in a closed circuit. In contrast to the embodiments described above, which all comprise an offset angle between the rotational position of the ODC/IDC control ports 23, 24 and the actual rotational position of the IDC and ODC, the ODC control port 24 and the IDC control port 23 of the hydraulic unit according to the fifth embodiment are arranged at the exact respective rotational positions of the IDC and the ODC, i.e. on the dead centre plane 7. This means, that the offset angles γ_0 / γ_1 are equal to zero. In consequence, the control behaviour of the hydraulic unit when adjusting the tilt angle of the displacement element 4 is independent of the direction of rotation of the cylinder block 3.

[0082] In the fifth embodiment, an adjustable orifice 29 is provided in the first bypass line 27. The orifice 31 arranged in the second bypass line 28 comprises a non-adjustable, constant opening size. Typically, hydraulic motors used in closed circuit applications are capable of rotating in two directions. Even though the displacement element 4 of such a hydraulic motor is tiltable only in one direction, and the pressure levels which are present at the first pressure port 21 and at the second pressure port 22 can be interchanged, in order to invert the direction of rotation of a rotating group 2 of the hydraulic unit. In the embodiment shown in Figure 7, the ODC control port 24 is connected to a hydraulic reservoir 100 via the second bypass line 28. Consequently, and regardless of the direction of rotation, lower system pressure is present at the ODC control port 24. According to the invention, high pressure can be provided to the IDC control port 23. For this purpose, a shuttle valve 35 is provided whose outlet 38 is connected to the first bypass line 27. A first inlet 36 of the shuttle valve 35 is connected to the second pressure port 22. A second inlet 37 of the shuttle valve 35 is connected to the first pressure port 21. The shuttle valve 35 is capable of always conducting the higher pressure level of the first pressure port 21 or of the second pressure port 22 to the first bypass line 27 via its outlet 38. Therefore, the adjustments in the opening size of the adjustable orifice 29 are always related to the high pressure level regardless of the direction of rotation of the hydraulic unit. The control of the tilt angle of the displacement element 4 of the hydraulic unit works similar to the control of the hydraulic unit according to the embodiments 1 to 4. For the sake of shortness of the present explanations, a detailed repetition is omitted.

[0083] Figure 8 schematically shows a valve segment 20 of a sixth embodiment of a hydraulic axial piston unit according to the invention. The sixth embodiment is similar to the fifth embodiment. However, the adjustable orifice in the bypass line

27 connecting the IDC control port 23 with the outlet 38 of the shuttle valve 35 is replaced by a non-adjustable orifice 31. Instead, an adjustable orifice 29 is provided in the first bypass line 28 which connects the ODC control port 24 to the hydraulic reservoir 100. The working principle of the displacement control by means of an adjustable orifice 29 in the first bypass line 28 connected to the ODC control port 24 was already described analogously above with respect to the pump of the second embodiment in Figure 4, where the IDC control port 23 is connected to the low system pressure side. Therefore, for the sake of shortness of the present explanations, it is refrained from a detailed repetition.

[0084] Figure 9 schematically shows a valve segment 20 of a seventh embodiment of a hydraulic axial piston unit according to the invention. The valve segment 20 according to the seventh embodiment comprises a first ODC control port 24 and a second ODC control port 26 both connected to the second pressure port 22 via bypass lines 27 and 33, wherein each bypass line 27 and 33 comprises an adjustable orifice 29 and 30. Further, the hydraulic unit comprises a first IDC control port 23 and a second IDC control port 25 both connected to the first pressure port 21 via bypass lines 28 and 32 which both as well comprise adjustable orifices 34 and 39. The first and second ODC control ports 24 and 26 and the first and second IDC control ports 23 and 25 are arranged in rotational direction on both sides of the rotational position of the dead centre plane 7 containing the rotational position of the ODC and the IDC. If the hydraulic unit is capable to rotate bidirectional, as indicated in Figure 9 with the two-sided arrow 80, the circumferential distance from the first IDC/ODC control ports 23 and 24 to the IDC/ODC positions on the valve segment 20 can be equal to the circumferential distance of the second IDC/ODC control ports 25 and 26 to the rotational IDC/ODC positions on the valve segment 20. Therewith, the control behaviour of the hydraulic unit is symmetrical and regardless of the direction of rotation. During operation of the hydraulic unit, the pressure levels which are present at the first pressure port 21 and the second pressure port 22 can be interchanged, e.g. due to a change of operation mode, e.g. from motor mode to pump mode or because a change of the direction of rotation of the hydraulic unit is desired. Therefore, a person with skills in the relevant art may arrange a shuttle valve 35 in the bypass lines 27 and 33 conducting high pressure to the ODC pressure ports 24, 26 if the hydraulic unit is operated as hydraulic pump, or to the IDC pressure ports 23, 25 if the hydraulic unit is operated as hydraulic motor.

[0085] Figure 10a, Figure 10b and Figure 11 schematically show an eighth embodiment of a hydraulic axial piston unit according to the invention, which can for example serve as pump in a closed hydraulic circuit. Similar to the above described examples, the hydraulic unit according to the eighth embodiment comprises a first pressure port 21 and a second pressure port 22. Preferably, the hydraulic pump comprises only one direction of rotation, as indicated by the arrow on the driving shaft 8 in Figure 10 and the arrows 80 on the valve segments 20 shown in Figures 10b and 11. In order to be able to supply hydraulic fluid in both directions, the displacement element 4 of the hydraulic unit is tiltable to positive and to negative angles. The displacement element 4 is forced into its neutral position, which normally is also the initial position of the displacement element 4, by a return mechanism 10.

[0086] Figure 10b additionally shows a valve arrangement comprising charge pressure valves 51 and 52 as common check valves each combined with a proportional flow valve and drained to a hydraulic reservoir 100. With this valve arrangement a start mechanism of hydraulic pump having a neutral return mechanism 10 can be achieved. When one of the flow valves, e.g. the one next to charge pressure valve 52 is opened, charge pressure is guided to the respective other charge pressure valve, in this example to charge pressure valve 51, whose flow valve is closed. Therewith an initial pressure difference at the valve plate 20 is created when the charge pump starts working. At same time by opening both adjustable orifices 29 and 30 a system pressure difference between the two control ports 23, 24 is established, enabling an initial tilt of the displacement element 4. Due to this initial tilt of the displacement element 4 system pressure is generated by the hydraulic pump which increase the pressure delta between the two control ports 23 and 24 as long as the higher system pressure is higher than the charge pressure, and the adjustable orifice 29 is kept at least partially open. With varying the flow passages through the adjustable orifices 29 and 30 the displacement volume can be set/adjusted as described above.

[0087] Due to the potential bi-directional inclination of the displacement element 4, the rotational positions of the IDC and of the ODC are not fixed but are interchanged when the algebraic sign of the tilt angle of the displacement element 4 changes. Therefore, the allocation of the control ports 23 and 24 to the ODC and IDC is not constant throughout the operation of the hydraulic unit, but changes with over-zero displacement of the displacement element 4. In a specific operational state, the rotational position of the ODC can be located on the left side of valve segment 20, e.g. as shown with Figure 11. Accordingly, the rotational position of the IDC can be located on the right side of Figure 11 and the corresponding control ports are labelled ODC control port 24 and IDC control port 23. The control ports 23, 24 are connected to the pressure ports 21, 22 via first and second bypass lines 27 and 28, each comprising an adjustable orifice 29 and 30.

[0088] The inlets 36 and 37 of a shuttle valve 35 whose working principle has already been explained above, are in fluid connection with the first pressure port 21 and the second pressure port 22. The outlet 38 of the shuttle valve 35 is fluidly connected to the first inlet 41 of a control valve 40 which further comprises a second inlet 42 connected to a hydraulic reservoir 100, or another source of low system pressure. Therefore the first inlet 41 of the control valve 40 is always connected to high system pressure which is provided via the shuttle valve 35. The second inlet 42 of the control valve 40 is always connected to low system pressure. The control valve 40 further comprises a first outlet 43 connected to the first bypass line 27, and a second outlet 44 connected to the second bypass line 28. The position of the control valve 40 is selected depending on the algebraic sign of the tilt angle of the displacement element 4 and depending on the use of the

hydraulic unit as a hydraulic pump or as a hydraulic motor. The control valve 40 can connect the first inlet 41 with the first outlet 43 and the second inlet 42 with the second outlet 44. In consequence, high pressure is conducted to the first bypass line 27 and low pressure is conducted to the second bypass line 28. Alternatively, the control valve 40 can connect the first inlet 41 with the second outlet 44 conducting high pressure to the second bypass line 28 and can connect the second inlet 42 to the first outlet 43 conducting low pressure to the first bypass line 27. The control valve 40 can further comprise a third position, in which the bypass lines 27 and 28 are hydraulically short-circuited and the connection between the inlets 41 and 42 and the outlets 43 and 44 are blocked. Depending on the type of use, shifting of the control valve 40 can be discrete or continuously. If the control valve 40 can be positioned continuously the control valve 40 can even serve as a variably adjustable orifice(s).

[0089] In the operating state of the control valve 40 shown with Figure 11 the pressures at the ODC control port 24 and at the IDC control port 23 are equal, as the control valve 40 is in its third position in which the ODC control port 23 is connected to the IDC control port 24. Therefore, no tilting moment is generated by a pressure difference between the ODC control port 24 and the IDC control port 23. As a result, only the - normally relatively high - forces of the neutralizing/returning mechanism 10 and the - normally relatively low - kit moments of the pistons in the cylinder bores 5 of the hydraulic unit contribute to the equilibrium of moments on the displacement element 4, and the displacement element 4 is forced into its neutral position.

[0090] According to the invention no additional servo piston is present in the hydraulic unit and the return mechanism 10 forces the displacement element 4 to a tilt angle of zero degrees. However, to enable start-up of the hydraulic unit, an initial pressure difference has to be provided at the control ports 23 and 24, such that a hydraulic flow can be generated by the hydraulic axial piston unit according to the invention and the tilt angle of the displacement element 4 can be controlled by means of different pressure levels at the ODC/IDC control ports 23 and 24 generated at the pressure ports 21 and 22 with different pressure levels. For this purpose and in order to start-up the hydraulic axial piston unit, a charge pump 50 is provided capable of providing a pressure level to the shuttle valve 35, which is sufficient to generate a force overcoming the neutralizing forces of the return mechanism 10 at one of the control ports 23, 24. This charge pressure is necessary as long as the pressure difference generated in the working lines of the hydraulic axial piston unit in the starting phase is not high enough to create a tilt moment on the displacement element 4 via the pressure levels at the control ports 23 and 24 being sufficient to overcome the neutralizing forces of the return mechanism 10. Once a pressure difference high enough is reached, hydraulic fluid supply to the shuttle valve 35 from the charge pump 50 can be stopped. Additionally, the charge pump 50 can be capable of replacing hydraulic fluid via the low pressure side which has been discharged, e.g. by leakage or for cooling purposes from the closed circuit.

[0091] Figure 12 shows a ninth embodiment of a hydraulic axial piston unit according to the invention. The presented embodiment can for example be used as a hydraulic pump in a closed hydraulic circuit. Similar to the embodiment shown with Figures 10 and 11, the hydraulic unit comprises only one direction of rotation, but the displacement element 4 of the hydraulic unit can be tilted in both directions with respect to its tilt axis 9 (c.f. Figure 1). Therefore, the position of the IDC and the ODC and the position of the corresponding control ports 23 and 24 can be inverted when the algebraic sign of the tilt angle of the displacement element 4 is changed.

[0092] A valve arrangement 55 is arranged fluidly between the first and second pressure ports 21 and 22 and the IDC and ODC control ports 23 and 24. By means of the valve arrangement 55, appropriate pressure levels can be provided to the control ports 23 and 24, for example high pressure to the ODC control ports 24 and low pressure to the IDC control port 23, when the pump is operated. The functionality of the valve arrangement 55 is similar to the functionality of the shuttle valve 35 in combination with the control valve 40 which has been described before. The valve arrangement 55 comprises a pressure operated valve 57 which comprises two inlets and two outlets. The pressure operated valve 57 is adapted to conduct higher pressure to one outlet, e.g. the first outlet, and lower pressure to the other outlet, e.g. the second outlet, regardless of whether the higher pressure is present at the first or the second inlet.

[0093] The outlets of the pressure operated valve 57 are connected to inlets of a start-up valve 59, which in the embodiment of Figure 12 is a 5-3-directional valve. The outlets of the start-up valve 59 are connected to the first and second bypass lines 27 and 28. In the operational position of the start-up valve 59 which is shown in Figure 12, the high pressure, and the low pressure present at the outlets of the pressure-operated valve 57 are conducted further by the start-up valve 59 to the bypass lines 27 and 28 without changing the direction of fluid flow.

[0094] However, when there is no pressure difference between the first and the second pressure ports 21 and 22, - e.g. when the hydraulic unit is started - no pressure difference is present at the control ports 23 and 24 and in consequence, no force can be generated in order to tilt the displacement element 4 of the hydraulic unit. To solve this problem, a third inlet of the start-up valve 59 is connected to a hydraulic reservoir 100, e.g. a tank, which is at a low pressure level. A charge pump 50 is provided which is capable of providing a charge pressure to the inlets of the pressure operated valve 57. This charge pressure is also present at the first and second inlet of the start-up valve 59. When the hydraulic unit is started and the cylinder block 3 is forced to rotate and the start-up valve 59 can be shifted, in order to conduct charge pressure to one of the bypass lines 27 or 28 and to conduct low pressure from the hydraulic reservoir 100 to the other bypass line 28 or 27.

