(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
13 August 2020 (13.08.2020)

WIPO | PCT

(10) International Publication Number
WO 2020/161237 A1

(51) International Patent Classification:
F04B 9/105 (2006.01) *F04B 43/067* (2006.01)
F04B 9/117 (2006.01) *F04B 53/22* (2006.01)

(21) International Application Number:
PCT/EP2020/052991

(22) International Filing Date:
06 February 2020 (06.02.2020)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
1901604.7 06 February 2019 (06.02.2019) GB

(71) Applicant: **MHWIRTH GMBH** [DE/DE]; 71-73, Kölner Strasse, 41812 Erkelenz (DE).

(72) Inventors: **JAEGER, Norbert**; An der Eiche 7a, 52525 Heinsberg (DE). **STOETZEL, Volker**; Oberfeldstrasse 78, 44369 Dortmund (DE).

(74) Agent: **ZACCO NORWAY AS**; Box 2003 Vika, 0125 OSLO (NO).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,

(54) Title: FLUID PUMP, PUMP ASSEMBLY AND METHOD OF PUMPING FLUID

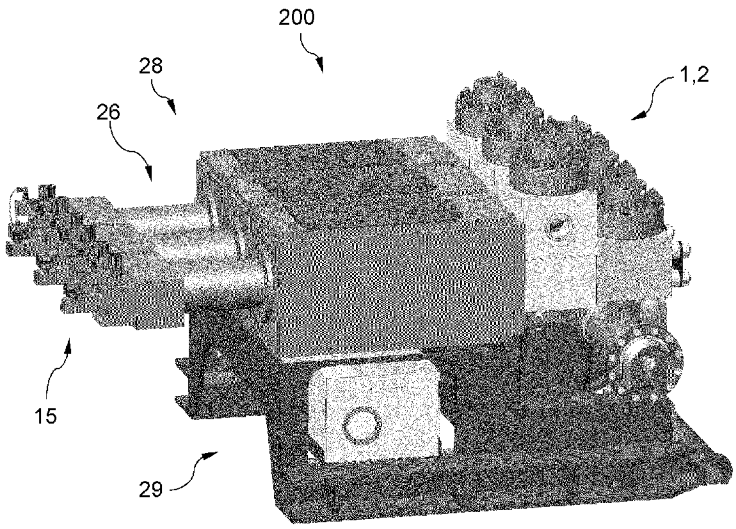

Fig. 7

(57) Abstract: A fluid pump (100-105) comprising a pump chamber (3) having an inlet (1) and an outlet (2) with respective inlet and outlet valves (1',2'), a linearly reciprocable pumping member (4) arranged in the pump chamber (3), a linear hydraulic actuator (9, 10) connected to the pumping member (4),and a controller (15) operatively connected to the linear hydraulic actuator (9, 10) for controlling the linear hydraulic actuator (9, 10). There is also provided a pump assembly comprising a plurality of fluid pumps (100-104)and a method of pumping fluid comprising providing a fluid pump and operating the linear hydraulic actuator (9, 10) to generate a cyclic, reciprocating movement of the pumping member (4).

WO 2020/161237 A1

[Continued on next page]

MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

— *with international search report (Art. 21(3))*

FLUID PUMP, PUMP ASSEMBLY AND METHOD OF PUMPING FLUID

The present disclosure relates to a fluid pumps, and particularly to heavy duty reciprocating fluid pumps suitable for conveying various types of liquids.

BACKGROUND

Reciprocating pumps are used in a variety of applications and for a wide range of purposes. One such application is the conveyance of fluids in large-scale plants for earth drilling or mining. Some examples of such pumps and their application are described in earlier patent publications US 8,920,146 B2, US 2015/0260178 A1 and US 9,695,808 B2 by the present applicant.

Other publications which may be useful to understand the field of technology include WO 2009/051474 A1; WO 2010/066754 A1; JP 4768244 B2; US 2003/0194328 A1; WO 94/019564 A1, and WO 97/23705.

Pumps for the applications mentioned above or related fields of use, often have demanding operating conditions, which may include requirements for high output pressures or flow rates and the need to handle challenging media, for example abrasive liquids and/or liquids containing solid particles. Many such pumps are used in mobile or remote installations, for example on drilling rigs, and have high demands for operational reliability and low maintenance requirements. In most applications, there is furthermore a desire for low weight, compactness and high efficiency.

The objective of the present invention is to provide fluid pumps with improvements in one or more of the abovementioned aspects compared to known solutions.

