(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 4 345 284 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
03.04.2024 Bulletin 2024/14

(21) Application number: **22198761.3**

(22) Date of filing: **29.09.2022**

(51) International Patent Classification (IPC):
F03C 1/247 *(2006.01)* ***F03C 1/40*** *(2006.01)*
F03C 1/30 *(2006.01)* *F04B 1/1071 (2020.01)*
F04B 1/063 (2020.01) *F04B 1/0413 (2020.01)*

(52) Cooperative Patent Classification (CPC):
F03C 1/247; F03C 1/0409; F03C 1/045; F03C 1/2407; F04B 1/0413; F04B 1/063; F04B 1/1071

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(71) Applicant: **Robert Bosch GmbH**
70442 Stuttgart (DE)

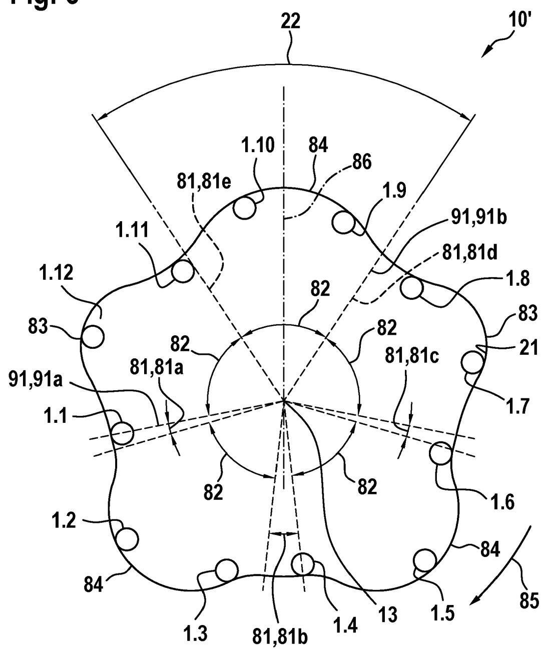
(72) Inventor: **Hare, David**
Kirkliston, EH29 9GH (GB)

(54) **MULTI PISTON MACHINE WITH CONSTANT RELATIONSHIP BETWEEN FLUID VOLUME AND ROTATION ANGLE IN EACH ROTATIONAL POSITION**

(57) The invention concerns with a rotor having multiple pistons (1.1 - 1.12) contacting a cam surface (21) having first and second sections (81; 82), which are arranged alternately with respect to a rotation of the rotor.

According to the invention set of reference positions (91) of the rotor is defined for each of the named switching positions of the valve assembly respectively, wherein at each reference position (91) a piston (1.1 - 1.12) connected to the first working port enters a second section (82), due to a rotation of the rotor, wherein an angular extent of at least one first section (81) with respect to the axis of rotation (13) is greater than zero, such that in at least one switching position of the valve assembly the pistons (1.1 - 1.11) contributing to the displacement volume of the multi piston machine (10') pass the associated reference positions (91) at essentially constant angular intervals during a complete revolution of the rotor.

Fig. 6



EP 4 345 284 A1

Description

[0001] The invention concerns a multi piston machine with a rotor, which is located within a casing and which is rotatable about an axis of rotation, wherein the casing has a first and second working port, wherein a first number of pistons are received in the rotor in a linearly movable manner, such that they define a cylinder with variable volume respectively, wherein the pistons are able to contact a cam surface of the casing, which has a second number of lobes, such that the number of strokes of a single piston during one revolution of the rotor equals the second number, wherein the cam surface defines a second number of first sections and a second number of second sections, which are arranged alternately with respect to a rotation of the rotor, wherein each piston contacts either a first or a second section in each angular position of the rotor, wherein the first sections are formed such that a piston contacting the first section is constantly at a position defining a smallest volume of the corresponding cylinder, wherein there is a valve assembly and a distributor, wherein the valve assembly has at least two switching positions, wherein the valve assembly and the distributor are configured such that each cylinder is either connected to the first working port, to the second working port or to short circuit connection at each angular position of the rotor, wherein the short circuit connection provides a short circuit between at least two cylinders, wherein the number of cylinders having a short circuit connection is different in the different switching positions.

[0002] US 4 807 519 shows a corresponding multi piston machine, which is configured as a radial piston motor. The number of switching positions of the valve assembly is two. The first number of pistons and the second number of lobes is typically selected such that the first and the second number have a common factor, which is different from one. The named factor may be three. Due to this common factor the symmetry in the movement of the pistons can be exploited to provide a constant relationship between the volume of pressure fluid provided at the first working port and the rotation angle of the rotor in each rotational position of the rotor. This common factor heavily restricts the possible selections for the first and second number. When the named symmetry in the movement of pistons is present, all first sections can be configured to have an angular extent of zero, i.e. there are only single points within the rotation of the rotor, where the cylinders have their smallest volume.

[0003] The present invention has the advantage that the first and the second number can be selected arbitrarily. Nevertheless the named constant relationship between the amount of pressure fluid provided at the first working port and the rotation angle of the rotor in each rotational position of the rotor can be achieved. Preferably the present invention is used with a multi piston machine having at least three switching positions of the valve assembly providing a non-zero displacement volume each, wherein the named displacement volumes are different from each other.

[0004] According to claim 1, a set of reference positions of the rotor is defined for each of the named switching positions of the valve assembly respectively, wherein at each reference position a piston connected to the first working port enters a second section, due to a rotation of the rotor, wherein an angular extent of at least one first section with respect to the axis of rotation is greater than zero, such that in at least one switching position of the valve assembly the pistons contributing to the displacement volume of the multi piston machine pass the associated reference positions at essentially constant angular intervals during a complete revolution of the rotor.

[0005] If the radial piston machine is configured as a motor the rotation of the rotor is preferably caused by a pressure at the first working port which is higher than the pressure at the second working port. If the radial piston machine is configured as a pump the rotation of the rotor is caused by drive motor which is in rotational driving engagement with the rotor, wherein the pressure fluid preferably flows from the second working port (lower pressure) through the rotor to the first working port (higher pressure).

[0006] Preferably, the named angular intervals are exactly equal among each other. Preferably, the multi piston machine is a radial piston machine, i.e. the direction of movement of the pistons is perpendicular to the axis of rotation. Preferably, the multi piston machine is used with a pressure fluid. Preferably the pressure fluid is a liquid and most preferably hydraulic oil.

[0007] Further improvements of the invention are indicated in the dependent claims.

[0008] Preferably, an angular extent of at least two first sections with respect to the axis of rotation is greater than zero and different from each other. With this configuration it is possible to achieve exactly constant angular intervals.

[0009] Preferably, the named angular interval is essentially constant for all switching positions of the valve assembly providing a non-zero displacement volume of the multi piston machine.

[0010] Preferably, the first and the second number have no common factor besides one.

[0011] Preferably, the angular extent of at least two second sections is equal to each other. Most Preferably, the angular extent of all second sections is equal to each other. With this configuration the named constant relationship between the volume of pressure fluid provided at the first working port and the rotation angle of the rotor in each rotational position of the rotor can be achieved.

[0012] Preferably, at least two second sections are formed identical to each other. Most preferably, at all second sections are formed identical to each other. With this configuration the named constant relationship between the volume of pressure fluid provided at the first working port and the rotation angle of the rotor in each rotational position of the rotor can be achieved.

[0013] Preferably, there are at least two first sections having the same non-zero angular extent.

[0014] Preferably, there is one and only one first section whose angular extent is at least twice as wide as the next smaller first section.

[0015] Preferably, the maximum angular extent of all first sections is at least 5°. Most preferably, the maximum angular extent of all first sections at least 10°.

[0016] Preferably, for at least one switching position of the valve assembly, the second number of lobes is split into a third and fourth number of lobes, wherein the third number is the number of lobes on which cylinders are connected to the first or second working ports and wherein the fourth number is the number of lobes on which cylinders are in a short circuit connection with each other, wherein the third and fourth number have no common factor besides one. In the second embodiment of the invention and the second switching position according to Fig. 6, the third number is two, wherein the fourth number is three. In the second embodiment of the invention and the third switching position according to Fig. 7, the third number is three, wherein the fourth number is two. In consequence the first switching position (full displacement) also shows the constant angular interval named in claim 1. This is basically due to the fact that the numbers two and three have no common factor besides one.