[0095] Therefore, a pressure difference between the two bypass lines 27 and 28 and in consequence between the ODC/IDC control ports 23 and 24 is established, which is capable of generating a torque on the displacement element 4

that is high enough to tilt the displacement element 4 out of the initial position. After the initial tilting of the displacement element 4 a pressure difference is generated at the first and second pressure ports 21 and 22 by the fore and aft movement of the working pistons 6 in the cylinder bores 5. This pressure difference can be conducted to the control ports 23 and 24 via the valve arrangement 55 when it is operated to its operational position shown with Figure 12, and the hydraulic unit can be operated as described in context with the preceding embodiments.

[0096] Figure 13 to 16 show two embodiments of adjustable orifices 29 according to the invention.

[0097] Figure 13 shows a first embodiment of an adjustable orifice 29 according to the invention in an open position. The orifice 29 comprises a valve body 60 in which a first valve port 66 and a second valve port 68 are arranged. A rotary valve spool 62 comprises a recess in its circumferential surface, which overlaps with the first and second valve port 66 and 68 such that a fluid connection between the two valve ports is established.

[0098] Figure 14 shows a first embodiment of an adjustable orifice 29 according to the invention in a closed position. When the rotary valve spool 62 is rotated, the first and second valve ports 66 and 68 do not overlap anymore with the recess in the rotary valve spool 62 and the fluid connection is interrupted. Needless to say that the rotary spool 62 could be replaced by a linear moving spool with a corresponding recess in the spool surface without departing from the scope of the invention.

[0099] Figure 15 shows a second embodiment of adjustable orifices 29 and 30 according to the invention in an open position. Figure 16 shows this second embodiment of the adjustable orifices 29 and 30 according to the invention in a closed position. In contrast to the embodiment shown with Figures 13 and 14, Figures 15 and 16 present a linear spool valve, however, the inventive concept can also be applied to a rotary spool valve. The adjustable orifices 29 and 30 comprise a common valve body 60 with a first valve port 66, a second valve port 68, a third valve port 70, and a fourth valve port 72. The linear movable spool 64 is slidably accommodated in a central bore of the valve body 60 and comprises two circumferential recesses which can be brought into overlap with the valve ports in order to establish a fluid connection between the first and second valve port 66 and 68, and between the third and the fourth valve port 70 and 72. The adjustable connection of the first valve port 66 with the second valve port 68 represents a first adjustable orifice 29. The adjustable connection of the third valve port 70 with the fourth valve port 72 represents a second adjustable orifice 30. As the first orifice 29 and the second orifice 30 share a common spool 62, the opening of the first adjustable orifice 29 and the opening of the second adjustable orifice 30 are mechanically coupled to each other. Thus, only one actuator/actuation mechanism is required in order to adjust the opening of both orifices. Preferably, the pressure levels which are present at the valve ports 66, 68, 70, and 72 are symmetrical with respect to a plane between the second valve port 68 and the third valve port 70. For example, the second valve port 68 and the third valve port 70 can be connected to a higher pressure, and the first valve port 66 and the fourth valve port 72 can be connected to a lower pressure level or vice versa. This requirement can be fulfilled e.g., when an ODC control port 24 of a hydraulic unit, e.g. a hydraulic pump, is connected to the second valve port 68 and an IDC control port 23 of the hydraulic unit, e.g. a hydraulic pump, is connected to the fourth valve port 72. Then, the forces generated on the valve spool 62 by the hydraulic flow (illustrated by arrows in Figures 11 to 14) balance each other and only a low force is required to hold the spool 62 in place or to shift the spool 62.

[0100] From the above disclosure and accompanying Figures and claims, it will be appreciated that the hydraulic axial piston unit according to the invention offers many possibilities and advantages over the prior art. It will be appreciated further by a person skilled in the relevant art that further modifications and changes known in the art could be made to a hydraulic axial piston as disclosed. Therefore all these modifications and changes are within the scope of the claims and covered by them. It should be further understood that the examples and embodiments described above are for illustrative purposes .

List of Reference Numerals

45	2	Rotating group	43	First outlet of control valve
	3	Cylinder block	44	Second outlet of control valve
	4	Displacement element	50	Charge pump
	5	Cylinder bores	51	Charge pressure valve
	6	Working pistons	52	Charge pressure valve
50	7	Dead centre plane		
	9	Tilt axis	55	Valve arrangement
	10	Return mechanism	57	Pressure-operated valve
	12	Rotational axis valve segment	59	Start-up valve
	13	Rotational axis cylinder block	60	Orifice valve body
55	20	Valve segment	62	Rotary spool
	21	First kidney-shaped pressure port	64	Linear spool

(continued)

	22	Second kidney-shaped pressure port	66	First valve port
			68	Second valve port
5	23	IDC control port	70	Third valve port
	24	ODC control port	72	Forth valve port
	25	Second IDC control port		
	26	Second ODC control port	80	Rotational direction
	27	First bypass line	100	Hydraulic reservoir
10	28	Second bypass line		
	29	Adjustable orifice	ECU	Electronic control unit
	30	Adjustable orifice	IDC	Inner dead centre
	31	Non-adjustable orifice	ODC	Outer dead centre
	32	Third bypass line	βi	Angle between second pressure port and inner dead centre
15	33	Fourth bypass line		
	34	Adjustable orifice	βO	Angle between second pressure port and outer dead centre
	35	Shuttle valve	γi	Angle between IDC control port and IDC
	36	First inlet of shuttle valve		
20	37	Second inlet of shuttle valve	γO	Angle between ODC control port and ODC
	38	Outlet of shuttle valve		
	39	Adjustable orifice	σi	Angle between first pressure port and inner dead centre
	40	Inverting valve	σO	Angle between first pressure port and outer dead centre
	41	First inlet of control valve		
25	42	Second inlet of control valve	τ	Angular extension of cylinder bore

Claims

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1. Hydraulic axial piston unit with a rotating group (2) whose displacement volume is set by means of a displacement element (4), the rotating group (2) comprising a rotatable cylinder block (3) with cylinder bores (5) in which working pistons (6) are mounted reciprocally moveable, and with a valve segment (20) comprising a kidney-shaped first pressure port (21) and a kidney-shaped second pressure port (22), wherein a cylinder bore (5) can be fluidly connected to an IDC control port (23) or an ODC control port (24) when the associated working piston (6) is at or close to its inner dead center (IDC) or at or close to its outer dead center (ODC), respectively, wherein the IDC control port (23) and the ODC control port (24) are located in circumferential direction between the respective circumferential ends of the first pressure port (21) and the second pressure port (22), wherein the circumferential distance from the IDC control port (23) to the first and second pressure ports (21, 22) and the circumferential distance from the ODC control port (24) to the first and second pressure ports (21, 22) is smaller than the circumferential extension of the cylinder bores (5), and wherein a first bypass line (27) and a second bypass line (28) are provided, each connecting one of the control ports (23, 24), with an adjustable orifice (29) arranged in the first bypass line (27), capable of continuously variably opening and closing the first bypass line (27) in order to enable an variably adjustable fluid flow connection between the connected control port (23, 24) and a connected pressure port (21, 22), **characterized in that**, the first bypass line (27) and the second bypass line (28) each connects the next pressure port (21, 22) after the connected control port (23, 24) in rotational direction of the cylinder block (3).
- 35
2. Hydraulic axial piston unit according to any of the preceding claims, wherein the second bypass line (28) is connected to a pressure compensation chamber.
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3. Hydraulic axial piston unit according to any of the preceding claims, wherein the openings of the cylinder bores (5) facing the valve segment (20) show a kidney-shaped cross section, wherein the circumferential extensions of the kidney-shaped openings of the cylinder bores (5) are smaller than the circumferential distance between the adjacent ends of the first and second kidney-shaped pressure ports (21, 22).
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4. Hydraulic axial piston unit according to any of the preceding claims, wherein an adjustable orifice (29, 30) is arranged in each of the bypass lines (27, 28).
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5. Hydraulic axial piston unit according to any of the preceding claims, wherein a parallel bypass line comprising an adjustable orifice (29, 30) or a non-adjustable orifice (31) establishes a fluid flow connection parallel to the fluid flow connection between the pressure port (21, 22) and the control port (23, 24) connected by the first bypass line (27) or between the pressure port (21, 22) and the control port (23, 24) connected by the second bypass line (28).
 6. Hydraulic axial piston unit according to claim 1, wherein each control port (23, 24) is additionally connected to the other pressure port (21, 22) via a third and a fourth bypass line (32, 33), wherein an adjustable orifice (29, 30) is arranged in each of the four bypass lines (27, 28, 32, 33).
 7. Hydraulic axial piston unit according to any of the preceding claims, wherein, in case the rotating group (2) is at maximum displacement in its initial position, a safety pressure limiter switching valve is arranged in at least one of the bypass lines (27, 28, 32, 33) in order to close the associated bypass line when a system pressure level exceeds a threshold value.
 8. Hydraulic axial piston unit according to any of the preceding claims, wherein the opening size of the orifices (29, 30) is controlled mechanically or by an electronic control unit (ECU) comprising a micro-controller, and being connected to at least one sensor selected from a group of sensors comprising a tilt angle sensor, a shaft position sensor, a pressure sensor, a flow sensor, a rotational speed sensor, a temperature sensor, a direction sensor, a torque sensor, an acceleration sensor or any other sensor capable of monitoring at least one operational parameter of the hydraulic unit.
 9. Hydraulic axial piston unit according to any of the preceding claims, comprising at least two adjustable orifices (29, 30) one provided in the first bypass line (27) and one provided in the second bypass line (28), wherein the opening sizes of the two adjustable orifices (29, 30) are adjustable separately or by means of a shared mechanical, electromechanical, hydraulic or pneumatic mechanism.
 10. Hydraulic axial piston unit according to any of the preceding claims, wherein the IDC and/or the ODC control port (23, 24) comprise a circular shape, an elongated shape, an ellipse shape, a triangle shape, a kidney-shape or any other shape.
 11. Hydraulic axial piston unit according to any of the preceding claims, wherein the IDC control port (23) and/or the ODC control port (24) are located on the valve segment (20) in circumferential direction with an angular offset to the rotational position on the valve segment (20) at which the working pistons (6) are at its inner dead center (IDC) and/or outer dead center (ODC), respectively.
 12. Hydraulic axial piston unit according to claim 11, wherein a second ODC control port (26) is located on the valve segment (20) such that the first and second ODC control ports (24, 26) being located in circumferential direction on both sides of the rotational position on the valve segment (20) which corresponds to the outer dead center (ODC) position of the working pistons (6).
 13. Hydraulic axial piston unit according to claim 12, wherein a second IDC control port (25) is located on the valve segment (20) such that the first and second IDC control ports (23, 25) being located in circumferential direction on both sides of the rotational position on the valve segment (20) which corresponds to the inner dead center (IDC) position of the working pistons (6).
 14. Hydraulic axial piston unit according to claim 12 or 13, wherein the second IDC control port (25) and/or the second ODC control port (26) are respectively connected to a third bypass line (32) and/or a fourth bypass line (33), wherein at least one of the third and fourth bypass lines (32, 33) comprises an adjustable orifice (34, 39) capable of continuously and variably opening and closing the associated bypass line.
 15. Hydraulic axial piston unit according to any of the preceding claims, operated in a closed hydraulic circuit and comprising a shuttle valve (35) having two inlets (36, 37) and one outlet (38), which inlets (36, 37) are in fluid connection with the first and second pressure ports (21, 22) and which outlet (38) is in fluid connection with the IDC control port (23) or the ODC control port (24), such that the shuttle valve (35) is capable of conducting the higher system pressure from one of the first and second pressure ports (21, 22) to the IDC control port (23) or to the ODC control port (24) and/or to a control valve (40).
 16. Hydraulic axial piston unit according to claim 15, wherein a control valve (40) is provided with a first inlet (41) connected to the outlet (38) of the shuttle valve (35), and a second inlet (42) connected to lower system pressure or to a

hydraulic reservoir (100), and with a first outlet (43) connectable to the IDC control port (23) or the ODC control port (24), and a second outlet (44) connectable to the other control port (24, 23), wherein the control valve (40) is capable of selectively connecting the first inlet (41) with the first outlet (43) and the second inlet (42) with the second outlet (44), or of connecting the first inlet (41) with the second outlet (44) and the second inlet (42) with the first outlet (43), or of short-circuiting the first outlet (43) with the second outlet (44).

17. Hydraulic axial piston unit according to claims 15 or 16, comprising a charge pump (50) capable of providing a hydraulic fluid flow to one of the first or second pressure port (21, 22) to generate an initial pressure difference between the first and second pressure ports (21, 22) and/or to switch the shuttle valve (35) when the hydraulic axial piston unit is in its neutral position.

18. Hydraulic axial piston unit according to any of the preceding claims, wherein the at least one adjustable orifice (29, 30) is controlled by the electronic control unit (ECU) based on a pressure and/or displacement feedback of at least one adjustable orifice (29, 30, 34, 39).

19. Hydraulic axial piston unit according to any of the preceding claims, wherein the control ports (23, 24) are inclined with respect to a rotational axis of the hydraulic axial piston unit.