SUMMARY

In an embodiment, there is provided a fluid pump comprising a pump chamber having an inlet and an outlet with respective inlet and outlet valves, a linearly reciprocable pumping member arranged in the pump chamber, a linear hydraulic actuator connected to the pumping member, and a controller operatively connected to the linear hydraulic actuator for controlling the linear hydraulic actuator.

In an embodiment, there is provided a pump assembly comprising a plurality of fluid pumps.

In an embodiment, there is provided a method of pumping fluid, the method comprising providing a fluid pump, and operating the linear hydraulic actuator to generate a cyclic, reciprocating movement of the pumping member.

The detailed description below and the appended claims outline further embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other characteristics will become clear from the following description of illustrative embodiments, given as non-restrictive examples, with reference to the attached drawings, in which:

Figure 1 is a schematic illustration of a pump.

Figure 2 is a schematic illustration of a pump.

Figures 3A and 3B are illustrations of piston speed profiles of a pump.

Figure 4 illustrates a pump assembly.

Figure 5 is a schematic illustration of a pump.

Figure 6 is a schematic illustration of a pump.

Figure 7 is a perspective view of a pump assembly.

DETAILED DESCRIPTION

Figure 1 shows an embodiment of a pump 100. The pump 100 has a pump chamber 3 having an inlet 1 and an outlet 2, the inlet 1 and outlet 2 having respective inlet and outlet valves 1’ and 2’ arranged in or adjacent the inlet 1 or outlet 2. The inlet valve 1’ functions as a suction valve for the pump chamber 3, and the outlet valve 2’ functions as a discharge valve for the pump chamber 3. The valves 1’ and 2’ may be passive, one-way valves, for example check valves or non-return valves. Alternatively, the valves 1’ and 2’ may be actively controlled, e.g. by valve actuators.

A linearly reciprocable pumping member 4 is arranged in the pump chamber 3. The pumping member 4 is in this embodiment a conventional pumping piston operating in a pump cylinder 5, however may alternatively be a different type, for example a plunger. The pumping member 4 operates on a fluid in the pump chamber 3, and provides a pumping effect by increasing and decreasing the volume of the pump chamber 3. (Illustrated by means of the double arrow.) By means of the valves 1,2, a fluid flow is effected into the pump chamber 3 from a low pressure side at the inlet 1 during a suction stroke (indicated by arrow 31) and out of the pump chamber 3 to a high pressure side at the outlet 2 during a discharge stroke (indicated by arrow 30).

A linear hydraulic actuator 26 is connected to the pumping member 4. The linear hydraulic actuator comprises an actuator piston 10 operating in a cylinder 21. The connecting rod 9 of the linear hydraulic actuator 26 is connected to a connecting rod 7 of the pump piston via a connection 8, for example a flanged connection. This makes the pumping member 4 is rigidly connected to the translator of the linear hydraulic actuator 26 (i.e., the rod 9 and piston 10) such that the pumping member 4, rods 7,9 and the piston 10 of the linear hydraulic actuator are reciprocable in unison.

A controller 15 is operatively connected to the linear hydraulic actuator 26 for controlling the linear hydraulic actuator 26, i.e. to control the movement of the piston 9. A hydraulic supply 20 provides the necessary hydraulic power to operate the linear hydraulic actuator 26. In this embodiment, the hydraulic supply 20 is a hydraulic power unit comprising a hydraulic pump 12 having a drive motor 13, for example an electric drive motor or a combustion engine. A hydraulic storage tank 11 is provided for supply of hydraulic operating fluid. A pressure control valve 14 may also be arranged to secure a correct hydraulic supply pressure from the hydraulic supply 20 to the controller 15, for example to avoid overpressure or undesired pressure peaks.

In the embodiment illustrated in Fig. 1, the fluid pump 100 is configured as a conventional piston pump, wherein the pumping member 4 operates directly on a pumped fluid, such as water, a slurry, or a drilling mud, supplied via the inlet 1. The pumping member 4 is consequently fluidly connected with the pumped fluid.

In some applications, the pumped fluid may be of a type where it is undesirable to have the pumping member 4 fluidly in contact with the pumped fluid. This may be the case if, for example, the pumped fluid is abrasive, have adverse chemical properties, etc. Fig. 2 illustrates an embodiment in which the fluid pump 101 comprises a diaphragm 6 (or membrane) separating the pumping member 4 from the pumped fluid supplied via the inlet 1. The diaphragm 6 may have a shape which is approximately circular, but may also be of another design, such as non-circular or tubular. Other components which have the same functionality as that described above are given the same reference numeral in Fig. 2.