[0017] Preferably, the cam surface is configured mirror-symmetrical with respect to an axis of symmetry. If the inventive configuration is present for one direction of rotation of the rotor, it is also present for the opposite direction of the rotor, if the name mirror symmetry is present. Preferably, the axis of symmetry intersects the axis of rotation perpendicularly.

[0018] It goes without saying that the features mentioned above and those which are still to be explained below can be used not only in the particular combination indicated but also in other combinations or in independent form without departing from the scope of the present invention.

[0019] The invention is explained in more detail below with reference to the accompanying drawings. It shows:

Fig. 1 a perspective view of a multiple piston machine according to a first embodiment of the invention;

Fig. 2 a perspective view of the rotor;

Fig. 3 a perspective view of the distributor;

Fig. 4 a schematic diagram comprising the pistons, the first and second control openings and the first to fourth fluid chamber;

Fig. 5 a schematic comprising the first and the second control valve, the first to fifth fluid chamber and the first and the second working port;

Fig. 6 a first schematic view of the cam surface and the pistons of a second embodiment of the invention, wherein this view is directed to a second switching position of the valve assembly; and

Fig. 7 a second schematic view which differs from Fig. 6 only in the angular position of the rotor, wherein this view is directed to a third switching position of the valve assembly.

[0020] Fig. 1 a perspective view of a multiple piston machine 10 according to a first embodiment of the invention. The first embodiment has a fist number of eighteen pistons and second number of seven lobes. The valve assembly has four switching positions, wherein three of the them correspond to non-zero displacement volumes. The fourth switching position is a free wheeling position, which is not relevant for the invention at hand.

[0021] The multiple piston machine 10 has a casing 60 comprising a first, a second, a third and a fourth casing part 61; 62; 63; 64, which together enclose all components of the multiple piston machine 10 in a fluid tight manner. The first, the second and the third casing part 61; 62; 63 are fixed to each other. Preferably, the third casing part 63 has a first flange 65, which can by connected to a frame of a vehicle for example. The fourth casing part 64 is rotatable about an axis of rotation 13 with respect to the remaining casing 61; 62; 63. It has a second flange 66, which can be connected to a wheel of the named vehicle for example.

[0022] The cup shaped first casing part 61 holds the distributor (no. 30 in Fig. 3) and the first and the second control valve 41; 42, wherein no. 41; 42 actually point to the section of the casing 60, which covers a spool of the first or second control valve 41; 42 respectively. The first and the second working port 11; 12 and the first and the second control port 43; 44 are located at the first casing part 61.

[0023] The third casing part 63 surrounds the rotor (no. 70 in Fig. 2) in a ring shaped manner. The inner circumferential surface of the third casing part 63 extents along the axis of rotation 13 with a constant cross section, wherein it forms the cam surface (no. 21 in Fig. 4).

[0024] The second casing part 62 surrounds a disc brake, which is known from EP 2 841 763 B1 for example. The fourth casing part 64 is fixed to the rotor (no. 70 in Fig. 2), via a splined shaft which is formed by the fourth casing part 64. The named shaft is supported by the second casing part 62 via roller bearings.

[0025] Fig. 2 shows a perspective view of the rotor 70. The rotor 70 at hand has eighteen pistons 1.1 - 1.18. The reference numerals 1.1 - 1.18 are assigned in numerical order around the rotor 70. The pistons 1.1 - 1.18 are movable radially with respect to axis of rotation 13, such that the axis of movement intersects axis of rotation 13 at 90°. It should be noted that the invention is not restricted to this angle. The axis of movement of the pistons could also be parallel to the axis of rotation 13 for example.

[0026] All pistons 1.1 - 1.18 are shown in their most inward position. During operation the piston 1.1 - 1.18 stick out of the rotor 70 such that they contact the cam surface (no. 21 in Fig. 4) with a roller 74. The roller 74 is held rotatably in the remaining piston via a hydrostatic bearing such that it can rotate with low friction despite the high forces acting on the pistons 1.1 - 1.18. All pistons are configured identically.

[0027] The rotor 70 has a even first control surface 71, which is perpendicular to the axis of rotation 13. On the first control surface 71 there is a first control opening 2.1 - 2.18 for each piston. The numbering (number after the point) of first openings 2.1 - 2.18 is identical to the numbering of the pistons 1.1 - 1.18. This means first control open 2.1 is connected to the cylinder (no. 73 in Fig. 4) of piston 1.1. The first control openings are equally distributed along a first circle 72 whose center is defined by the axis of rotation 13. All first control openings 2.1 - 2.18 are identical to each other, wherein they are circular.

[0028] The rotor 50 has a splined bore 75 via which it is connected to the fourth casing part (no. 64 in Fig. 1) in a rotationally fixed manner.

[0029] Fig. 3 shows a perspective view of the distributor 30. The distributor 30 is a one-piece part providing the second control surface 36 and the first to fifth fluid chamber 31 - 35. The even second control surface 36 is perpendicular to the axis of rotation 13. It has fourteen second control openings 3.1 - 3.14 which are nearly equally distributed along a second circle 37 in numerical order. The center of the second circle 37 is defined by the axis of rotation 13, wherein its diameter is equal to the diameter of the first circle (no. 72 in Fig. 2). The second control openings 3.1 - 3.14 are nearly identical to each other, wherein they are formed like a oblong hole which extents in radial direction.

[0030] The distributer 30 has an outer surface which rotationally symmetric with respect to the axis of rotation 13 and which is adapted to the first casing part (no. 61 in Fig. 1) in a fluid tight manner. The hydraulic pressure in the first to fifth fluid chamber 31 - 35 urges the distributer 30 in the direction of the axis of rotation 13, such that the second control surface 36 abuts against the first control surface (no. 71 in Fig. 1) in a fluid tight manner. During one revolution of the rotor each first control opening overlaps each second control opening in at least in one rotational position of the rotor.

[0031] The first to fifth fluid chamber 31 - 35 are for formed by grooves on the circumferential surface of the distributor 30, which are arranged along the axis rotation 13 in numerical order. The connection between the first to fourth fluid chamber 31 - 34 with the second control openings will be explained with reference to Fig. 4 below. These permanent connections are formed by channels inside the distributor 30, which were made during the casting of the blank distributor. The fifth fluid chamber provides a fluid connection between the first and the second control valve, which is marked in Fig. 5 with no. 35.

[0032] The notch 38 prevents a rotation of the distributor 30 with respect to the axis of rotation 13. A pin, which is held by the second casing part extents into the notch 38. By definition the notch is located between the second control openings 3.1 and 3.2.

[0033] Fig. 4 shows a schematic diagram comprising the pistons 1.1 - 1.18, the first and second control openings 2.1 - 2-18; 3.1 - 3.14 and the first to fourth fluid chamber 31; 32; 33; 34. For sake of clarity some of the reference numerals 1.1 - 1.18; 2.1 - 2.18; 3.1 - 3.14 were missed out. In all three cases there is a consecutive numbering, which ascends from left to right in Fig. 4.

[0034] The piston 1.1 - 1.18 are equally distributed around the axis of rotation (no. 13 in Fig. 2), wherein they are shown in an unfolded way in Fig. 4. The cam surface 21, the rotor 70 and the distributor 30 are shown correspondingly. The the two dash-dot lines 15 refer to the same circumferential position with respect to the axis of rotation (no. 13 in Fig. 2, namely the center of piston 1.18.

[0035] The cam surface 21 on the inner circumference of the second casing part (no. 62 in Fig. 1) has seven lobes, wherein it is basically sinus shaped. Further details are explained with reference to Fig. 6. The fluid pressures in the cylinders 74 urges the moveable pistons 1.1 - 1.18 against the cam surface 21 such that they follow the cam surface 21 when the rotor 70 rotates. In consequence during one rotation of the rotor 70 each piston 1.1 - 1.18 executes seven strokes.

[0036] The distributor 30 has fourteen second control control openings 3.1 - 3.14, i.e. two for each lobe of the cam surface 21. The rotational position of the distributor 30 relative to the cam surface 21 is fixed by a notch 38 (see Fig. 3 too) which engages with a cylindrical pin fixed in the second casing part (no. 62 in Fig. 1), such that each dead center (maximum or minimum) of the cam surface 21 is located between two neighboring second control openings 3.1 - 3.14.