20. Method for variably controlling the displacement volume of a hydraulic rotating group (2) driving or being driven by a driving shaft (8), having a displacement element (4) tiltable for adjusting the displacement volume of the rotating group (2), wherein the rotating group (2) comprises a rotatable cylinder block (3) in which working pistons (6) are mounted reciprocally moveable in cylinder bores (5), and a valve segment (20) with a kidney-shaped first pressure port (21) and with a kidney-shaped second pressure port (22), wherein an IDC control port (23) and an ODC control port (24) are located on the valve segment (20) in circumferential direction between the respective circumferential ends of the first pressure port (21) and the second pressure port (22), wherein a cylinder bore (5) can be fluidly connected to the IDC control port (23) or the ODC control port (24) when the associated working piston (6) is at or close to its inner dead center (IDC), or is at or close to its outer dead center (ODC), respectively, wherein the circumferential distance from the IDC control port (23) to the first and second pressure ports (21, 22) and the circumferential distance from the ODC control port (24) to the first and second pressure ports (21, 22) is smaller than the circumferential extension of the cylinder bores (5),

wherein the method comprises the following steps:

- draining or supplying of hydraulic fluid from or to the passing cylinder bores (5) via the IDC control port (23) by means of a first bypass line (27) having a first orifice (29),
- supplying or draining of hydraulic fluid to or from the passing cylinder bores (5) via the ODC control port (24) by means of a second bypass line (28) having a second orifice (30),
- adjusting an opening size of the first orifice (29), or an opening size of the second orifice (30), or adjusting both opening sizes of the first orifice (29) and the second orifice (30) in order to set or adjust the angle of tilt of the displacement element (4) and to control the displacement volume of the hydraulic rotating group (2), **characterized in that** hydraulic fluid from the ODC and IDC control ports (23, 24) is supplied or drained with the pressure level of the next pressure port (21, 22) in rotational direction of the cylinder block (3).

21. Method according to claim 20, further comprising the step of:

- processing a command of a control unit or an operator by means of an electronic control unit (ECU) having a microcontroller for adjusting the opening sizes of the orifices (29, 30) in the first bypass line (27) and/or in the second bypass line (28), in order to control the pressure in the cylinder bores (5) for controlling the displacement volume of the hydraulic axial piston unit.

22. Method according to claim 21, further comprising the step of:

- continuously monitoring the operational parameters of the hydraulic axial piston unit in order to smoothen pressure transition between the first and second pressure ports (21, 22) and vice versa, and/or for controlling the pressure in the cylinder bores (5), and/or for adjusting the tilt angle of the displacement element (4).

23. Method according to any of claims 20 to 22, further comprising in case the rotating group (2) is used in a closed circuit hydraulic application having a charge pump (50), the steps of:

- supplying charge pressure to one of the first or second pressure ports (21, 22) via a charge pressure valve (51,52), when the rotating group (2) is in its neutral position;
- guiding of hydraulic fluid by means of one of the first or the second bypass line (27, 28) from the pressure port (21, 22) with the higher pressure to the associated control port (23, 24);
- draining of hydraulic fluid by means of the other bypass line (28, 27) from the other control port (24, 23) to a hydraulic fluid reservoir (100).

Patentansprüche

1. Hydraulische Axialkolbeneinheit mit einem Triebwerk (2), dessen Verdrängungsvolumen über ein Verdrängungselement (4) eingestellt wird, wobei das Triebwerk (2) einen drehbaren Zylinderblock (3) mit Zylinderbohrungen (5) aufweist, in denen Arbeitskolben (6) hin- und herbewegbar gelagert sind, und mit einem Ventilsegment (20), das einen nierenförmigen ersten Druckanschluss (21) und einen nierenförmigen zweiten Druckanschluss (22) aufweist, wobei eine Zylinderbohrung (5) mit einem IDC-Steueranschluss (23) oder einem ODC-Steueranschluss (24) in Fluidverbindung gebracht werden kann, wenn sich der zugehörige Arbeitskolben (6) an oder nahe seinem inneren Totpunkt (IDC) bzw. an oder nahe seinem äußeren Totpunkt (ODC) befindet, wobei der IDC-Steueranschluss (23) und der ODC-Steueranschluss (24) in Umfangsrichtung zwischen den jeweiligen Umfangsenden des ersten Druckanschlusses (21) und des zweiten Druckanschlusses (22) angeordnet sind, wobei der Abstand in Umfangsrichtung vom inneren Totpunkt (23) zum ersten und zweiten Druckanschluss (21, 22) und der Abstand in Umfangsrichtung vom äußeren Totpunkt (24) zum ersten und zweiten Druckanschluss (21, 22) kleiner ist als die Ausdehnung der Zylinderbohrungen (5) in Umfangsrichtung, und wobei eine erste Bypass-Leitung (27) und eine zweite Bypass-Leitung (28) vorgesehen sind, die jeweils einen der Steueranschlüsse (23, 24) verbinden, wobei in der ersten Bypass-Leitung (27) eine einstellbare Blende (29) angeordnet ist, die in der Lage ist, die erste Bypassleitung (27) kontinuierlich variabel zu öffnen und zu schließen, um eine variabel einstellbare Flüssigkeitsströmung zwischen dem angeschlossenen Steueranschluss (23, 24) und einem angeschlossenen Druckanschluss (21, 22) zu ermöglichen, **dadurch gekennzeichnet, dass** die erste Bypassleitung (27) und die zweite Bypassleitung (28) jeweils den in Drehrichtung des Zylinderblocks (3) nächsten Druckanschluss (21, 22) mit dem angeschlossenen Steueranschluss (23, 24) verbinden.
2. Hydraulische Axialkolbeneinheit nach einem der vorhergehenden Ansprüche, wobei die zweite Bypassleitung (28) mit einer Druckausgleichskammer verbunden ist.
3. Hydraulische Axialkolbeneinheit nach einem der vorhergehenden Ansprüche, wobei die Öffnungen der Zylinderbohrungen (5), die zum Ventilsegment (20) zeigen, einen nierenförmigen Querschnitt aufweisen, und wobei die Ausdehnungen der nierenförmigen Öffnungen der Zylinderbohrungen (5) in Umfangsrichtung kleiner sind als der Abstand zwischen den benachbarten Enden des ersten und zweiten nierenförmigen Druckanschlusses (21, 22) in Umfangsrichtung.
4. Hydraulische Axialkolbeneinheit nach einem der vorhergehenden Ansprüche, wobei in jeder der Bypass-Leitungen (27, 28) eine einstellbare Drossel (29, 30) angeordnet ist.
5. Hydraulische Axialkolbeneinheit nach einem der vorstehenden Ansprüche, wobei eine parallele Bypassleitung, die eine einstellbare Drossel (29, 30) oder eine nicht einstellbare Drossel (31) aufweist, eine Flüssigkeitsströmungsverbindung parallel zu der Flüssigkeitsströmungsverbindung zwischen dem Druckanschluss (21, 22) und dem Steueranschluss (23, 24), die durch die erste Bypassleitung (27) verbunden sind, oder zwischen dem Druckanschluss (21, 22) und dem Steueranschluss (23, 24) herstellt, die durch die zweite Bypassleitung (28) verbunden sind.
6. Hydraulische Axialkolbeneinheit nach Anspruch 1, wobei jeder Steueranschluss (23, 24) zusätzlich über eine dritte und eine vierte Bypassleitung (32, 33) mit dem anderen Druckanschluss (21, 22) verbunden ist, wobei in jeder der vier Bypassleitungen (27, 28, 32, 33) eine einstellbare Drossel (29, 30) angeordnet ist.
7. Hydraulische Axialkolbeneinheit nach einem der vorhergehenden Ansprüche, wobei für den Fall, dass das Triebwerk (2) in seiner Ausgangsposition maximale Verdrängung aufweist, in mindestens einer der Bypassleitungen (27, 28, 32, 33) ein Sicherheitsdruckbegrenzer-Schaltventil angeordnet ist, um die zugehörige Bypassleitung zu schließen, wenn ein Systemdruckniveau einen Grenzwert überschreitet.
8. Hydraulische Axialkolbeneinheit nach einem der vorhergehenden Ansprüche, wobei die Größe der Öffnung der Drosseln (29, 30) mechanisch oder durch eine elektronische Steuereinheit (ECU) gesteuert wird, die einen Mikro-

controller aufweist und mit mindestens einem Sensor verbunden ist, der aus einer Gruppe von Sensoren ausgewählt ist, die einen Sensor für den Schwenkwinkel, einen Sensor für die Position der Welle, einen Drucksensor, einen Durchflusssensor, einen Sensor für die Drehzahl, einen Temperatursensor, einen Richtungssensor, einen Drehmomentsensor, einen Beschleunigungssensor oder jeden anderen Sensor aufweist, der in der Lage ist, mindestens einen Betriebsparameter der Hydraulikeinheit zu überwachen.

9. Hydraulische Axialkolbeneinheit nach einem der vorhergehenden Ansprüche, die zumindest zwei einstellbare Drosseln (29, 30) aufweist, von denen eine in der ersten Bypass-Leitung (27) und eine in der zweiten Bypass-Leitung (28) vorgesehen ist, wobei die Größen der Öffnungen der beiden einstellbaren Drosseln (29, 30) separat oder mittels eines gemeinsamen mechanischen, elektromechanischen, hydraulischen oder pneumatischen Mechanismus einstellbar sind.
10. Hydraulische Axialkolbeneinheit nach einem der vorhergehenden Ansprüche, wobei der IDC-Steueranschluss und/oder der ODC-Steueranschluss (23, 24) eine Kreisform, eine längliche Form, eine Ellipsenform, eine Dreiecksform, eine Nierenform oder eine andere Form aufweist.
11. Hydraulische Axialkolbeneinheit nach einem der vorhergehenden Ansprüche, wobei der IDC-Steueranschluss (23) und/oder der ODC-Steueranschluss (24) am Ventilsegment (20) in Umfangsrichtung mit einem Winkelversatz bezüglich der Winkelstellung am Ventilsegment (20) angeordnet sind, in der sich die Arbeitskolben (6) an ihrem inneren Totpunkt (IDC) bzw. äußeren Totpunkt (ODC) befinden.
12. Hydraulische Axialkolbeneinheit nach Anspruch 11, wobei ein zweiter ODC-Steueranschluss (26) derart am Ventilsegment (20) angeordnet ist, dass der erste und der zweite ODC-Steueranschluss (24, 26) in Umfangsrichtung beidseitig der Winkelstellung am Ventilsegment (20) angeordnet sind, die der Position des äußeren Totpunkts (ODC) der Arbeitskolben (6) entspricht.
13. Hydraulische Axialkolbeneinheit nach Anspruch 12, wobei ein zweiter IDC-Steueranschluss (25) derart am Ventilsegment (20) angeordnet ist, dass der erste und der zweite IDC-Steueranschluss (23, 25) in Umfangsrichtung beidseitig der Winkelstellung am Ventilsegment (20) angeordnet sind, die der Position des inneren Totpunkts (IDC) der Arbeitskolben (6) entspricht.
14. Hydraulische Axialkolbeneinheit nach Anspruch 12 oder 13, wobei der zweite IDC-Steueranschluss (25) und/oder der zweite ODC-Steueranschluss (26) jeweils mit einer dritten Bypassleitung (32) und/oder einer vierten Bypassleitung (33) verbunden sind, wobei zumindest eine der dritten und vierten Bypassleitungen (32, 33) eine einstellbare Drossel (34, 39) aufweist, die in der Lage ist, die zugehörige Bypassleitung kontinuierlich und variabel zu öffnen und zu schließen.
15. Hydraulische Axialkolbeneinheit nach einem der vorhergehenden Ansprüche, die in einem geschlossenen Hydraulikkreislauf betrieben wird und ein Wechselventil (35) mit zwei Eingängen (36, 37) und einem Ausgang (38) aufweist, wobei die Eingänge (36, 37) in Fluidverbindung mit dem ersten und zweiten Druckanschluss (21, 22) stehen und der Auslass (38) in Fluidverbindung mit dem IDC-Steueranschluss (23) oder dem ODC-Steueranschluss (24) steht, derart, dass das Wechselventil (35) in der Lage ist, den höheren Systemdruck von einem der ersten und zweiten Druckanschlüsse (21, 22) zum IDC-Steueranschluss (23) oder zum ODC-Steueranschluss (24) und/oder zu einem Steuerventil (40) zu leiten.
16. Hydraulische Axialkolbeneinheit nach Anspruch 15, wobei ein Steuerventil (40) vorgesehen ist, mit einem ersten Einlass (41), der mit dem Auslass (38) des Wechselventils (35) verbunden ist, und mit einem zweiten Einlass (42), der mit einem niedrigeren Systemdruck oder mit einem Hydraulikreservoir (100) verbunden ist, und mit einem ersten Auslass (43), der mit dem IDC-Steueranschluss (23) oder dem ODC-Steueranschluss (24) verbindbar ist, und mit einem zweiten Auslass (44), der mit dem anderen Steueranschluss (24, 23) verbunden werden kann, wobei das Steuerventil (40) in der Lage ist, selektiv den ersten Einlass (41) mit dem ersten Auslass (43) und den zweiten Einlass (42) mit dem zweiten Auslass (44) zu verbinden, oder den ersten Einlass (41) mit dem zweiten Auslass (44) und den zweiten Einlass (42) mit dem ersten Auslass (43) zu verbinden, oder den ersten Auslass (43) mit dem zweiten Auslass (44) kurzzuschließen.
17. Hydraulische Axialkolbeneinheit nach Anspruch 15 oder 16, aufweisend eine Speisepumpe (50), die in der Lage ist, eine hydraulische Flüssigkeitsströmung entweder dem ersten oder dem zweiten Druckanschluss (21, 22) zuzuführen, um eine anfängliche Druckdifferenz zwischen dem ersten und dem zweiten Druckanschluss (21, 22) zu

erzeugen und/oder das Wechselventil (35) zu schalten, wenn sich die hydraulische Axialkolbeneinheit in ihrer Neutralstellung befindet.