The diaphragm 6 defines a closed volume between the pumping member 4 and the diaphragm 6 wherein an intermediate fluid is disposed, typically a fluid which is incompressible or substantially incompressible. The intermediate fluid may, for example, be a suitable oil-based fluid. The pumping member 4 acts on the intermediate fluid, which causes a cyclic movement of the diaphragm 6 to produce a pumping effect through the inlet 1 and outlet 2, similarly as described above.

The operation of the fluid pump may include operating the controller 15 to produce the cyclic, reciprocating movement of the pumping member 4 via the linear hydraulic actuator. The controller 15 may for this purpose have a microprocessor-based control unit and a set of hydraulic valves to enable timed switching in the hydraulic supply to the linear hydraulic actuator. A sensor 22 (see Fig. 1), such as a linear encoder, may provide a feedback signal to the controller 15 which represents the position of the piston assembly 4, 7, 8, 9, 10. The controller 15 may, in response to an input from the sensor 22, input from other sensors, pre-determined set points and operating schedules, and/or other parameters, control the supply of hydraulic fluid to the cylinder 21.

Advantageously, a pump according to embodiments described herein may allow greater flexibility in the operation of the pump. For example, a stroke length of the pumping member 4 may be variable by means of electronic control through the controller 15.

While the controller 15 has been illustrated as a simple hydraulic valve in the figures, it should be noted that, in practice, the controller may be more advanced.

For example, the controller 15 may comprise one or more microcontrollers configured to operate a plurality of hydraulic valves within the controller 15, and/or the controller 15 may be set up with pilot valves or equivalent to produce a smoother operation of the actuator 26.

In the shown embodiments, the movement of the pumping member 4 is not constrained by a crank mechanism, but more freely controllable by influencing the balance of forces acting on it. This consequently provides significantly more freedom and control flexibility than a crank-driven pump, in which the motion of the pumping member 4 is constrained mechanically, such that

$$x = r\cos A + \sqrt{l^2 - r^2 \sin^2 A}$$

where *x* is piston position, *r* is crankshaft radius, *l* is connecting rod length, and *A* is crank angle. The piston velocity and acceleration profiles over the reciprocating cycle for a crank-driven pump are determined by the crank mechanism in a similar manner.

A pump according to embodiments described herein may thus be operated to provide advantageous motion profiles for the pumping member 4. One such profile is illustrated in Fig. 3A, which shows an illustrative plot of piston speed over one full cycle, i.e. the instantaneous linear velocity of the piston 4 in the cylinder 5. Plot 33 (dashed) illustrates the speed profile of a conventional, crank-driven pump, in which the speed profile is fixed as a sinusoidal-type trajectory, determined by design parameters of the crank mechanism, as shown above. In contrast, according to embodiments of the present invention, the speed profile may be variable, and have a different shape.

For example, piston acceleration around the stroke endpoints may be higher and the peak piston speed may be lower compared to a conventional, crank-driven pump (at the same reciprocating speed of the pump). This can be seen in the illustrative piston velocity profile 32 (solid line) in Fig. 3A. The figure illustrates one cycle, starting at the beginning of a discharge stroke A (“bottom dead center”). As can be seen, the peak velocity 32’ of the pumping member 4 during the discharge stroke A is lower than the peak velocity during a corresponding crank-driven piston motion. The same is the case for the peak piston member 4 velocity 32” during the subsequent suction (or intake) stroke B.

This may provide advantages in that the peak fluid flow rates through the valves 1,2 are reduced (since these are substantially proportional to the instantaneous velocity of the pumping member 4), which can reduce pressure losses across the valves and increase valve lifetime. Lower velocity during the suction stroke may also reduce the risk of cavitation, for example if the supply pressure at the inlet 1 is low and/or if the pump is handling fluids with dissolved gas.

In an embodiment, the operation of the pump may therefore comprise operating the pump with a cyclic, reciprocating movement which is non-sinusoidal. By “sinusoidal” is meant a smooth periodic oscillation which can be a pure sine wave but may be a combination of sine and cosine terms such as the expression for piston motion in a piston machine shown above.