[0037] The rotor 70 has eighteen pistons 1.1 - 1.18 which are accommodated in a respective cylinder 73 of the rotor 70 so that the can move linearly. Each piston 1.1 - 1.18 contacts the cam surface 21 via a roller (no. 74 in Fig. 2) which is not shown in Fig. 4. Each cylinder 73 has as a respective first control opening 2.1 - 2.18, wherein each first control opening 2.1 - 2.18 overlaps each second control opening 3.1 - 3.14 during one rotation of the rotor 70.

[0038] Below no. 30 in Fig. 4 the internal connections of the distributor are shown, which are selected to provide three switchable non-zero displacement volumes according to the invention. Since the first number of pistons 1.1 - 1.18 and the third number of second control openings 3.1 - 3.14 have number two as a common prime factor there are pairs of pistons which have a 180° phase relation. For instance piston 1.2 and 1.11 show a phase relation of 180°. In theory it is possible to short circuit such a pair of pistons so that it does no contribute to the overall displacement volume of the multi piston machine, wherein no pressure peaks are produced. This is the basic working principle of US 6 050 173 A. But exactly this option is not used with the present invention. There is no position of the first and second control valve (no. 41; 42 in Fig. 5) which results in such a short circuit of the named pair of pistons 1.2/1.11, i.e. in a short circuit between the second and third fluid chamber 32; 33 in the rotor position shown in Fig. 4. Instead the claimed connections are used.

[0039] There is a first and second group of second control openings A; B, wherein neighboring second control openings 2.1 - 2.14 belong to a different first or second group A; B. The first fluid chamber 3.1 is permanently connected to three second control openings 3.6; 3.8; 3.14 belonging to the first group A. The second fluid chamber 32 is permanently connected to four second control openings 3.2; 3.4; 3.10. 3.12 belonging to the first group A. The third fluid chamber 33 is permanently connected to three second control openings 3.1; 3.7; 3.9 belonging to the second group B. The fourth fluid chamber 34 is permanently connected to four second control openings 3.3; 3.5; 3.11; 3.13 belonging to second group B.

[0040] Fig. 5 shows a schematic comprising the first and the second control valve 41; 42, the first to fifth fluid chamber 31 - 35 and the first and the second working port 11; 12. The first and the second control valve 41; 42 and the first and the second auxiliary valve 45; 56 are preferably configured as spool valves respectively. The first control valve 41; has a first and a second position 51; 52, wherein the second control valve 42 has a third an a fourth position 53; 54. In Fig. 5 the first and third positions 51; 53 are active such that all second control openings belonging to group A are connected to the first port 11, wherein all second control openings belonging to group B are connected to the second working port 12. Namely the first control valve 41 connects the first working port 11 with the first fluid chamber 31 and the second working port 12 with the third fluid chamber 33. The second control valve 42 connects the first working port 11 with the second fluid chamber 32 and the second working port 12 with the fourth fluid chamber 34. The fifth fluid chamber 35 is not used in this switching position, in which the multi piston machine works with the maximum displacement volume.

[0041] The second to maximum displacement volume is a active, when the first control valve 41 is in the second position 52, wherein the second control valve 42 is in the third position 53. Then the first working port 11 is only connected to the second fluid chamber 32, wherein the second working port 12 is only connected to the fourth fluid chamber 34 wherein both connections are provided by the second control valve 42. The first control valve 41 provides a direct connection between the first and the third fluid chamber 31; 33 via its first short circuit connection 55. Consequently the second control openings 3.1; 3.6; 3.7; 3.8; 3.9; 3.14 are connected to each other. The two pairs 3.1/3.8 and 3.8/3.14 provide an exact 180° phase shift. The remaining pair 3.6/3.9 does not exactly provide a 180° phase shift, but nearly. To minimize pressure peaks due to this small miss-match the first auxiliary valve 45 provides a connection between the first short connection 55 and the first control port 43, when it is switched into its open position by a pressure in the first control port 43, which urges the first control valve 41 into is second position 52. In this state eight of the fourteen second control openings contribute to the net displacement volume so that the net displacement volume is 8/14 of the maximum displacement volume.

[0042] The third to maximum displacement volume is a active, when the first control valve 41 is in the first position 51, wherein the second control valve 42 is in the fourth position 54. Then the first working port 11 is only connected to the first fluid chamber 31, wherein the second working port 12 is only connected to the third fluid chamber 33 wherein both connections are provided by the first control valve 41. The second control valve 42 provides a direct connection between the second and the fourth fluid chamber 32; 34 via its second short circuit connection 56. Consequently the second control openings 3.2; 3.3; 3.4;3.5; 3.10; 3.11; 3.12; 3.13 are connected to each other. The three pairs 3.3/3.10; 3.4/3.11 and 3.5/3.12 provide an exact 180° phase shift. The remaining pair 3.2/3.13 does not exactly provide a 180° phase shift, but nearly. To minimize pressure peaks due to this small miss-match the second auxiliary valve 46 provides a connection between the second short connection 46 and the second control port 44, when it is switched into its open position by a pressure in the second control port 44, which urges the second control valve 42 into its fourth position 54. In this state six of the fourteen second control openings contribute to the net displacement volume so that the net displacement volume is 6/14 of the maximum displacement volume.

[0043] When first control valve 41 is switch into its second position 52 and the second control valve 42 is switched into its fourth position 54 the multi piston machine is in a free wheeling state. There is a direct connection between the first an and the second working 11; 12 port via the fifth fluid chamber 35. Furthermore the first to fourth fluid chamber 31 - 34 are short circuited to each other. When the multi piston machine drives an associated wheel of a vehicle, the wheel can be turned with low resistance, wherein fluid pressure at the first or second working port 11; 12 does not drive the vehicle.

[0044] Fig. 6 shows a first schematic view of the cam surface 21 and the pistons 1.1 - 1.12 of a second embodiment of the invention, wherein this view is directed to a second switching position of the valve assembly. Only the rollers (no. 74 in Fig. 2) of the pistons 1.1 - 1.12 are shown, because they define the contact between a piston 1.1 - 1. 12 and the cam surface 21.

[0045] Besides the differences explained below the second embodiment is identical to the first embodiment. Reference is made to the description of Figs. 1 to 5 above in this respect. In Figs. 1 to 7, identical or corresponding features are marked with the same reference numbers.

[0046] The second embodiment has a first number of twelve pistons 1.1 - 1.12 and a second number of five lobes 22. The number first and second control openings is selected accordingly. The first and the second number have no common factor besides one.

[0047] As with the first embodiment the corresponding valve assembly has four switching positions. In the first switching position all pistons 1.1 - 1.12 contribute to the displacement of the multi piston machine. In the second position only the pistons 1.1 - 1.12 contacting the two lobes marked with no. 83 contribute to the displacement of the multi piston machine, while the remaining pistons 1.1 - 1.12 contacting the remaining three lobes marked with no. 84 are short circuited. In the third switching position only the pistons 1.1 - 1.12 contacting the three lobes marked with no. 84 contribute to the displacement of the multi piston machine, while the remaining pistons 1.1 - 1.12 contacting the remaining two lobes marked with no. 83 are short circuited. The fourth switching position position may be a free wheeling position in which all pistons 1.1 - 1.12 are short circuited.

[0048] The five second sections 82 of the cam surface 21 are configured identical to each other, wherein the have a sinusoidal shape as with a conventional multi piston machine. The angular extent of the five second sections 82 is identical to each other, wherein the named angular extent equals to 67.5° for example.

[0049] The first sections 81 of the cam surface 21 are located at the angular positions of the pistons 1.1 - 1.12 where the corresponding cylinders (no. 80 in Fig. 4) have their smallest volume. The angular extent of the first sections 81 differ from each other. The fourth and the fifth copies 81d; 81d of the first section 81 have an angular extend of 0° as with a conventional multi piston machine. The first and the third copies 81a; 81c of the first section 81 have an angular extend of 5° for example. The second copy 81b of the first section 81 has an angular extend of 12.5°. Especially the first to third copies 81a; 81b; 81c of the first section are configured cylindrical with respect to the axis of rotation 13. The configuration of the second sections 81 is mirror symmetric with respect to an axis of symmetry 86. The first group 83 of lobes is mirror symmetric with respect to the axis of symmetry 86. The second group 84 of lobes is mirror symmetric with respect to the axis is of symmetry 86. Because of this symmetry, the machine works equally well in both opposite directions of rotation of the rotor.