5 18. Hydraulische Axialkolbeneinheit nach einem der vorhergehenden Ansprüche, wobei die zumindest eine einstellbare Drossel (29, 30) von der elektronischen Steuereinheit (ECU) auf Basis eines Druck- und/oder Verdrängungs-Feedbacks der zumindest einen einstellbaren Drossel (29, 30, 34, 39) gesteuert wird.

10 19. Hydraulische Axialkolbeneinheit nach einem der vorhergehenden Ansprüche, wobei die Steueranschlüsse (23, 24) in Bezug auf eine Rotationsachse der hydraulischen Axialkolbeneinheit geneigt sind.

15 20. Verfahren zum variablen Steuern des Verdrängungsvolumens eines hydraulischen Triebwerks (2), das von einer Antriebswelle (8) angetrieben wird oder diese antreibt, mit einem schwenkbaren Verdrängungselement (4) zur Einstellung des Verdrängungsvolumens des Triebwerks (2), wobei das Triebwerk (2) einen drehbaren Zylinderblock (3) aufweist, in dem Arbeitskolben (6) in Zylinderbohrungen (5) hin- und herbewegbar angeordnet sind, und mit einem Ventilsegment (20) mit einem nierenförmigen ersten Druckanschluss (21) und mit einem nierenförmigen zweiten Druckanschluss (22), wobei ein IDC-Steueranschluss (23) und ein ODC-Steueranschluss (24) an dem Ventilsegment (20) in Umfangsrichtung zwischen den jeweiligen Umfangsenden des ersten Druckanschlusses (21) und des zweiten Druckanschlusses (22) angeordnet sind, wobei eine Zylinderbohrung (5) mit dem IDC-Steueranschluss (23) oder mit dem ODC-Steueranschluss (24) fluidisch verbunden werden kann, wenn sich der zugehörige Arbeitskolben (6) an oder nahe seinem inneren Totpunkt (IDC) bzw. an oder nahe seinem äußeren Totpunkt (ODC) befindet, wobei der Abstand in Umfangsrichtung vom IDC-Steueranschluss (23) zu den ersten und zweiten Druckanschlüssen (21, 22) und der Abstand in Umfangsrichtung vom ODC-Steueranschluss (24) zu den ersten und zweiten Druckanschlüssen (21, 22) kleiner ist als die Ausdehnung der Zylinderbohrungen (5) in Umfangsrichtung, wobei das Verfahren die folgenden Schritte aufweist:

- 25
- Ablassen oder Zuführen von Hydraulikflüssigkeit von oder zu den vorbeilaufenden Zylinderbohrungen (5) über den IDC-Steueranschluss (23) mittels einer ersten Bypassleitung (27) mit einer ersten Drossel (29),
 - Zuführen oder Ablassen von Hydraulikflüssigkeit zu oder von den vorbeilaufenden Zylinderbohrungen (5) über den ODC-Steueranschluss (24) mittels einer zweiten Bypassleitung (28) mit einer zweiten Drossel (30),
 - 30 - Einstellen einer Öffnungsgröße der ersten Drossel (29) oder einer Öffnungsgröße der zweiten Drossel (30) oder Einstellen beider Öffnungsgrößen der ersten Drossel (29) und der zweiten Drossel (30), um den Schwenkwinkel des Verdrängungselements (4) einzustellen oder anzupassen und das Verdrängungsvolumen des hydraulischen Triebwerks (2) zu steuern, **dadurch gekennzeichnet, dass** Hydraulikflüssigkeit aus den ODC- und IDC-Steueranschlüssen (23, 24) mit dem Druckniveau des in Drehrichtung des Zylinderblocks (3) nächsten Druckanschlusses (21, 22) zugeführt oder abgelassen wird.
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21. Verfahren nach Anspruch 20, weiter aufweisend den Schritt:

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- Verarbeiten eines Befehls einer Steuereinheit oder eines Bedieners mittels einer elektronischen Steuereinheit (ECU) mit einem Mikrocontroller zum Einstellen der Öffnungsgrößen der Drosseln (29, 30) in der ersten Bypassleitung (27) und/oder in der zweiten Bypassleitung (28), um den Druck in den Zylinderbohrungen (5) zum Steuern des Verdrängungsvolumens der hydraulischen Axialkolbeneinheit zu steuern.

45 22. Verfahren nach Anspruch 21, weiter aufweisend den Schritt:

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- kontinuierliches Überwachen der Betriebsparameter der hydraulischen Axialkolbeneinheit, um den Druckübergang zwischen dem ersten und zweiten Druckanschluss (21, 22) und umgekehrt zu glätten, und/oder zum Steuern des Drucks in den Zylinderbohrungen (5), und/oder zum Einstellen des Schwenkwinkels des Verdrängungselements (4).

55 23. Verfahren nach einem der Ansprüche 20 bis 22, weiter aufweisend für den Fall, dass das Triebwerk (2) in einem geschlossenen Hydraulikkreislauf mit einer Speisepumpe (50) eingesetzt wird, die folgenden Schritte:

- Zuführen von Speisedruck zu einem der ersten oder zweiten Druckanschlüsse (21, 22) über ein Speisedruckventil (51, 52), wenn sich das Triebwerk (2) in seiner Neutralstellung befindet;
- Leiten von Hydraulikflüssigkeit über eine der ersten oder zweiten Bypassleitungen (27, 28) von dem Druckanschluss (21, 22) mit dem höheren Druck zu dem zugehörigen Steueranschluss (23, 24);
- Ablassen von Hydraulikflüssigkeit mittels der anderen Bypassleitung (28, 27) von dem anderen Steueran-

schluss (24, 23) zu einem Hydraulikflüssigkeitsreservoir (100).

Revendications

- 5
1. Unité hydraulique à pistons axiaux dotée d'un groupe rotatif (2) dont la cylindrée est définie au moyen d'un élément de cylindrée (4), le groupe rotatif (2) comprenant un bloc-cylindres rotatif (3) pourvu d'alésages de cylindre (5), dans lesquels des pistons de travail (6) sont montés mobiles en va-et-vient, et pourvu d'un segment de vanne (20) comprenant un premier orifice de pression en forme de haricot (21) et un deuxième orifice de pression en forme de haricot (22), un alésage de cylindre (5) pouvant être en communication fluïdique avec un orifice de commande de point mort inférieur (IDC) (23) ou un orifice de commande de point mort supérieur (ODC) (24) quand le piston de travail associé (6) se situe au niveau ou à proximité de son IDC ou au niveau ou à proximité de son ODC, respectivement, l'orifice de commande d'IDC (23) et l'orifice de commande d'ODC (24) étant situés dans une direction circonférentielle entre les extrémités circonférentielles respectives du premier orifice de pression (21) et du deuxième orifice de pression (22), la distance circonférentielle de l'orifice de commande d'IDC (23) aux premier et deuxième orifices de pression (21, 22) et la distance circonférentielle de l'orifice de commande d'ODC (24) aux premier et deuxième orifices de pression (21, 22) étant plus petites que l'extension circonférentielle des alésages de cylindre (5), et une première conduite de by-pass (27) et une deuxième conduite de by-pass (28) étant fournies, chacune reliant l'un des orifices de commande (23, 24), avec un orifice réglable (29) agencé dans la première conduite de by-pass (27), apte à ouvrir et fermer de manière variable et continue la première conduite de by-pass (27) afin de permettre un raccordement d'écoulement fluïdique réglable de manière variable entre l'orifice de commande (23, 24) raccordé et un orifice de pression (21, 22) raccordé, **caractérisée en ce que**, la première conduite de by-pass (27) et la deuxième conduite de by-pass (28) raccordent chacune l'orifice de pression (21, 22) suivant après l'orifice de commande (23, 24) raccordé dans une direction de rotation du bloc-cylindres (3).
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2. Unité hydraulique à pistons axiaux selon l'une quelconque des revendications précédentes, dans laquelle la deuxième conduite de by-pass (28) est raccordée à une chambre de compensation de pression.
3. Unité hydraulique à pistons axiaux selon l'une quelconque des revendications précédentes, dans laquelle les ouvertures des alésages de cylindre (5) faisant face au segment de vanne (20) présentent une section transversale en forme de haricot, les extensions circonférentielles des ouvertures en forme de haricot des alésages de cylindre (5) étant plus petites que la distance circonférentielle entre les extrémités adjacentes des premier et deuxième orifices de pression (21, 22) en forme de haricot.
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4. Unité hydraulique à pistons axiaux selon l'une quelconque des revendications précédentes, dans laquelle un orifice réglable (29, 30) est agencé dans chacune des conduites de by-pass (27, 28).
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5. Unité hydraulique à pistons axiaux selon l'une quelconque des revendications précédentes, dans laquelle une conduite de by-pass parallèle comprenant un orifice réglable (29, 30) ou un orifice non réglable (31) établit un raccordement d'écoulement fluïdique parallèle au raccordement d'écoulement fluïdique entre l'orifice de pression (21, 22) et l'orifice de commande (23, 24) raccordés par la première conduite de by-pass (27) ou entre l'orifice de pression (21, 22) et l'orifice de commande (23, 24) raccordés par la deuxième conduite de by-pass (28).
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6. Unité de piston radial hydraulique selon la revendication 1, dans laquelle chaque orifice de commande (23, 24) est en outre raccordé à l'autre orifice de pression (21, 22) par l'intermédiaire d'une troisième et d'une quatrième conduite de by-pass (32, 33), un orifice réglable (29, 30) étant agencé dans chacune des quatre conduites de by-pass (27, 28, 32, 33).
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7. Unité hydraulique à pistons axiaux selon l'une quelconque des revendications précédentes, dans laquelle, dans le cas où le groupe rotatif (2) est à la cylindrée maximale dans sa position initiale, une vanne de commutation de limiteur de pression de sécurité est agencée dans au moins l'une des conduites de by-pass (27, 28, 32, 33) afin de fermer la conduite de by-pass associée quand un niveau de pression du système dépasse une valeur seuil.
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8. Unité hydraulique à pistons axiaux selon l'une quelconque des revendications précédentes, dans laquelle la taille de l'ouverture des orifices (29, 30) est commandée mécaniquement ou par une unité de commande électronique (ECU) comprenant un microcontrôleur, et étant raccordée à au moins un capteur sélectionné parmi un groupe de capteurs comprenant un capteur d'angle d'inclinaison, un capteur de position d'arbre, un capteur de pression, un capteur de débit, un capteur de vitesse de rotation, un capteur de température, un capteur de direction, un capteur de couple, un

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capteur d'accélération ou tout autre capteur apte à surveiller au moins un paramètre opérationnel de l'unité hydraulique.

- 5 9. Unité hydraulique à pistons axiaux selon l'une quelconque des revendications précédentes, comprenant au moins deux orifices réglables (29, 30), un disposé dans la première conduite de by-pass (27) et un disposé dans la deuxième conduite de by-pass (28), les dimensions d'ouverture des deux orifices réglables (29, 30) étant réglables séparément ou au moyen d'un mécanisme mécanique, électromécanique, hydraulique ou pneumatique partagé.
- 10 10. Unité hydraulique à pistons axiaux selon l'une quelconque des revendications précédentes, dans laquelle l'orifice de commande d'IDC et/ou d'ODC (23, 24) comprend une forme circulaire, une forme allongée, une forme elliptique, une forme triangulaire, une forme en haricot ou toute autre forme.
- 15 11. Unité hydraulique à pistons axiaux selon l'une quelconque des revendications précédentes, dans laquelle l'orifice de commande d'IDC (23) et/ou l'orifice de commande d'ODC (24) sont situés sur le segment de vanne (20) dans une direction circonférentielle avec un décalage angulaire par rapport à la position rotationnelle sur le segment de vanne (20) à laquelle les pistons de travail (6) sont à leur point mort inférieur (IDC) et/ou leur point mort supérieur (ODC), respectivement.
- 20 12. Unité hydraulique à pistons axiaux selon la revendication 11, dans laquelle un deuxième orifice de commande d'ODC (26) est situé sur le segment de vanne (20) de telle sorte que les premier et deuxième orifices de commande d'ODC (24, 26) soient situés dans la direction circonférentielle de part et d'autre de la position rotationnelle sur le segment de vanne (20) qui correspond à la position du point mort supérieur (ODC) des pistons de travail (6).
- 25 13. Unité hydraulique à pistons axiaux selon la revendication 12, dans laquelle un deuxième orifice de commande d'IDC (25) est situé sur le segment de vanne (20) de telle sorte que les premier et deuxième orifices de commande d'IDC (23, 25) soient situés dans la direction circonférentielle de part et d'autre de la position rotationnelle sur le segment de vanne (20) qui correspond à la position du point mort inférieur (IDC) des pistons de travail (6).
- 30 14. Unité hydraulique à pistons axiaux selon la revendication 12 ou 13, dans laquelle le deuxième orifice de commande d'IDC (25) et/ou le deuxième orifice de commande d'ODC (26) sont respectivement raccordés à une troisième conduite de by-pass (32) et/ou une quatrième conduite de by-pass (33), au moins une des troisième et quatrième conduites de by-pass (32, 33) comprenant un orifice réglable (34, 39) apte à ouvrir et fermer de manière variable et continue la conduite de by-pass associée.
- 35 15. Unité hydraulique à pistons axiaux selon l'une quelconque des revendications précédentes, fonctionnant dans un circuit hydraulique fermé et comprenant un sélecteur de circuit (35) ayant deux entrées (36, 37) et une sortie (38), les entrées (36, 37) étant en communication fluïdique avec les premier et deuxième orifices de pression (21, 22) et la sortie (38) étant en communication fluïdique avec l'orifice de commande d'IDC (23) ou l'orifice de commande d'ODC (24), de telle sorte que le sélecteur de circuit (35) soit apte à conduire la pression haute du système de l'un des premier et deuxième orifices de pression (21, 22) vers l'orifice de commande d'IDC (23) ou l'orifice de commande d'ODC (24) et/ou vers une vanne de commande (40).
- 40 16. Unité hydraulique à pistons axiaux selon la revendication 15, dans laquelle une vanne de commande (40) est pourvue d'une première entrée (41) raccordée à la sortie (38) du sélecteur de circuit (35), d'une deuxième entrée (42) raccordée à une pression basse du système ou à un réservoir hydraulique (100), d'une première sortie (43) pouvant être raccordée à l'orifice de commande d'IDC (23) ou l'orifice de commande d'ODC (24) et d'une deuxième sortie (44) pouvant être raccordée à l'autre orifice de commande (24, 23), la vanne de commande (40) étant apte à raccorder sélectivement la première entrée (41) à la première sortie (43) et la deuxième entrée (42) à la deuxième sortie (44), ou à raccorder la première entrée (41) à la deuxième sortie (44) et la deuxième entrée (42) à la première sortie (43), ou à court-circuiter la première sortie (43) avec la deuxième sortie (44).
- 45 17. Unité hydraulique à pistons axiaux selon les revendications 15 ou 16, comprenant une pompe de charge (50) apte à fournir un flux de fluïde hydraulique vers l'un du premier ou du deuxième orifice de pression (21, 22) pour générer une différence de pression initiale entre les premier et deuxième orifices de pression (21, 22) et/ou pour commuter le sélecteur de circuit (35) quand l'unité hydraulique à pistons axiaux est dans sa position neutre.
- 50 18. Unité hydraulique à pistons axiaux selon l'une quelconque des revendications précédentes, dans laquelle le ou les orifices réglables (29, 30) sont commandés par l'unité de commande électronique (ECU) sur la base d'une rétroaction
- 55