The pump may be controlled by the controller 15 such that the suction strokes in the successive suction and discharge strokes of the pump are carried out faster than the discharge strokes, or the other way around. This is illustrated in Fig. 3B, which, as above, illustrates a discharge stroke A taking place first (negative piston speed), and then a subsequent suction stroke (positive piston speed). As can be seen, in a conventional, crank-driven pump, the suction stroke and the discharge stroke are necessarily carried out over an equal length in time, since the motion is constrained by the crank system and these will have symmetric, mirrored profiles. According to embodiments of the present invention, this “split” between the length of the suction stroke and the length of the discharge stroke may be adjusted by means of the controller 15, for example to carry out the suction stroke faster and spend (relatively) more time in the discharge stroke. For this purpose, the peak velocity 32’,32’’ of the pumping member 4 may be higher in the suction stroke B than in the discharge stroke A. Operating the pump in this manner may provide operational optimization advantages, for example to minimize losses and maximize efficiency, to reduce peak energy demands and/or dynamic loads on pump components, to reduce pressure fluctuations or flow variations at the outlet in a multi-cylinder pump (see below), and/or to optimize other operational parameters. Alternatively, the peak velocity of the pumping member can be made during the discharge stroke than during the suction stroke, and the discharge stroke be carried out faster than the suction stroke. This may be advantageous, for example, if it is desirable to carry out the suction stroke “slower”, e.g. to reduce the risk of cavitation in the intake fluid.

In one embodiment, a pump assembly 200 may comprise a plurality of fluid pumps according to any of the embodiments described herein. The plurality of fluid pumps may be powered by a common hydraulic supply 20, for example via a hydraulic common rail. This is illustrated schematically in Fig. 4, wherein three fluid pumps 102,103,104 are provided, each of which may be any of the embodiments of fluids pumps 100,101 described herein. The pump assembly 200 may, however, have any suitable number of fluid pumps, e.g. 2, 4, 5, 6, 7, 8 or more.

The three fluid pumps 102-104 are provided with hydraulic power from a common hydraulic power supply 20. The common hydraulic power supply 20 may be a dedicated hydraulic supply for the pump assembly 200 (such as a dedicated hydraulic power unit, HPU), or it may be a hydraulic supply which is shared between the pump assembly 200 and other consumers.

In this embodiment, the fluid pumps 102-104 are fluidly connected to, and provided with inlet fluid, from a common inlet line 23, which is connected to the inlet 1 of each pump 102-104. This inlet line 23 may, for example, be connected to a mud tank, or to another type of tank, pit, or other supply of the fluid which is to be pumped.

In this embodiment, the fluid pumps 102-104 are also fluidly connected to a common discharge line 24, which is connected to the outlet 2 of each pump 102-104. In this manner, all the pumps provide pressurized fluid to the common discharge line 24, which may, for example, lead to a subterranean well or to an elevated location.

Advantageously, by controlling the motion profile of the pumping member 4, the pressure and fluid flow rate in the discharge line 24 may be influenced and controlled. It is a well-known challenge with conventional multi-cylinder and crankshaft-driven piston pumps that the pressure and flow rate in the discharge line may fluctuate. The problem is more prevalent for pumps with a low number of cylinders; for example, a duplex pump will have larger such variations than a triplex pump. This is due to the interaction between the individual cylinders and the phase shift between them.

Due to the increased flexibility in the control of the individual pumps 102-104 in a pump assembly according to embodiments described here, such variations in pressure and/or flow fluctuations in the discharge line 24 may be reduced. This can be achieved by controlling the motion of the pumping member 4 in each of the pumps 102-104 individually, for example by adjusting the phase shift between the discharge strokes, the speed and acceleration of the pumping member 4, the motion profile of the pumping member 4 over the discharge stroke, etc.

In an advantageous embodiment, also illustrated schematically in Fig. 4, the pump assembly 200 is arranged as part of a drilling plant, wherein the drilling plant comprises a hydraulically powered hoisting system 25, and the hoisting system 25 is powered from the hydraulic supply 20. The hoisting system 25 may be a cylinder-based hoisting system such as the RamRig™ technology supplied by the present applicant. For example, WO 97/23705 describes one possible arrangement of such cylinder-based hoisting systems. The inventors have discovered that a pump assembly according to embodiments of the present invention display particular advantages in such an arrangement, in that for example complementary hydraulic demand profiles allow more efficient utilisation of the plant and improved energy efficiency.

In one embodiment, the fluid pump 100,101 comprises a releasable actuator unit 27, illustrated in Fig. 5. The fluid pump 100,101 has a pump housing 28, in which the pump chamber 3 (see e.g. Fig. 1), pumping member 4, pump cylinder 5, and associated components are arranged. A frame 29 may be arranged to hold and provide a mounting foundation for the pump housing 28, for example on a floor or a deck. The actuator unit 27 holds the linear hydraulic actuator 26 and its associated components 9,10,21, and is releasably connected to the pump housing 28 via a releasable coupling 30, for example a bolted flange or another type of mechanical connection. By means of the releasable coupling 30, together with the releasable connection 8 between the connecting rods 7,9 (see e.g. Fig. 1), the linear hydraulic actuator may be quickly removed from the pump 100,101, for example for inspection, maintenance or replacement. It may, for example, be beneficial to replace the linear hydraulic actuator with one having a different design if the pump 100,101 needs to switch between low-pressure, high flow rate operation and high-pressure, low flow rate operation.