[0050] No steps or kinks are present at a transition between a first and a second section 81; 82. The sum of all angular extents of all first an second sections 81; 82 named above amounts to 360° such that each piston 1.1 - 1.12 contacts either a first or a second section 81; 82 in each angular position of the rotor.

[0051] As with the first embodiment the first control openings (2.1 - 2.18 in Fig. 2) and the second control openings (3.1 - 3.14 in Fig. 3) are preferably equally distributed around the axis of rotation 13. Based on this configuration there is a direct relationship between the position of piston 1.1 - 1.12 with relation to the cam surface 21 and it's connection to the first and second working port (11; 12 in Fig. 1) or its short circuit connection.

[0052] With respect to a motor with the configuration shown in Fig. 6 and the first switching position (full displacement) of the valve assembly and and a clockwise rotation 85 of the rotor, the pistons 1.3; 1.6; 1.8; 1.10 moving clearly outward are connected to the first working port (higher pressure). The pistons 1.2; 1.5; 1.7; 1.9; 1.11 moving clearly inward are connected to the second working port (lower pressure). Piston 1.12 is at a transition state from the first working port to the second working port. Piston 1.4 is in a transition state from the second working port to the first working port. Since piston 1.4 is located within the second copy 81b of the first section 81, it does not contribute to the overall fluid flow of the multiple piston machine at the instance of time shown in Fig. 6. Piston 1.1 is also in a transition state from the second working port to the first working port.

[0053] Fig. 6 is directed to the second switching position, where the first group of lobes 83 defines the displacement volume of the multi piston machine. Therefore pistons 1.1; 1.7; 1.8; 1.11; 1.12 contribute to the displacement volume of the multi piston machine with the angular position of the rotor shown in Fig. 6. They are connected to the first and second working port as described with reference to the first switching position above. The remaining pistons 1.2; 1.3; 1.4; 1.5; 1.6; 1.9; 1.10 are assigned to the second group of lobes 84 and are short circuited to each other, such that they do not contribute to fluid flow of the multi pistons machine.

[0054] In case of a motor one design goal is to have a constant relationship between the volume of fluid flowing into the first working port (higher pressure) and the resulting rotation angle of the rotor in every rotational position of the rotor. With conventional multi piston machines this goal may be achieved by having some sort of symmetry which is based on a common factor between the first number of pistons and the second number of lobes. In Fig. 6 no such common factor is present. Therefore with the invention the named goal is achieved in the second switching position by setting the angular extent of the first sections 81 such that the first reference positions 91 are passed by a piston 1.1 - 1.12 at a constant interval of rotation. The first reference positions 91 are at a position where a piston 1.1 - 1.12 connected to the first working port just enters a lobe 83 assigned to the first group (active lobe). In the second switching position there are two first reference positions 91a; 91b, since there are two lobes in the first group 83.

[0055] In Fig. 6 piston 1.1 is located exactly at the first reference position 91a. The next piston which which will pass a first reference position 91 is piston 1.9. With 15° of rotor rotation along the direction 85 starting form the rotor position shown in Fig. 6 piston 1.9 will pass the first reference position 91b. With a further 15° of rotor rotation piston 1.2 will pass the first reference position 91a. Since the angular distance between two adjacent pistons 1.1 - 1.12 is 30° at this point the multi piston machine has the same configuration as shown in Fig. 6 but with the numbering of the pistons 1.1 - 1.12 shifted by one. Therefore the constant interval of 15° is present for a complete revolution of the rotor.

[0056] Fig. 7 shows a second schematic view which differs from Fig. 6 only in the angular position of the rotor, wherein this view is directed to the third switching position of the valve assembly.

[0057] In the third switching position the second group of lobes 84 defines the displacement volume of the multi piston machine. Therefore pistons 1.1; 1.4; 1.5; 1.8; 1.9; 1.10; 1.11; 1.12 contribute to the displacement volume of the multi piston machine with the angular position of the rotor shown in Fig. 7. The remaining pistons 1.2; 1.3; 1.6; 1.7 are assigned to the first group of lobes 83 and are short circuited to each other, such that they do not contribute to the fluid flow of the multi piston machine.

[0058] Now the second reference positions 92 are relevant for the design goal named above. The second reference positions 92 are at a position where a piston 1.1 - 1.12 connected to the first working port (higher pressure) just enters a lobe 84 assigned to the second group (active lobe). In the third switching position there are three second reference positions 92a; 92b; 92c since there are three lobes in the second group 84.

[0059] In Fig. 7 piston 1.1 is located exactly at first reference position 92a. The next piston which which will pass a second reference position 92 is piston 1.6. With 10° of rotor rotation along the direction 85 starting form the rotor position shown in Fig. 7 piston 1.6 will pass the second reference position 92c. With a further 10° of rotor rotation piston 1.11 will pass the second reference position 92b. With a further 10° of rotor rotation piston 1.2 will pass the second reference position 92a. Since the angular distance between two adjacent pistons 1.1 - 1.12 is 30° at this point the multi piston machine has the same configuration as shown in Fig. 7 but with the numbering of the pistons 1.1 - 1.12 shifted by one. Therefore the constant interval of 10° is present for a complete revolution of the rotor.

[0060] Since there is a constant interval in the second and in the third switching position of the valve assembly, there is a constant angular interval in the first switching position (full displacement) too. This angular interval is equal to 5°.

[0061] Since there is a constant volumetric displacement per angle of revolution in both second and third switching positions there is also a constant volumetric displacement per angle of revolution when all five lobes are active such as is the case in the first switching position (full displacement).

Reference Numerals

[0062]

A first group of second control openings
B second group of second control openings

1.1 piston

1.18 piston

2.1 first control opening

2.18 first control opening

3.1 second control opening

3.14 second control opening

10 multi piston machine (first embodiment)
10' multi piston machine (second embodiment)
11 first working port
12 second working port
13 axis of rotation
14 angle of rotation
15 dash-dot line

21 cam surface
22 lobe
23 cam ring
24 dead center
30 distributor
31 first fluid chamber
32 second fluid chamber
33 third fluid chamber
34 fourth fluid chamber
35 fifth fluid chamber
36 second control surface
37 second circle
38 notch (alignment cam surface)

40 valve assembly
41 first control valve
42 second control valve
43 first control port
44 second control port
45 first auxiliary valve
46 second auxiliary valve
47 spring

51 first position
52 second position
53 third position
54 fourth position
55 first short circuit connection
56 second short circuit connection

60 casing
61 first casing part
62 second casing part (cam ring)
63 third casing part
64 fourth casing part
65 first flange
66 second flange

70 rotor
71 first control surface
72 first circle
73 cylinder
74 roller
75 splined bore

80 cylinder
81 first section
81a first section (first copy)
81b first section (second copy)
81c first section (third copy)
81d first section (fourth copy)
81e first section (fifth copy)
82 second sections
83 lobe assigned to a first group
84 lobe assigned to a second group
85 direction of movement of the rotor
86 axis of symmetry

91 first reference position
91a first reference position (first copy)
91b first reference position (second copy)
92 second reference position
92a second reference position (first copy)
92b second reference position (second copy)
92c second reference position (third copy)