de pression et/ou de cylindrée d'au moins un orifice réglable (29, 30, 34, 39).

5 19. Unité hydraulique à pistons axiaux selon l'une quelconque des revendications précédentes, dans laquelle les orifices de commande (23, 24) sont inclinés par rapport à un axe de rotation de l'unité hydraulique à pistons axiaux.

10 20. Procédé permettant de commander de manière variable la cylindrée d'un groupe rotatif hydraulique (2) menant ou mené par un arbre d'entraînement (8), ayant un élément de cylindrée (4) inclinable pour ajuster la cylindrée du groupe rotatif (2), le groupe rotatif (2) comprenant un bloc-cylindres rotatif (3) dans lequel des pistons de travail (6) sont montés mobiles en va-et-vient dans des alésages de cylindre (5), et un segment de vanne (20) doté d'un premier orifice de pression en forme de haricot (21) et d'un deuxième orifice de pression en forme de haricot (22), un orifice de commande d'IDC (23) et un orifice de commande d'ODC (24) étant situés sur le segment de vanne (20) dans une direction circonférentielle entre les extrémités circonférentielles respectives du premier orifice de pression (21) et du deuxième orifice de pression (22), un alésage de cylindre (5) pouvant être en communication fluidique avec l'orifice de commande d'IDC (23) ou l'orifice de commande d'ODC (24) quand le piston de travail (6) associé se situe au niveau ou à proximité de son point mort inférieur (IDC), ou se situe au niveau ou à proximité de son point mort supérieur (ODC), respectivement, la distance circonférentielle de l'orifice de commande d'IDC (23) aux premier et deuxième orifices de pression (21, 22) et la distance circonférentielle de l'orifice de commande d'ODC (24) aux premier et deuxième orifices de pression (21, 22) étant plus petite que l'extension circonférentielle des alésages de cylindre (5), le procédé comprenant les étapes suivantes consistant à :

- 20
- drainer ou alimenter un fluide hydraulique depuis ou vers les alésages de cylindre (5) passants par l'intermédiaire de l'orifice de commande d'IDC (23) au moyen d'une première conduite de by-pass (27) ayant un premier orifice (29),
 - 25 - alimenter ou drainer un fluide hydraulique vers ou depuis les alésages de cylindre (5) passants par l'intermédiaire de l'orifice de commande d'ODC (24) au moyen d'une deuxième conduite de by-pass (28) ayant un deuxième orifice (30),
 - régler une taille d'ouverture du premier orifice (29) ou une taille d'ouverture du deuxième orifice (30), ou régler les deux tailles d'ouverture du premier orifice (29) et du deuxième orifice (30) afin de définir ou de régler l'angle d'inclinaison de l'élément de cylindrée (4) et de commander la cylindrée du groupe rotatif hydraulique (2),
 - 30 **caractérisé en ce qu'un fluide hydraulique provenant des orifices de commande d'ODC et d'IDC (23, 24) est alimenté ou drainé avec le niveau de pression de l'orifice de pression (21, 22) suivant dans une direction de rotation du bloc-cylindres (3).**

35 21. Procédé selon la revendication 20, comprenant en outre l'étape consistant à :

- 40
- traiter une commande d'une unité de commande ou d'un opérateur au moyen d'une unité de commande électronique (ECU) ayant un microcontrôleur destiné au réglage des tailles d'ouverture des orifices (29, 30) dans la première conduite de by-pass (27) et/ou dans la deuxième conduite de by-pass (28), afin de commander la pression dans les alésages de cylindre (5) pour commander la cylindrée de l'unité hydraulique à pistons axiaux.

45 22. Procédé selon la revendication 21, comprenant en outre l'étape consistant à :

- 50
- surveiller en continu les paramètres opérationnels de l'unité hydraulique à pistons axiaux afin de lisser la transition de pression entre les premier et deuxième orifices de pression (21, 22) et vice versa, et/ou pour commander la pression dans les alésages de cylindre (5), et/ou pour ajuster l'angle d'inclinaison de l'élément de cylindrée (4).

55 23. Procédé selon l'une quelconque des revendications 20 à 22, comprenant en outre, dans un cas où le groupe rotatif (2) est utilisé dans une application hydraulique à circuit fermé ayant une pompe de charge (50), les étapes consistant à :

- 60
- alimenter une pression de charge vers l'un des premier ou deuxième orifices de pression (21, 22) par l'intermédiaire d'une vanne de pression de charge (51, 52), quand le groupe rotatif (2) est dans sa position neutre ;
 - guider le fluide hydraulique au moyen de l'une de la première ou la deuxième conduite de by-pass (27, 28) de l'orifice de pression (21, 22) ayant la pression la plus élevée vers l'orifice de commande (23, 24) associé ;
 - 65 - drainer le fluide hydraulique au moyen de l'autre conduite de by-pass (28, 27) de l'autre orifice de commande (24, 23) vers un réservoir de fluide hydraulique (100).