The pump housing 28 may also be designed to allow for the retrieval and replacement also of the pumping member 4 and, optionally, the pump cylinder 5 when the coupling 30 is released. This may allow maintenance or replacement of these components in a quick and efficient manner, reducing the downtime of the pump for these operations.

Fig. 6 illustrates another embodiment, in which a fluid pump 105 is double-acting. The design of the fluid pump 105 may otherwise be equivalent to that described in relation to any of the other embodiments herein. The piston 4 consequently drives a pumping action in two pump chamber parts 3a and 3b, each being provided with inlet fluid via inlet parts 1a,1b, and discharging pumped fluid to outlet parts 2a,2b. The embodiment shown in Fig. 6 may, for example, allow a more compact overall pump design, in that a single cylinder 21 (and associated components) may serve two pumping chamber parts 3a,3b.

In Fig. 6, the fluid pump 105 is “direct-acting”, similar to the pump 100 illustrated in Fig. 1, however the fluid pump 105 may equally well be a double-acting membrane pump equivalent to that shown in Fig. 2, i.e. with membranes or diaphragms 6 arranged in the pumping chamber parts 3a and 3b.

Fig. 7 illustrates a pump assembly 200 comprising three fluid pumps with a common inlet and outlet line (not shown) connected to the inlet 1 and outlet 2 of each of the fluid pumps. As described above, a controller 15 is provided to control hydraulic actuators 26 for each individual pump. A pump housing 28 holds pump components, which may be releaseable or retrievable as described above, for easy replacement or maintenance. In this example, the frame 29 is a skid arrangement. Fig. 7 illustrates the compact layout of the pump assembly 200 which can be achieved with embodiments described here, when compared to conventional, crank-driven pumps.

Generally, a design operating pressure of the hydraulic actuator (e.g. the cylinder 21 with piston 10, and associated hydraulic components) may be less than 200%, less than 150% or less than 120% that of a design maximum outlet pressure for the pump, i.e. the maximum design pressure at the outlet 2. This may be particularly advantageous in applications intended for pumping drilling muds or slurries. The maximum design outlet pressure may be, for example, more than 200 bar, more than 250 bar, or more than 300 bar.

If the linear hydraulic actuator is a piston-cylinder actuator 10,21, a working area of the hydraulic piston 10 may be more than 50%, more than 75% or more than 100% of the size of the working area of the pumping piston 4.

The fluid pump or pump assembly may have an output of more than 1000 kW, more than 1500 kW or more than 2000 kW pumping power.

The pump 100,101 or pump assembly 200 may be a pump / pump assembly for pumping slurry or drilling mud.

According to various embodiments described herein, fluid pumps, pump assemblies and methods for pumping fluid are provided, having advantageous properties compared to know technology. A simple structure and improved modularization may allow more efficient and cost-effective manufacturing, lower maintenance cost, and enhanced flexibility in the installation and placement of the pump or pump assembly. Accessibility for maintenance or repairs can be improved, compared to conventional, crank-driven pumps. Operational optimization may allow enhanced performance, for example improved response to varying load demands and reduced pressure or volume fluctuations during operation. A pump or pump assembly according to disclosed embodiments may further reduce vibrations (e.g. due to the complete absence of rotating masses), and reduce noise pollution (e.g. due to less moving parts, no gears, and size reductions and installation flexibility which makes insulation easier). One or more of these advantages may be realized using the teaching herein, individually or in combinations.

The invention is not limited by the embodiments described above; reference should be had to the appended claims.

CLAIMS

1. A fluid pump (100-105) comprising:
   a pump chamber (3) having an inlet (1) and an outlet (2), the inlet (1) and outlet (2) having respective inlet and outlet valves (1’,2’),
   a linearly reciprocable pumping member (4) arranged in the pump chamber (3),
   a linear hydraulic actuator (9, 10) connected to the pumping member (4),
   a controller (15) operatively connected to the linear hydraulic actuator (9, 10) for controlling the linear hydraulic actuator (9, 10).

2. A fluid pump (100-105) according to claim 1, further comprising a hydraulic supply (20).

3. A fluid pump (100-105) according to claim 2, wherein the hydraulic supply (20) is a hydraulic power unit comprising a hydraulic pump (12) having a drive motor (13), and a hydraulic storage tank (11).