Claims

1. Multi piston machine (10; 10') with a rotor (70), which is located within a casing (60) and which is rotatable about an axis of rotation (13), wherein the casing has a first and second working port (11; 12), wherein a first number of pistons (1.1 - 1.18) are received in the rotor (70) in a linearly movable manner, such that they define a cylinder (80) with variable volume respectively, wherein the pistons (1.1 - 1.18) are able to contact a cam surface (21) of the casing (60), which has a second number of lobes (22), such that the number of strokes of a single piston (1.1 - 1.18) during one revolution of the rotor (70) equals the second number,

wherein the cam surface (21) defines a second number of first sections (81) and a second number of second sections (82), which are arranged alternately with respect to a rotation of the rotor (70), wherein each piston (1.1 - 1.18) contacts either a first or a second section (81; 82) in each angular position of the rotor (70), wherein the first sections (81) are formed such that a piston contacting the first section (81) is constantly at a position defining a smallest volume of the corresponding cylinder (80),
wherein there is a valve assembly (40) and a distributor (20), wherein the valve assembly (40) has at least two switching positions, wherein the valve assembly (40) and the distributor (20) are configured such that each cylinder (80) is either connected to the first working port (11), to the second working port (12) or to short circuit connection (55; 56) at each angular position of the rotor (70), wherein the short circuit connection (55; 56) provides a short circuit between at least two cylinders (80), wherein the number of cylinders (80) having a short circuit connection (55; 56) is different in the different switching positions,
characterized in that, a set of reference positions (91; 92) of the rotor (70) is defined for each of the named switching positions of the valve assembly (40) respectively, wherein at each reference position (91; 92) a piston (1.1 - 1.18) connected to the first working port (21) enters a second section (82), due to a rotation of the rotor (70),
wherein an angular extent of at least one first section (81) with respect to the axis of rotation (13) is greater than zero, such that in at least one switching position of the valve assembly (40) the pistons (1.1 - 1.18) contributing to the displacement volume of the multi piston machine (10; 10') pass the associated reference positions (91; 92) at essentially constant angular intervals during a complete revolution of the rotor (70).

2. Multi piston machine (10; 10') according to claim 1, wherein an angular extent of at least two first sections (81a; 81b) with respect to the axis of rotation (13) is greater than zero and different from each other.

3. Multi piston machine (10; 10') according to any of the preceding claims,
wherein the named angular interval is essentially constant for all switching positions of the valve assembly (40) providing a non-zero displacement volume of the multi piston machine (10; 10').

4. Multi piston machine (10; 10') according to any of the preceding claims,
wherein the first and the second number have no common factor besides one.

5. Multi piston machine (10; 10') according to any of the preceding claims,
wherein the angular extent of at least two second sections (82) is equal to each other.

6. Multi piston machine (10; 10') according to claim 5, wherein at least two second sections (82) are formed identical to each other.

7. Multi piston machine (10; 10') according to any of

the preceding claims,
wherein there are at least two first sections (81a; 81c) having the same non-zero angular extent.

8. Multi piston machine (10; 10') according to any of the preceding claims,
wherein there is one and only one first section (81b) whose angular extent is at least twice as wide as the next smaller first section (81a; 81c).

9. Multi piston machine (10; 10') according to any of the preceding claims,
wherein the maximum angular extent of all first sections (81) is at least 5°, preferably at least 10°.

10. Multi piston machine (10; 10') according to any of the preceding claims,
wherein, for at least one switching position of the valve assembly (40), the second number of lobes (22) is split into a third and fourth number of lobes (83; 84), wherein the third number is the number of lobes (22) on which cylinders (80) are connected to the first or second working ports (21; 22) and wherein the fourth number is the number of lobes on which cylinders (80) are in a short circuit connection with each other, wherein the third and fourth number have no common factor besides one.

11. Multi piston machine (10; 10') according to any of the preceding claims,
wherein the cam surface (21) is configured mirror-symmetrical with respect to an axis of symmetry (86).

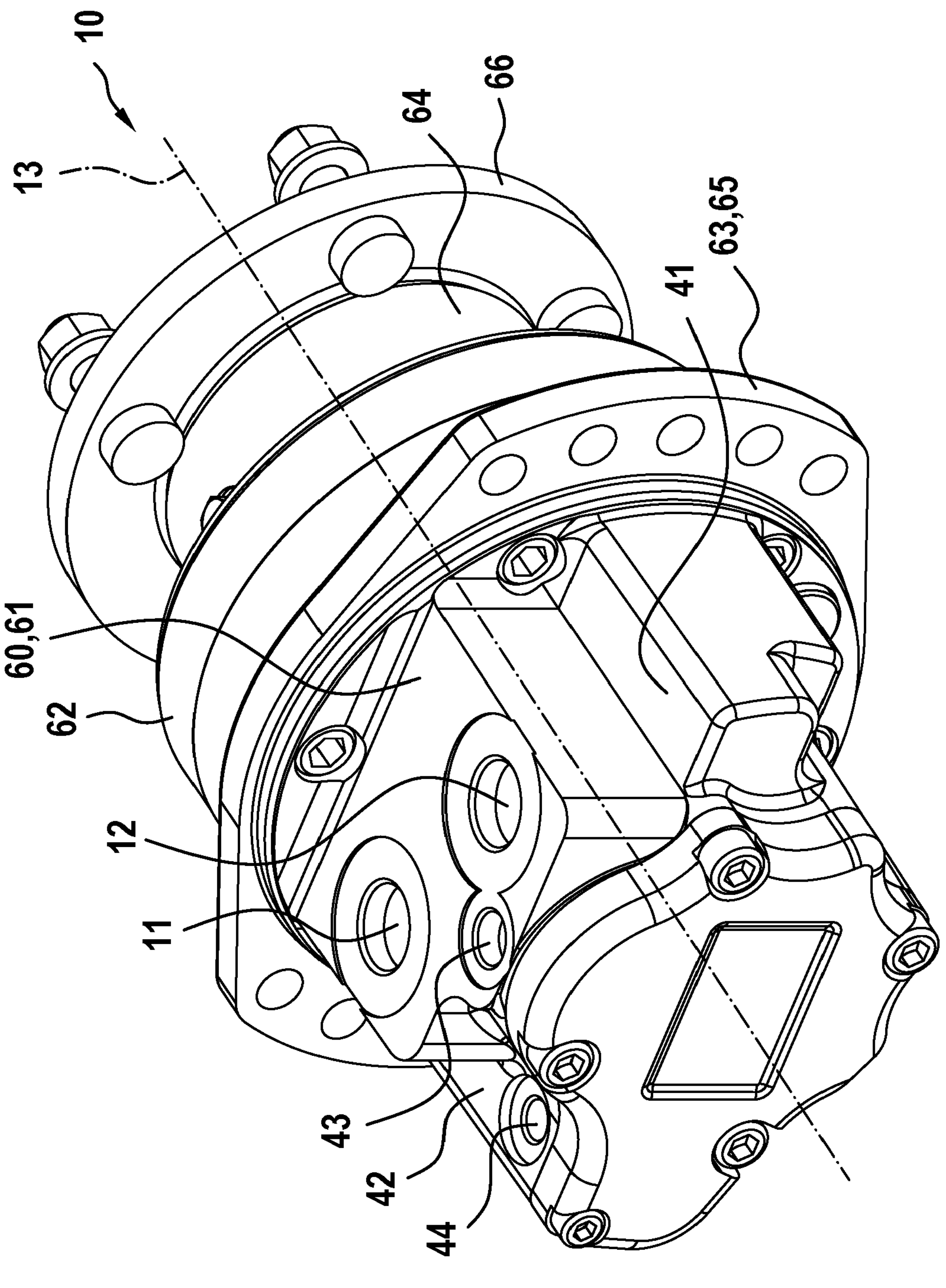
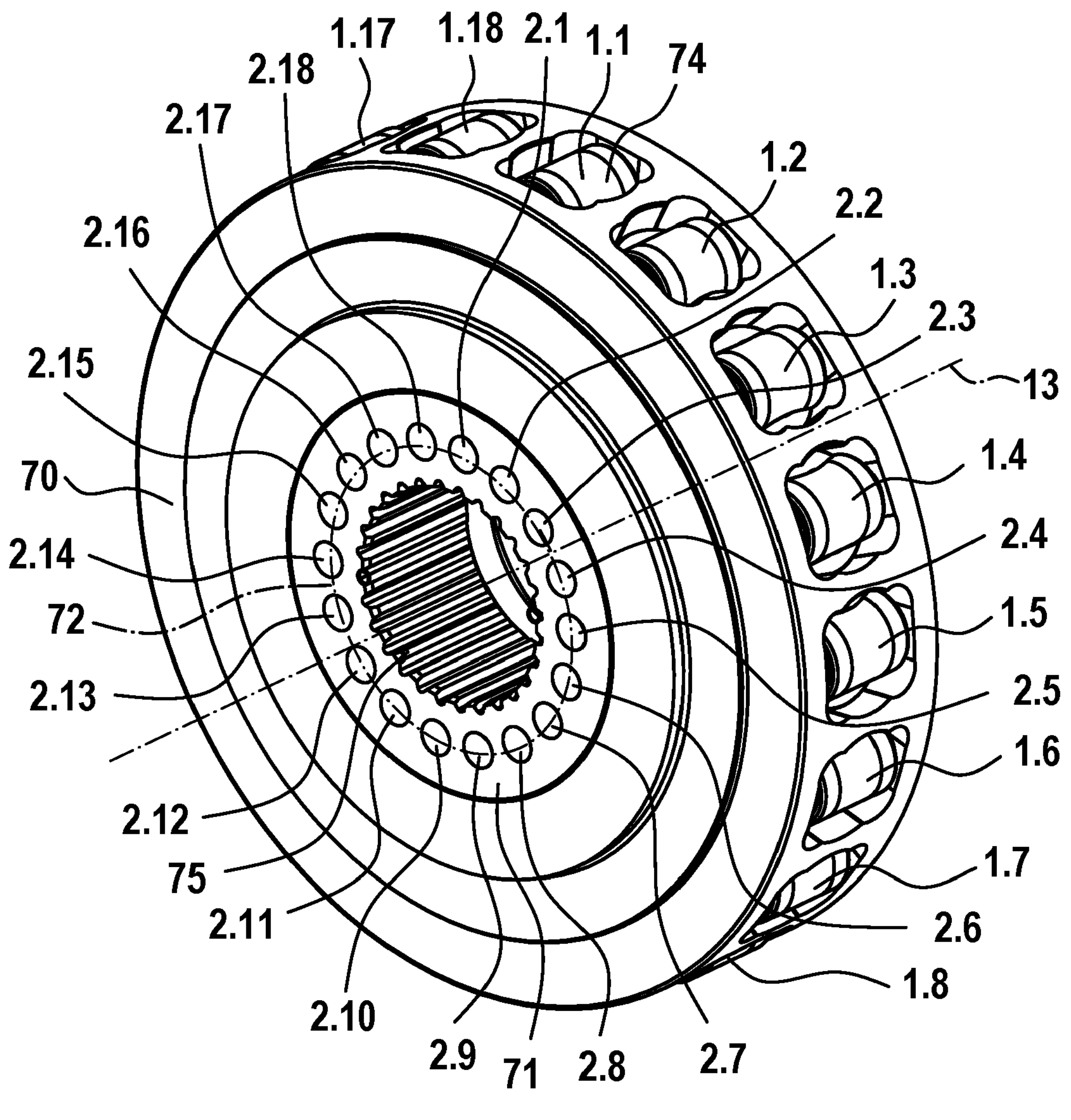