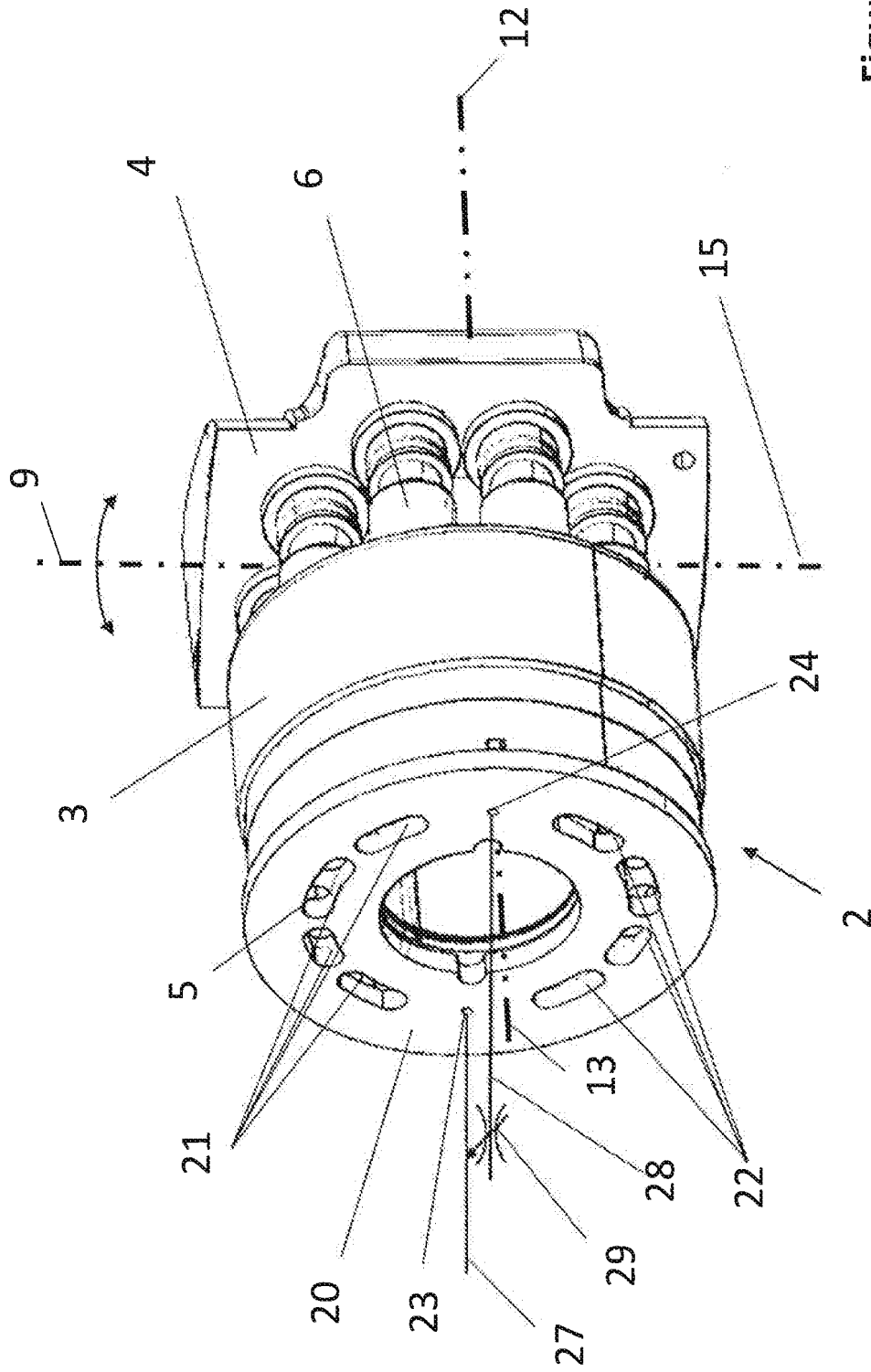


Figure 1

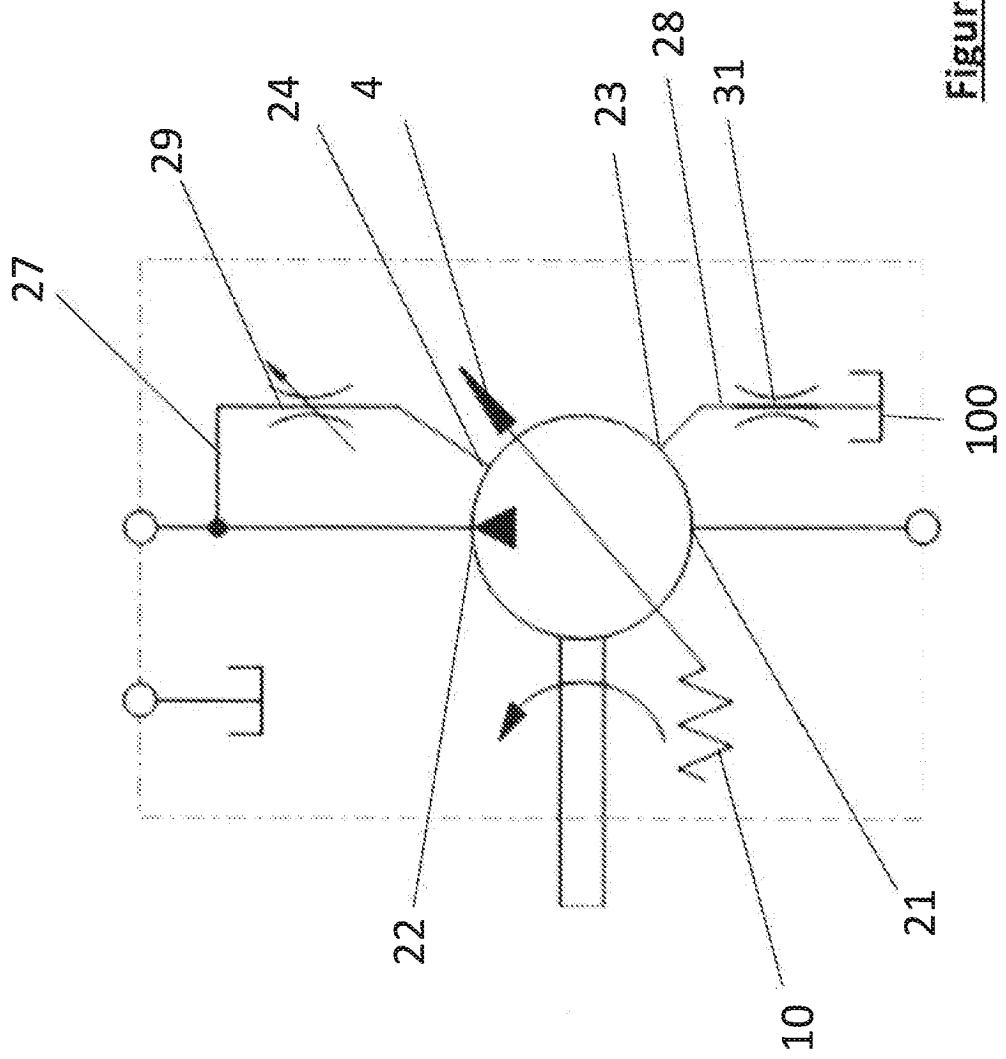


Figure 2

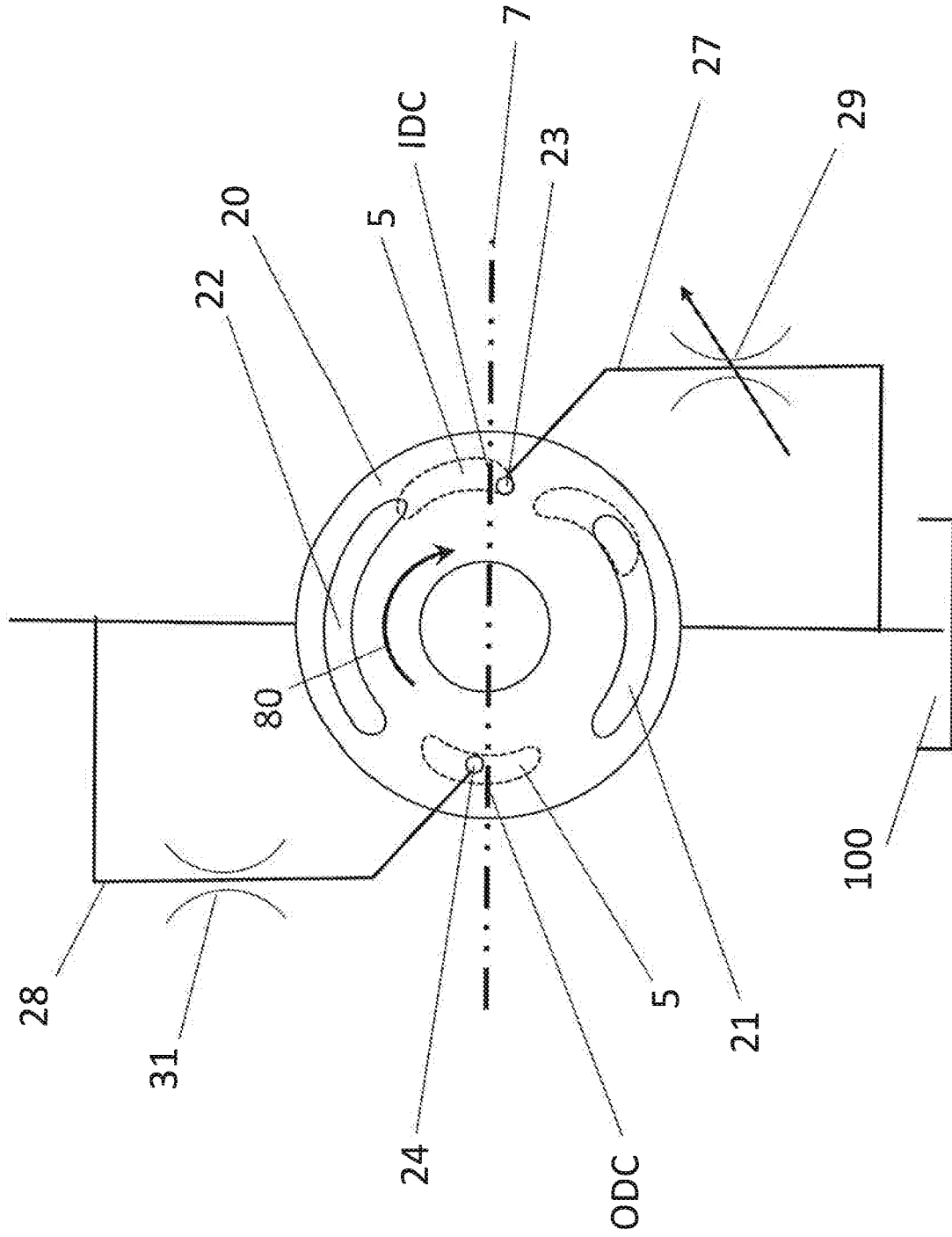


Figure 4

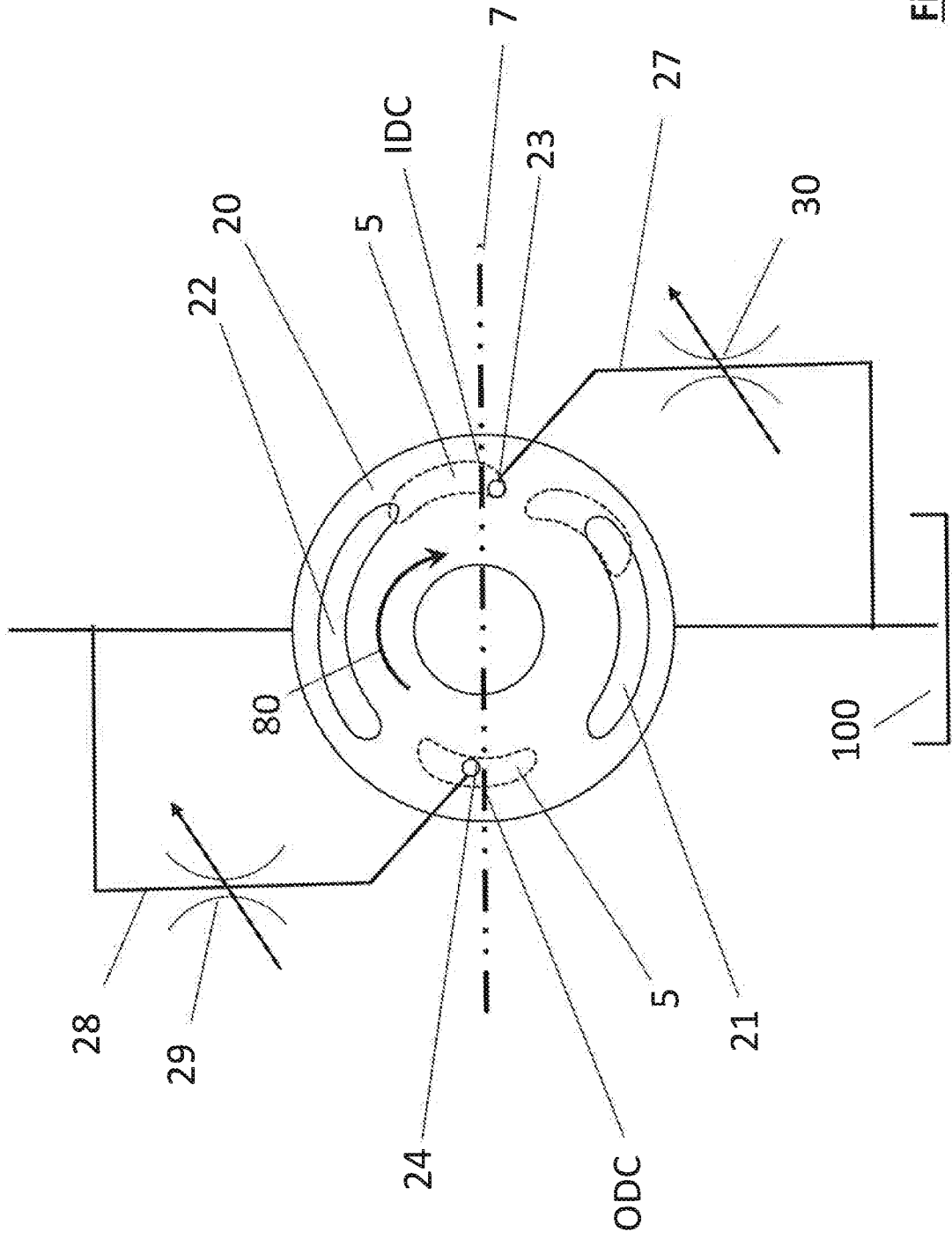


Figure 5

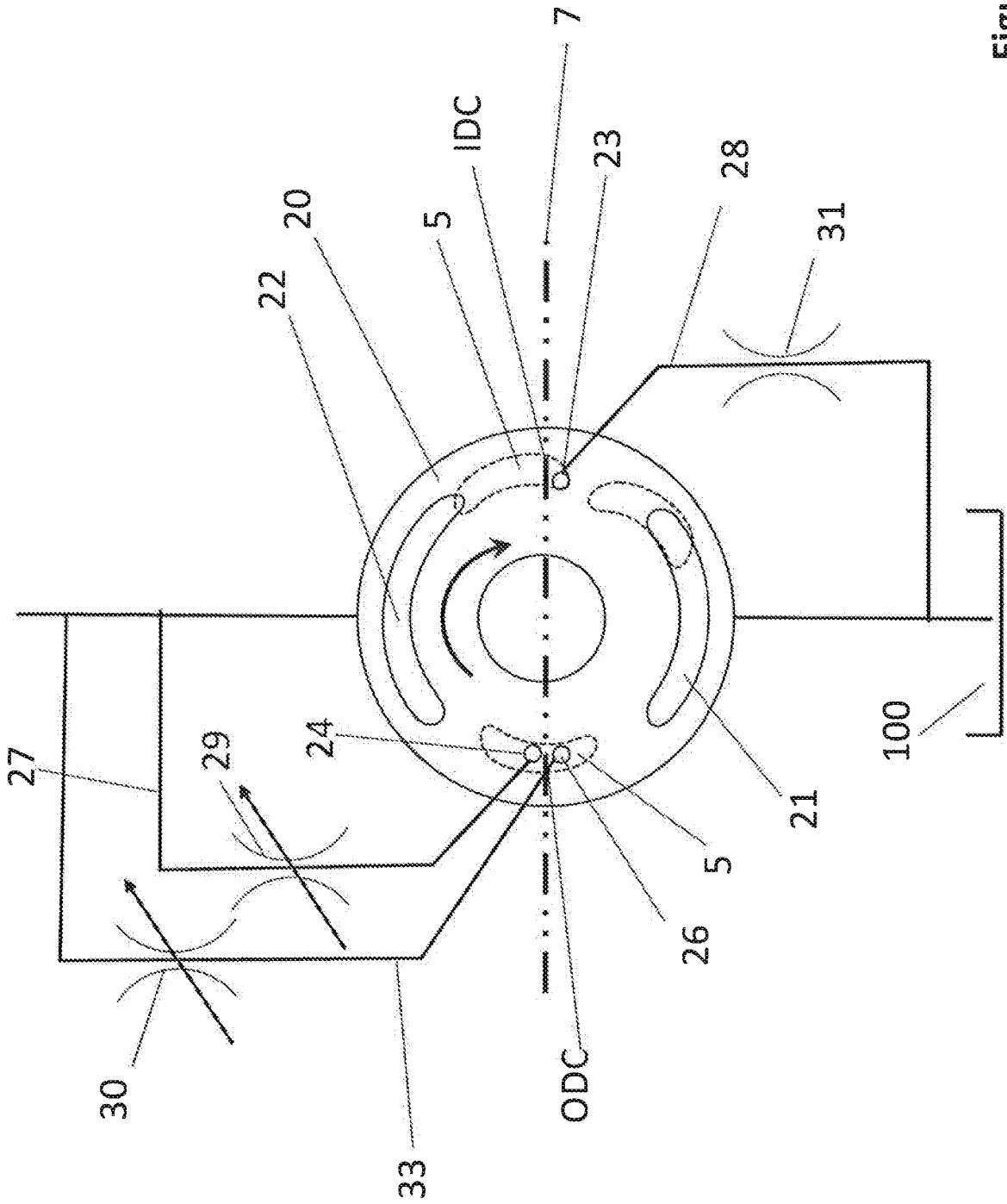


Figure 6