4. A fluid pump (100-105) according to any preceding claim, wherein the pumping member (4) is configured to operate directly on a pumped fluid supplied via the inlet (1).

5. A fluid pump (100-105) according to any of claims 1-3, comprising a diaphragm (6) separating the pumping member (4) from a pumped fluid supplied via the inlet (1).

6. A fluid pump (100-105) according to any preceding claim, wherein the pumping member (4) is
   a piston, or
   a plunger.

7. A fluid pump (100-105) according to any preceding claim, wherein the pumping member (4) is rigidly connected to the linear hydraulic actuator (9,10) via a shaft (7,8), the pumping member (4), shaft (7,8) and a translator of the linear hydraulic actuator (9,10) being reciprocable in unison.

8. A fluid pump (100-105) according to any preceding claim, wherein the pump chamber (3) and the linearly reciprocable pumping member (4) are arranged in a pump housing (28) and the linear hydraulic actuator (9, 10) is arranged in an actuator unit (27), and wherein the actuator unit (27) is releasably fixed to the pump housing (28) via a coupling (30).

9. A fluid pump (100-105) according to the preceding claim, wherein the linearly reciprocable pumping member (4) is retrievable from the pump housing (28) when the coupling (30) is released.

10. A fluid pump (100-105) according to any preceding claim, wherein the pump (100-105) is double-acting, whereby the linearly reciprocable pumping member (4) separates the pump chamber (3) into a first pump chamber part (3a) and a second pump chamber part (3b), the inlet (1) comprises a first inlet (1a) to the first pump chamber part (3a) and a second inlet (1b) to the second pump chamber part (3b), and the outlet (2) comprises a first outlet (2a) from the first pump chamber part (3a) and a second outlet (2b) from the second pump chamber part (3b).

11. A pump assembly comprising a plurality of fluid pumps (100-105) according to any preceding claim.

12. A pump assembly according to the preceding claim,
wherein the plurality of fluid pumps (100-105) are powered by a common hydraulic supply (20), and/or
wherein the plurality of fluid pumps (100-105) discharge pumped fluid to a common discharge line (24).

13. A method of pumping fluid, the method comprising
providing a fluid pump according to any preceding claim,
operating the linear hydraulic actuator (9, 10) to generate a cyclic, reciprocating movement of the pumping member (4).

14. A method according to the preceding claim, wherein the cyclic, reciprocating movement is non-sinusoidal.

15. A method according to any of the two preceding claims, comprising carrying out successive suction and discharge strokes, and

wherein the suction strokes are carried out faster than the discharge strokes, or

wherein the discharge strokes are carried out faster than the suction strokes.

16. A method according to any of the three preceding claims, comprising carrying out successive suction and discharge strokes, and

wherein a peak velocity of the pumping member (4) during the discharge strokes is higher than a peak velocity of the pumping member (4) during the suction strokes, or

wherein a peak velocity of the pumping member (4) during the suction strokes is higher than a peak velocity of the pumping member (4) during the discharge strokes.