Fig. 1

Fig. 2


1.17
1.18
2.1
1.1
74
2.18
2.17
1.2
2.2
2.16
1.3
2.3
13
2.15
1.4
70
2.4
2.14
1.5
72
2.13
2.5
1.6
2.12
1.7
75
2.6
2.11
1.8
2.10
2.9
71
2.8
2.7

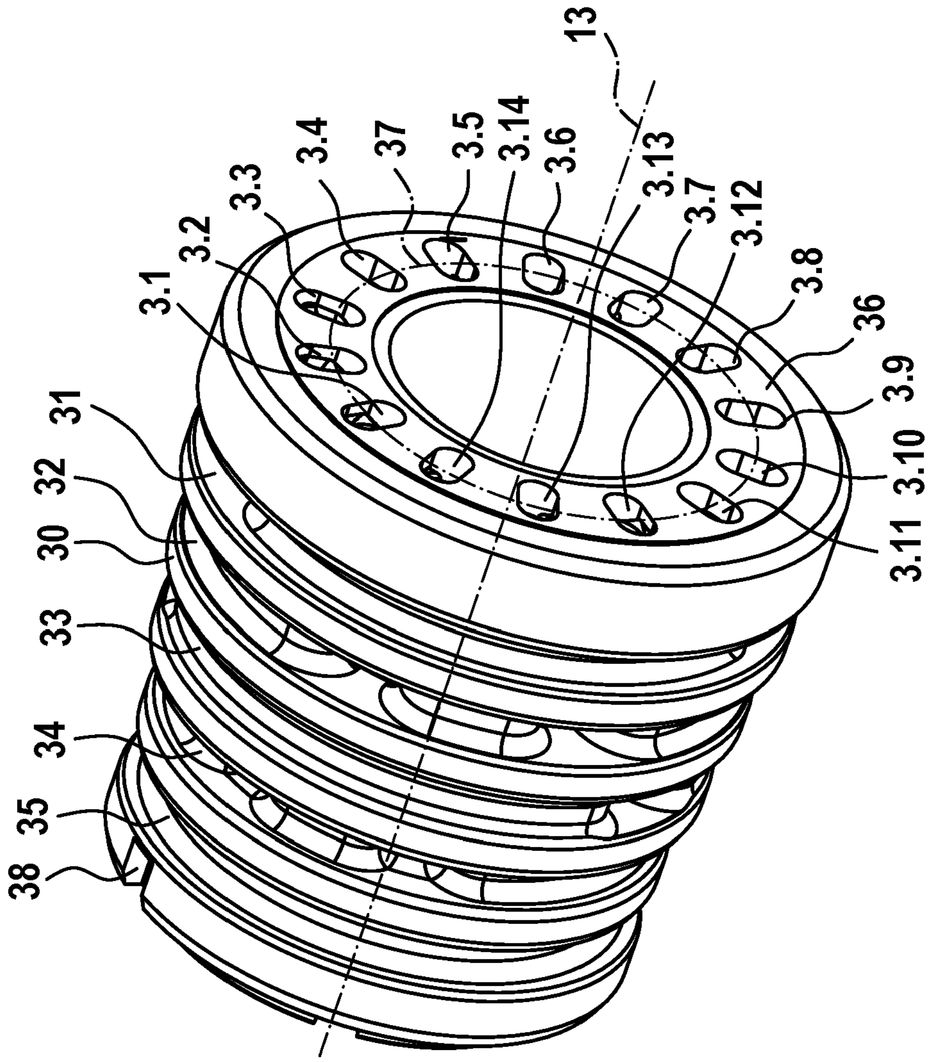

13
3.1
3.2
3.3
3.4
37
3.5
3.14
3.6
3.13
3.7
3.12
3.8
36
3.9
3.10
3.11
31
32
30
33
34
35
38