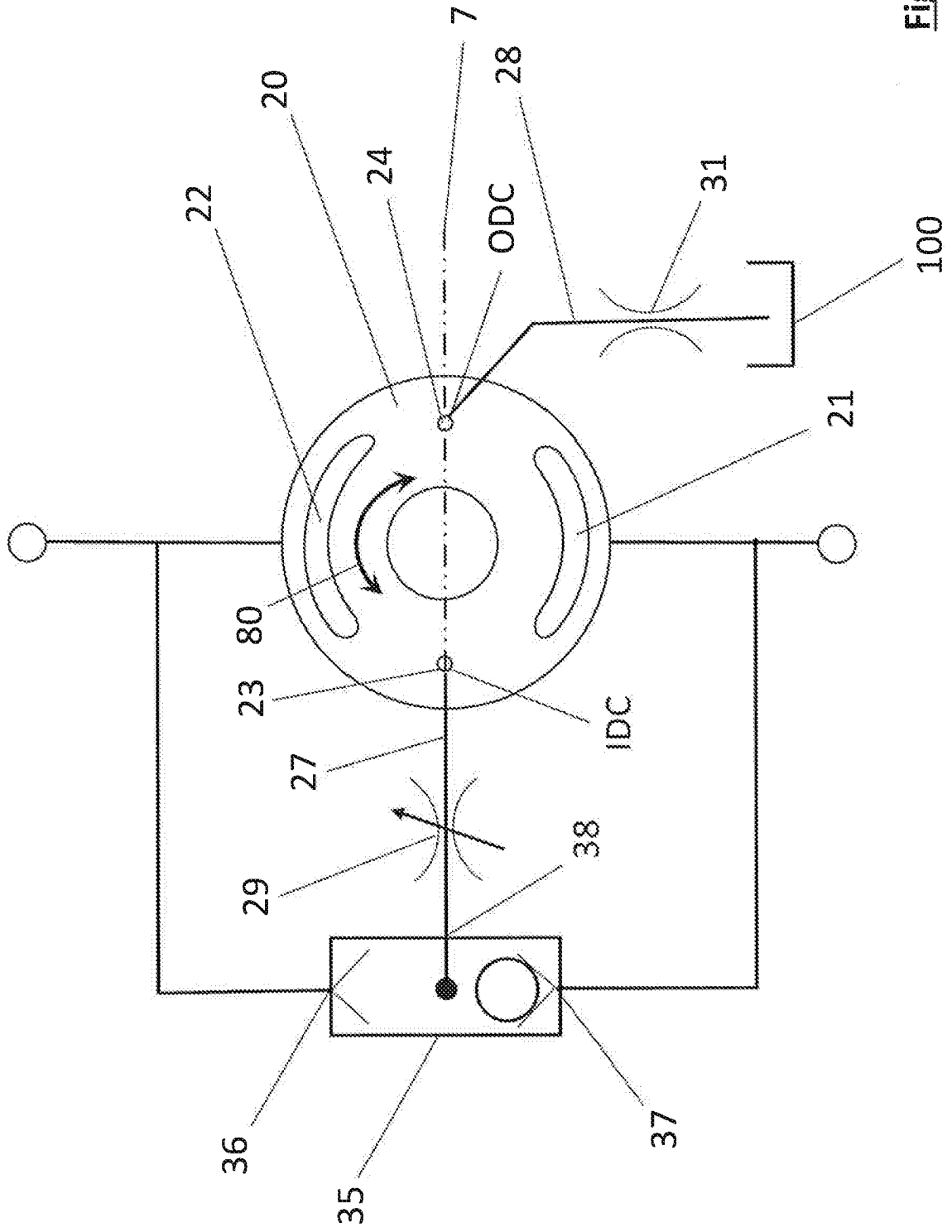


Figure 7

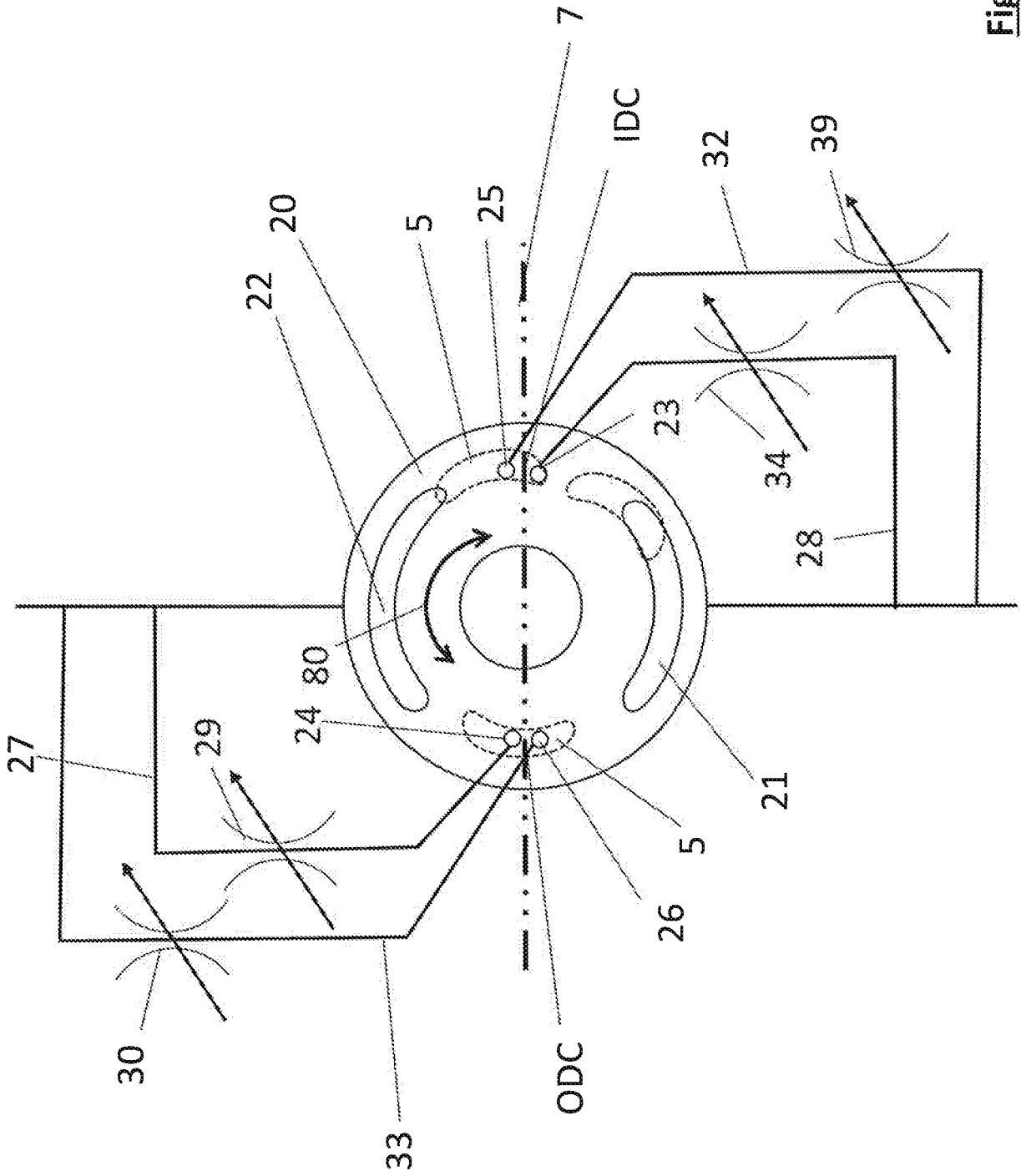


Figure 9

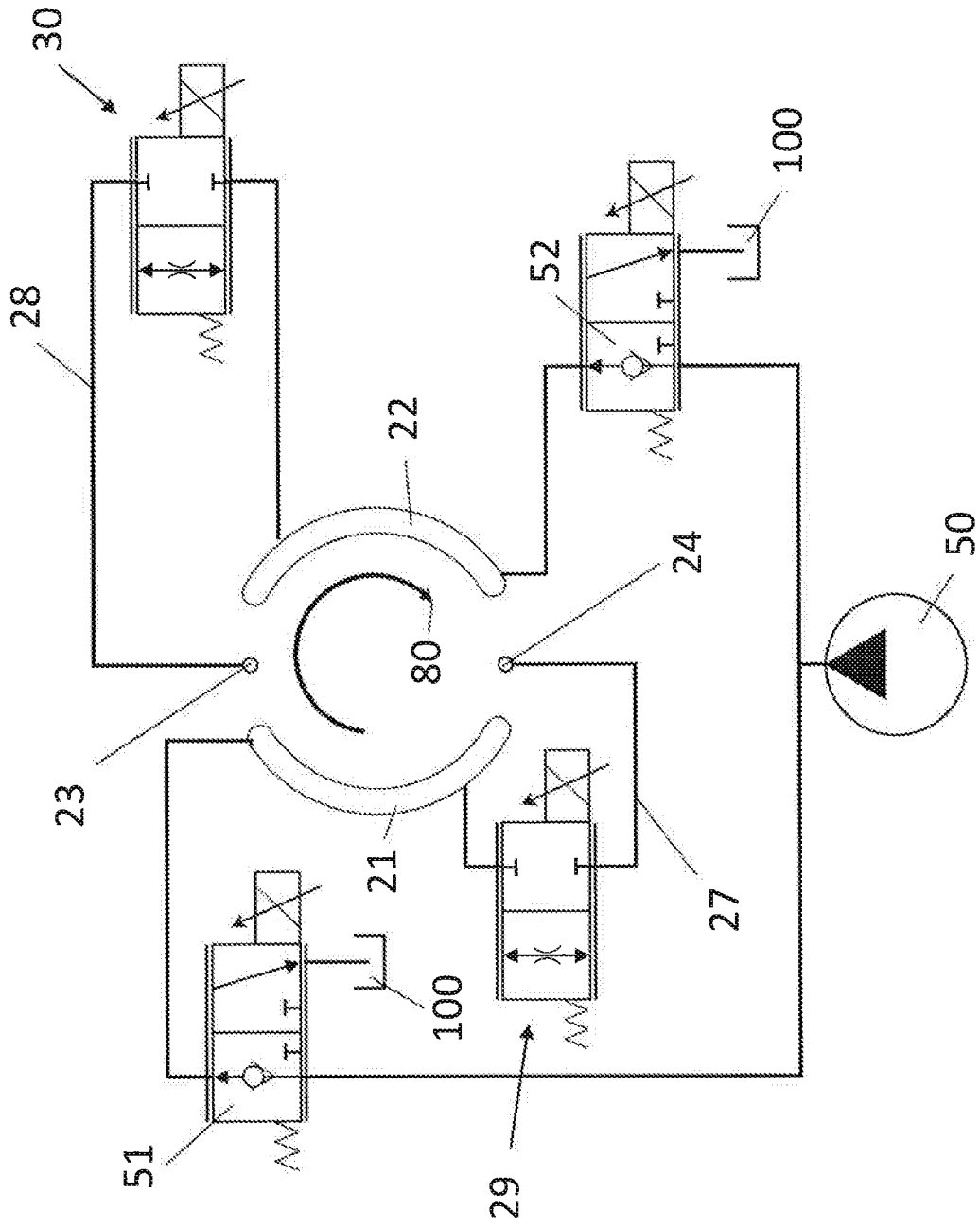


Figure 10b

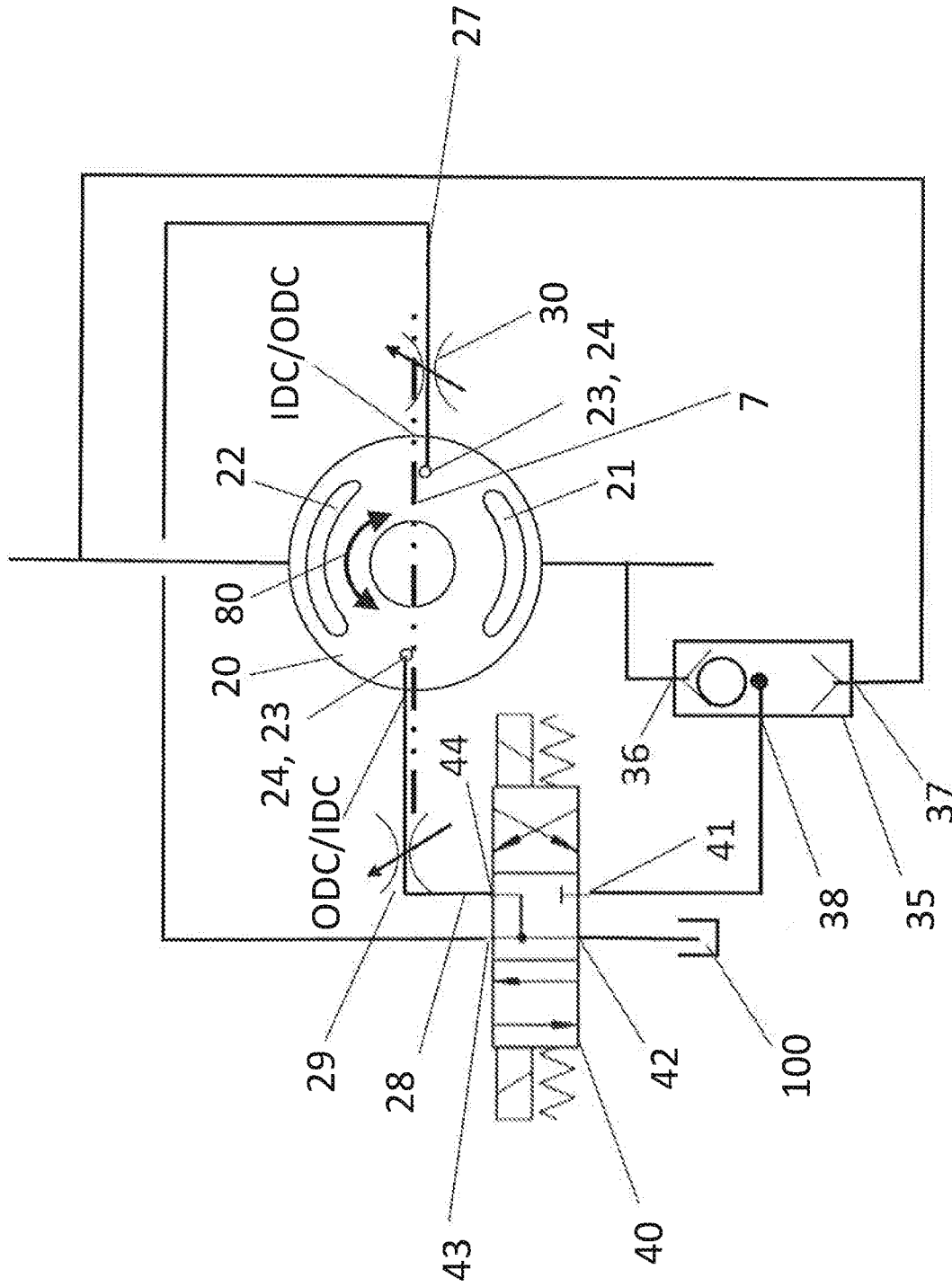


Figure 11

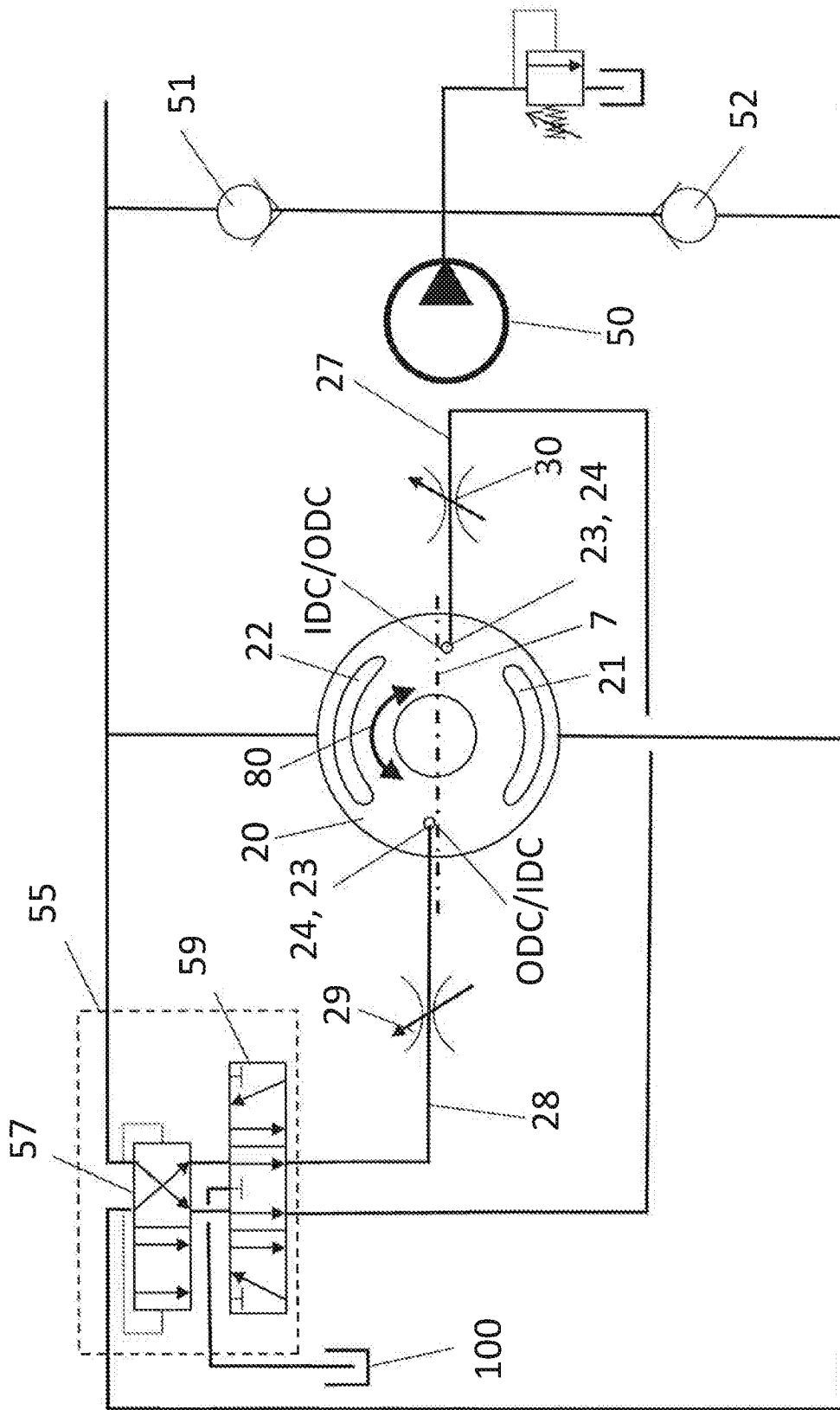


Figure 12

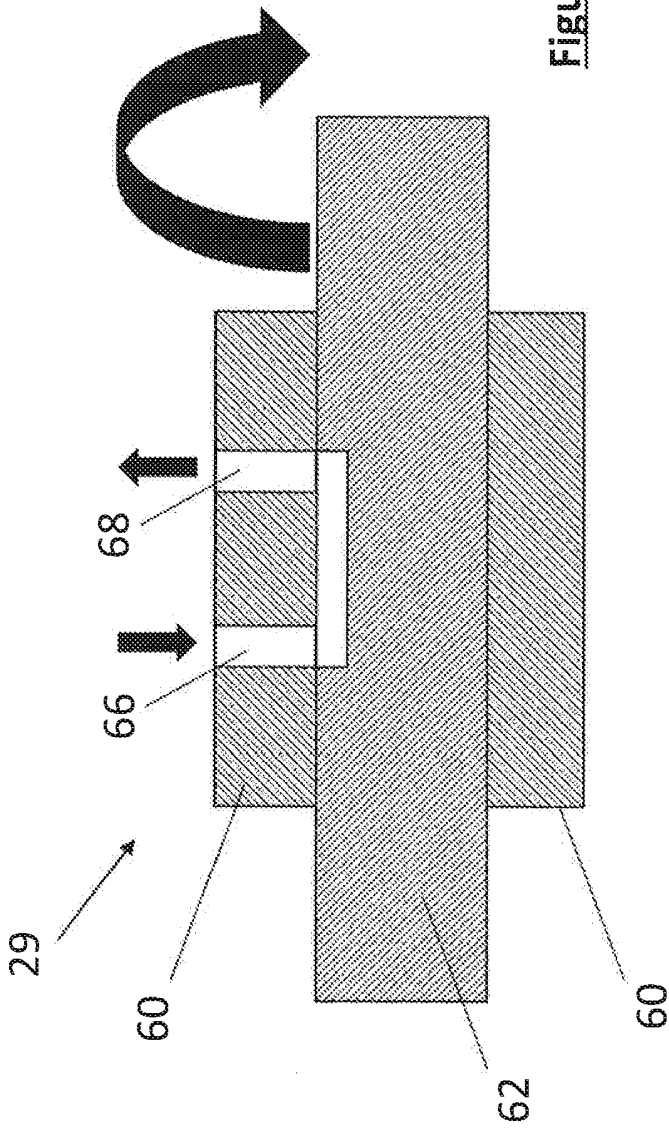