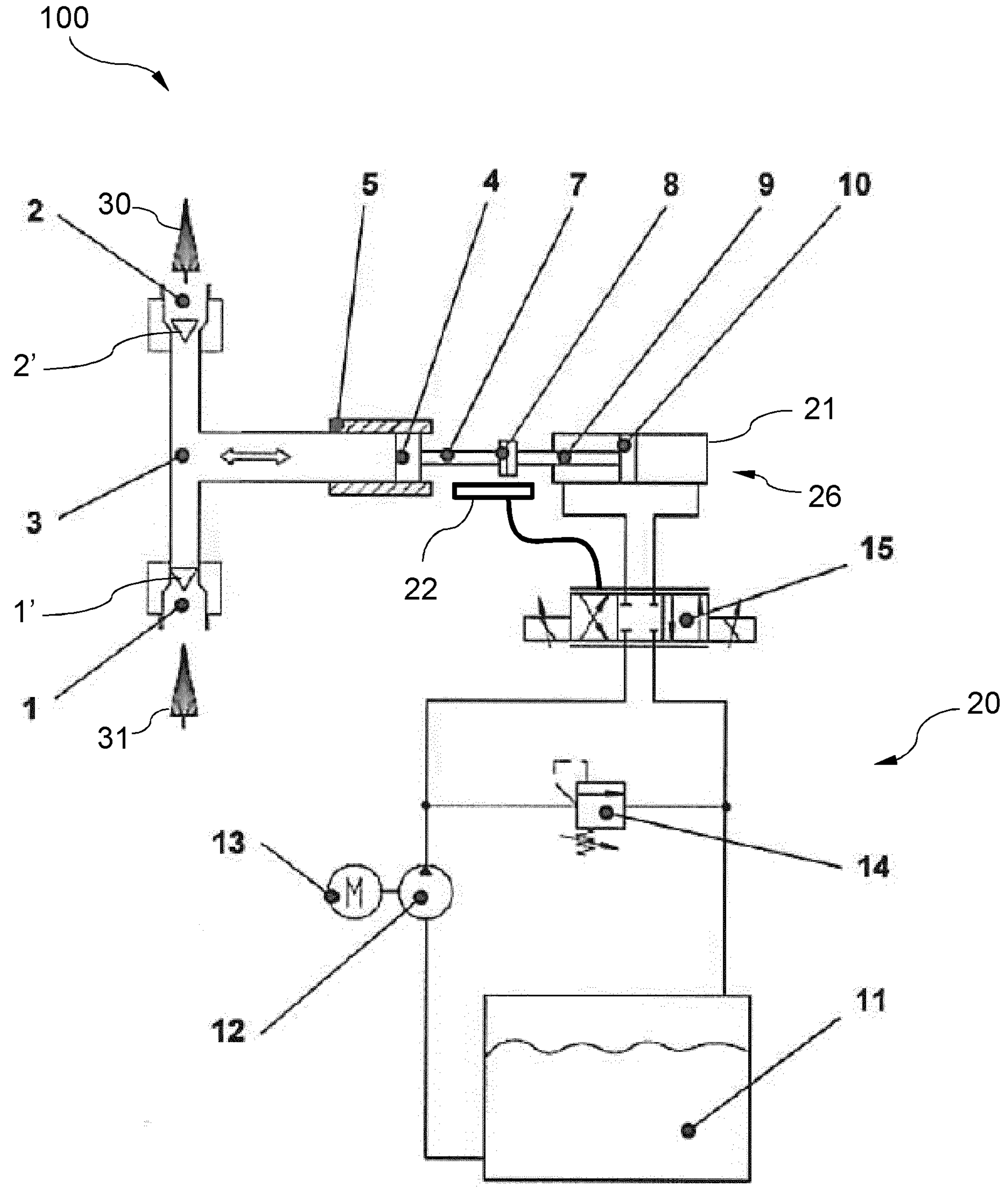

Fig. 1

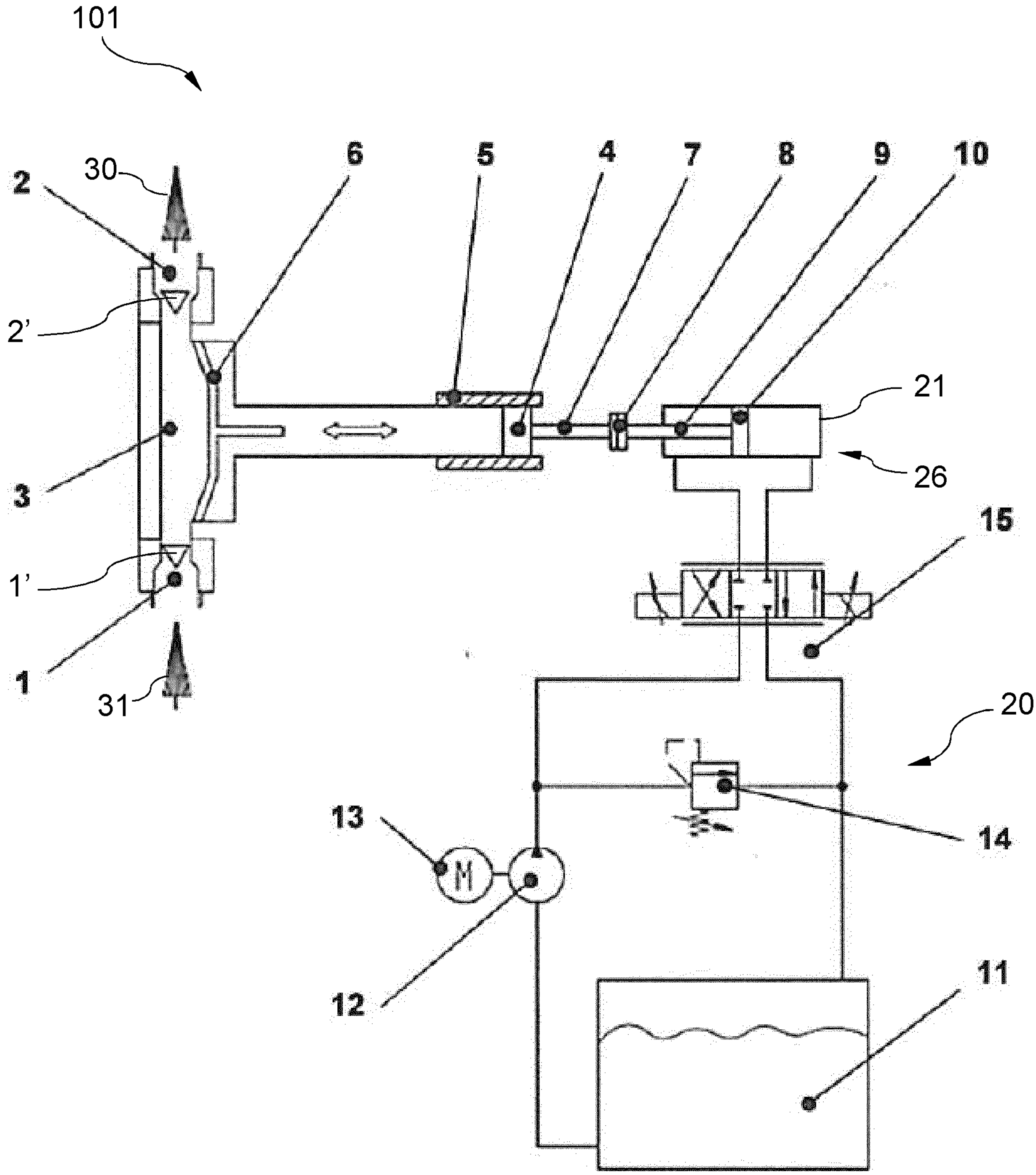