Fig. 3

Fig. 4

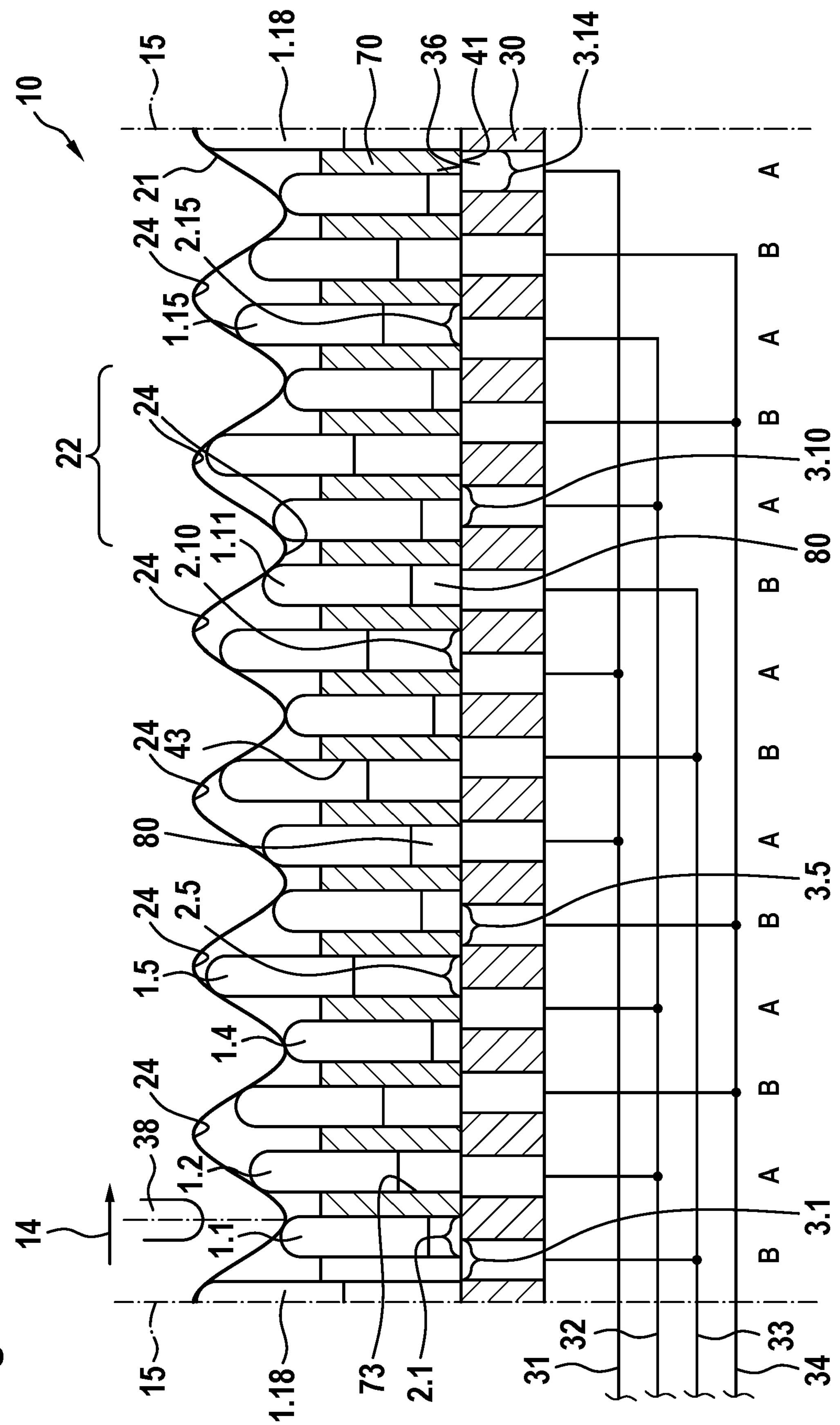

10
15
1.18
70
36
41
30
3.14
21
24
2.15
1.15
22
2.10
1.11
3.10
80
43
3.5
2.5
1.5
1.4
38
1.2
14
1.1
73
2.1
3.1
31
32
33
34
A
B