Figure 13

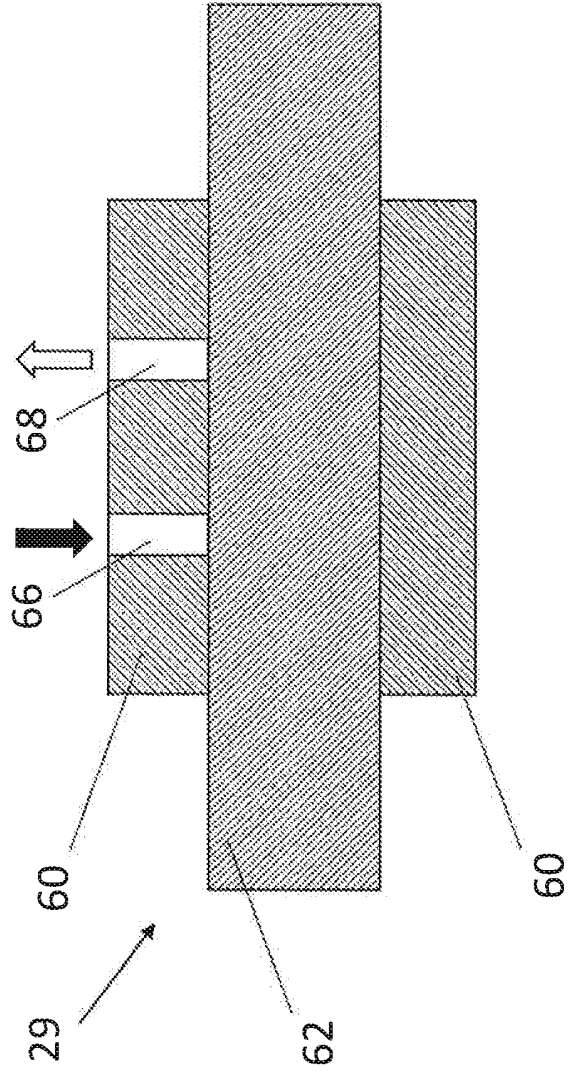


Figure 14

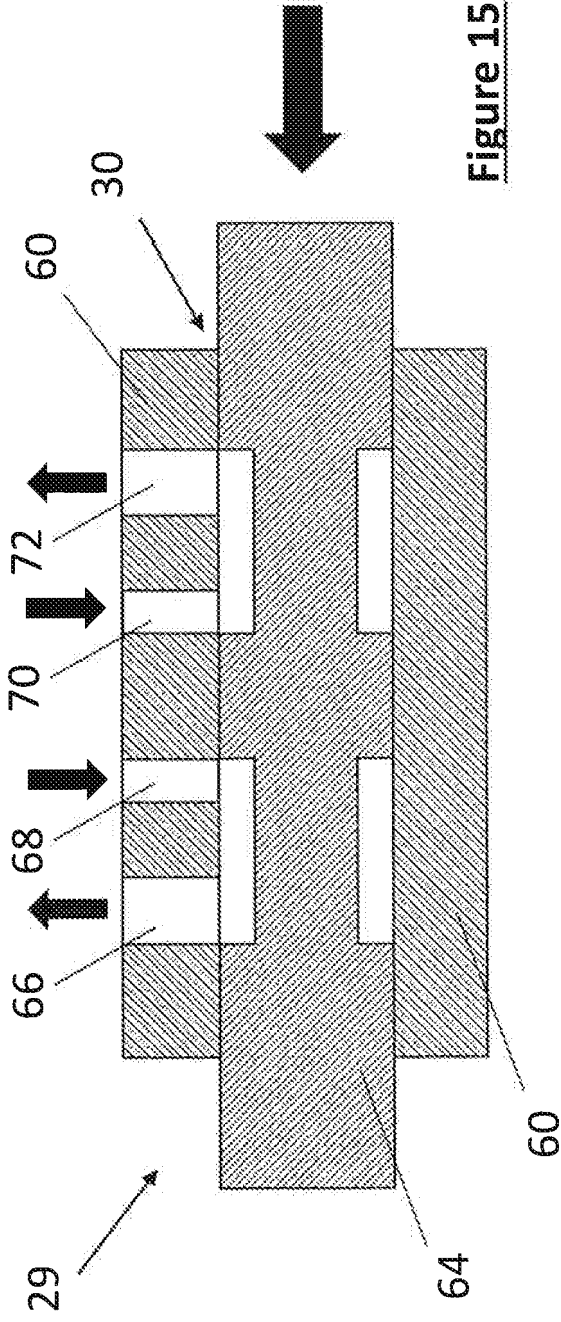


Figure 15

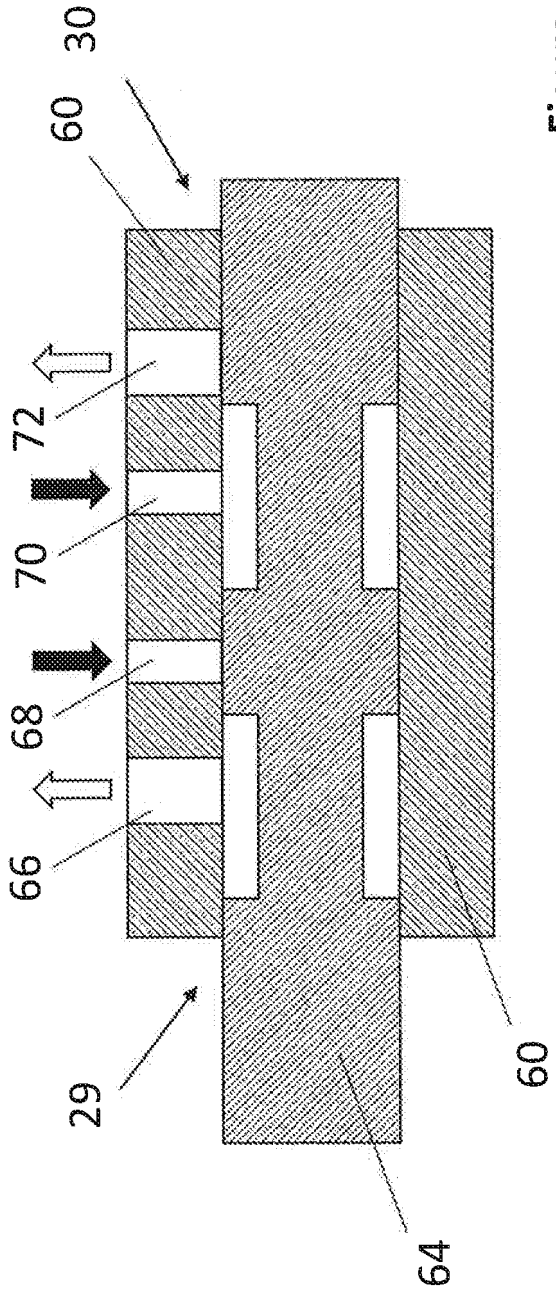


Figure 16

REFERENCES CITED IN THE DESCRIPTION

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