Fig. 5

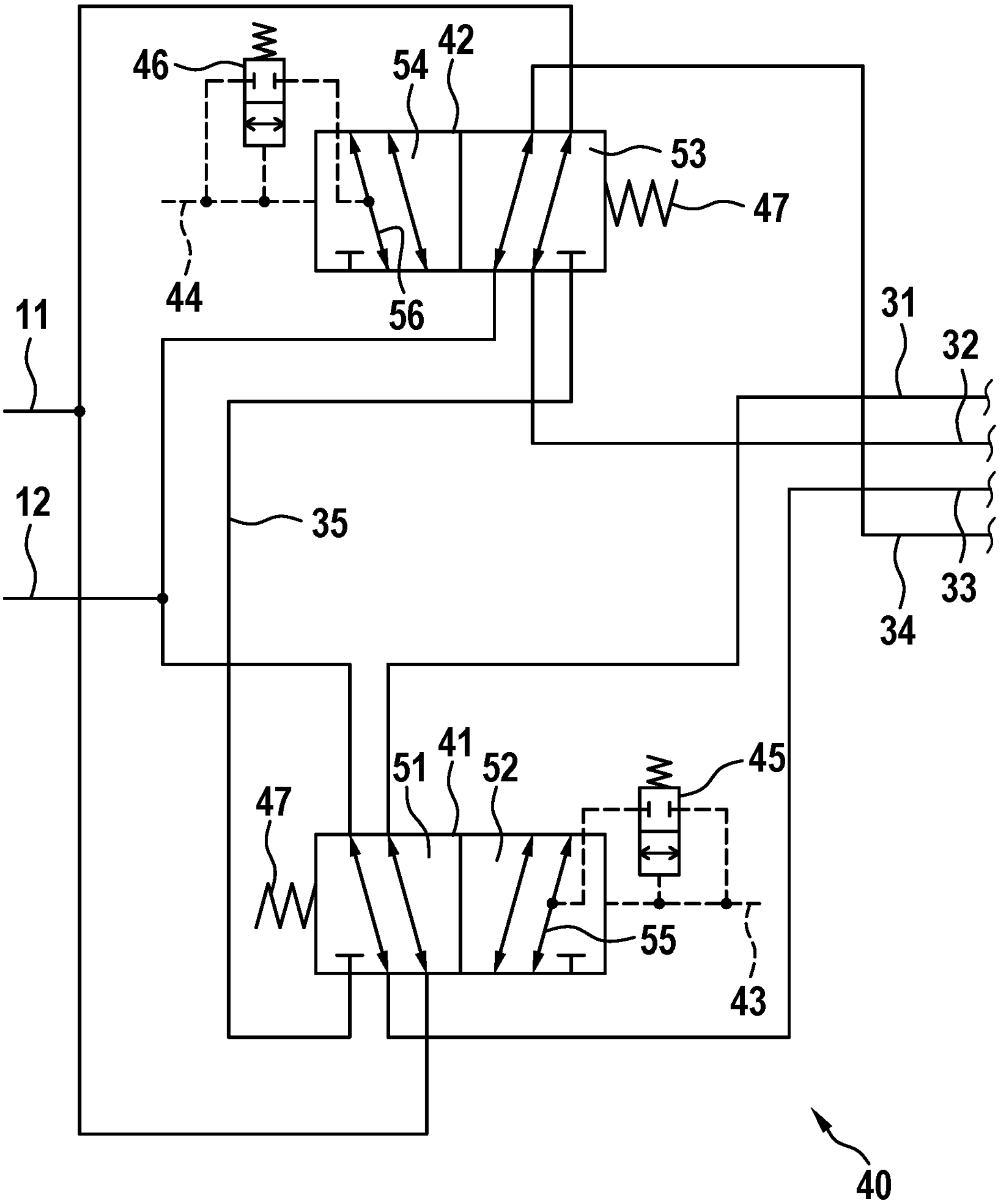


Fig. 6

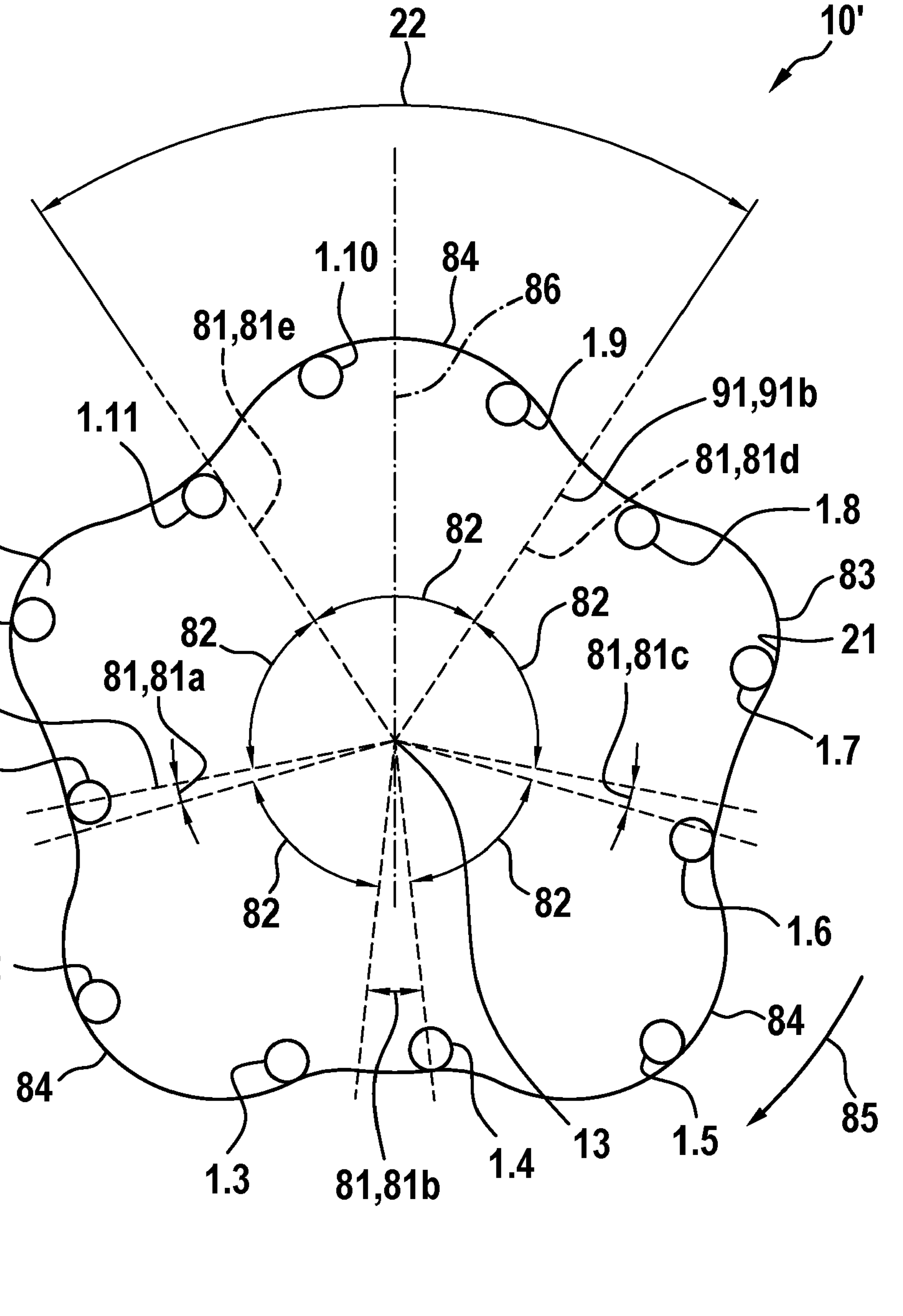
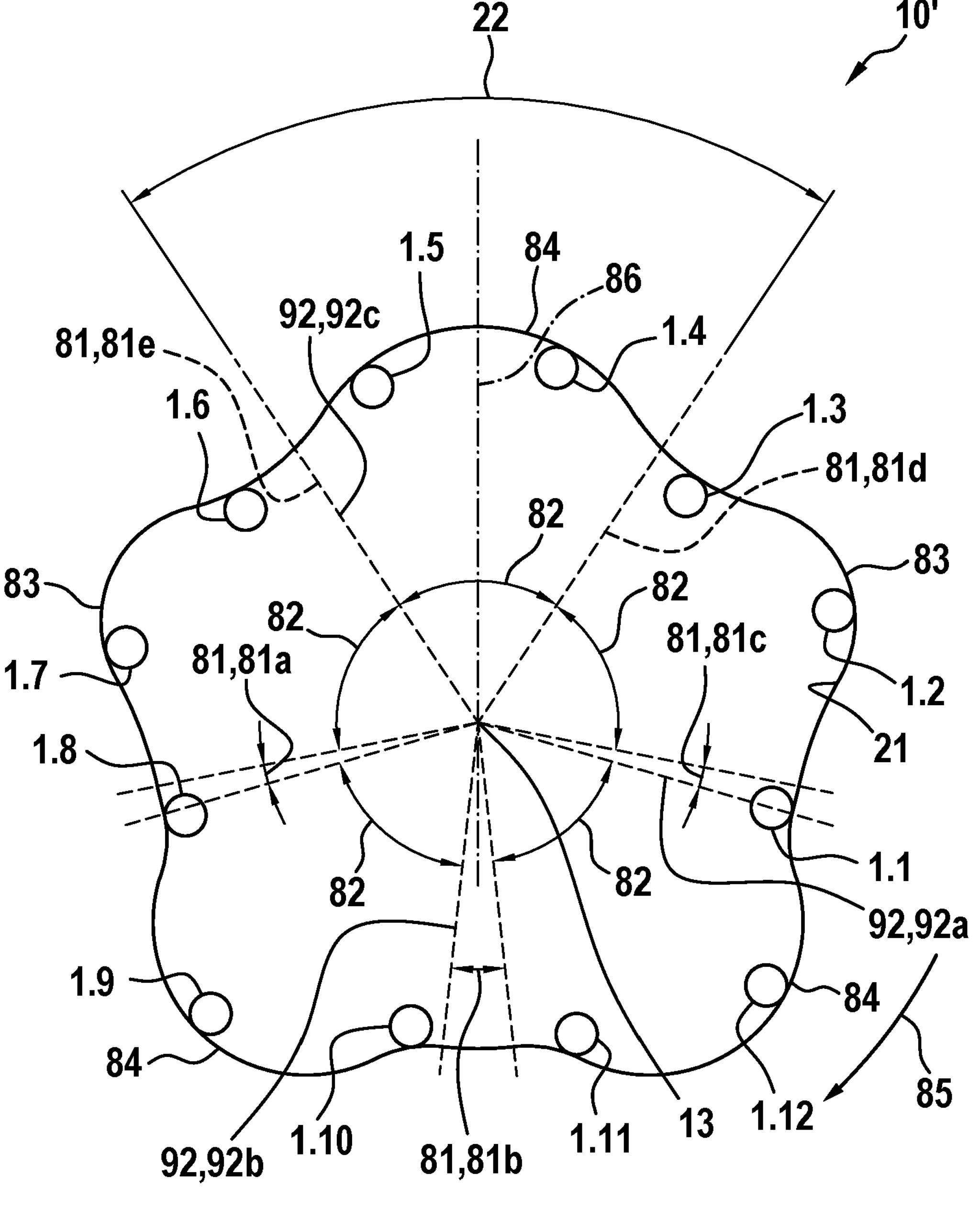

22
10'
1.10
84
86
81,81e
1.9
91,91b
1.11
81,81d
1.12
82
1.8
83
83
82
82
21
81,81c
81,81a
91,91a
1.7
1.1
1.6
82
82
1.2
84
84
85
1.3
81,81b
1.4
13
1.5

Fig. 7


22
10'
1.5
84
86
92,92c
1.4
81,81e
1.6
1.3
81,81d
82
83
83
82
82
81,81c
81,81a
1.7
1.2
21
1.8
1.1
82
82
92,92a
1.9
84
84
85
1.12
13
1.11
1.10
81,81b
92,92b

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 22 19 8761

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
E	EP 4 102 052 A1 (BOSCH GMBH ROBERT [DE]) 14 December 2022 (2022-12-14) * the whole document * -----	1-11	INV. F03C1/247 F03C1/40 F03C1/30 ADD. F04B1/1071 F04B1/063 F04B1/0413
X	DE 41 13 413 A1 (POCLAIN HYDRAULICS SA [FR]) 31 October 1991 (1991-10-31) * column 4, line 19 - column 10, line 43; figures 1-8 * -----	1-11	
A	DE 28 53 552 A1 (BOCK RUDOLF) 19 June 1980 (1980-06-19) * page 14, line 1 - page 17, line 16; figures 1,2,8 * -----	1-11	
A	US 2018/187661 A1 (BOZIC ANTÉ [FR] ET AL) 5 July 2018 (2018-07-05) * paragraph [0083] - paragraph [0113]; figures 1-3 * -----	1-11	

TECHNICAL FIELDS SEARCHED (IPC)
F03C
F04B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	7 February 2023	Homan, Peter

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 22 19 8761

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

07-02-2023

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
EP 4102052	A1	14-12-2022	CN	115506944	A	23-12-2022
			EP	4102051	A1	14-12-2022
			EP	4102052	A1	14-12-2022
			US	2022389902	A1	08-12-2022
DE 4113413	A1	31-10-1991	BR	9101687	A	26-11-1991
			DE	4113413	A1	31-10-1991
			FI	911769	A	27-10-1991
			FR	2661456	A1	31-10-1991
			GB	2243881	A	13-11-1991
			JP	H04228878	A	18-08-1992
DE 2853552	A1	19-06-1980	NONE			
US 2018187661	A1	05-07-2018	CN	107709769	A	16-02-2018
			EP	3317537	A1	09-05-2018
			FR	3038348	A1	06-01-2017
			US	2018187661	A1	05-07-2018
			WO	2017001802	A1	05-01-2017

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- US 4807519 A **[0002]**
- EP 2841763 B1 **[0024]**
- US 6050173 A **[0038]**