Fig. 2

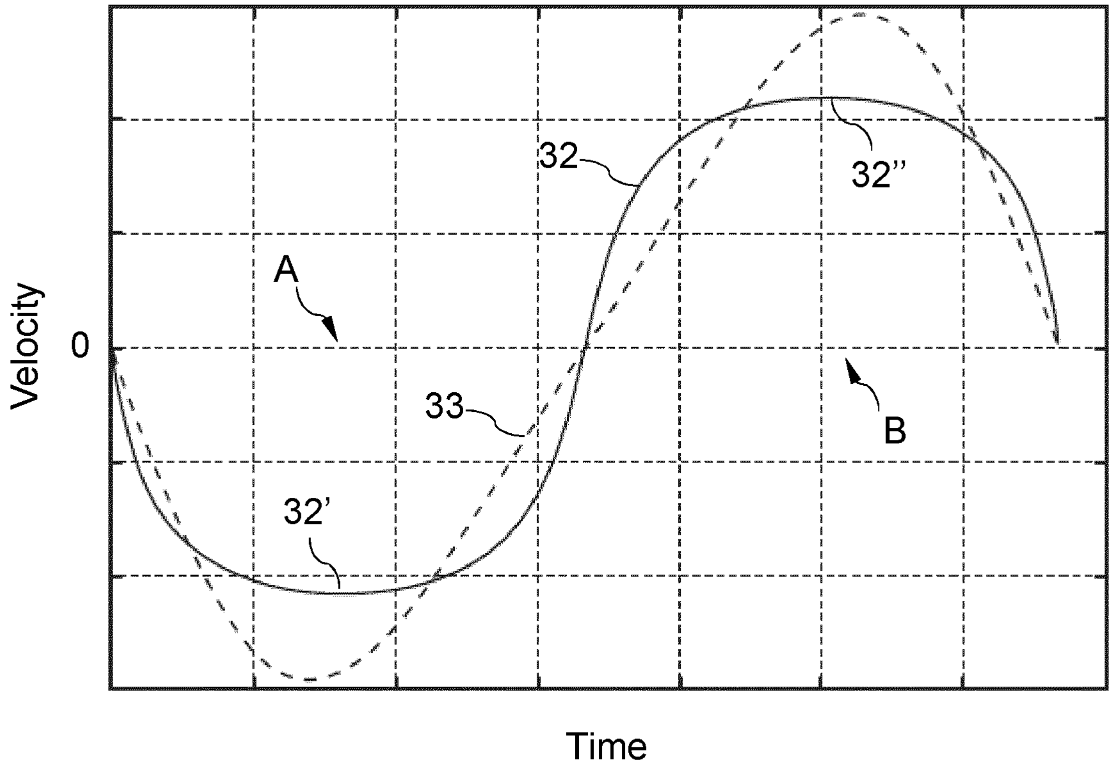

Fig. 3A

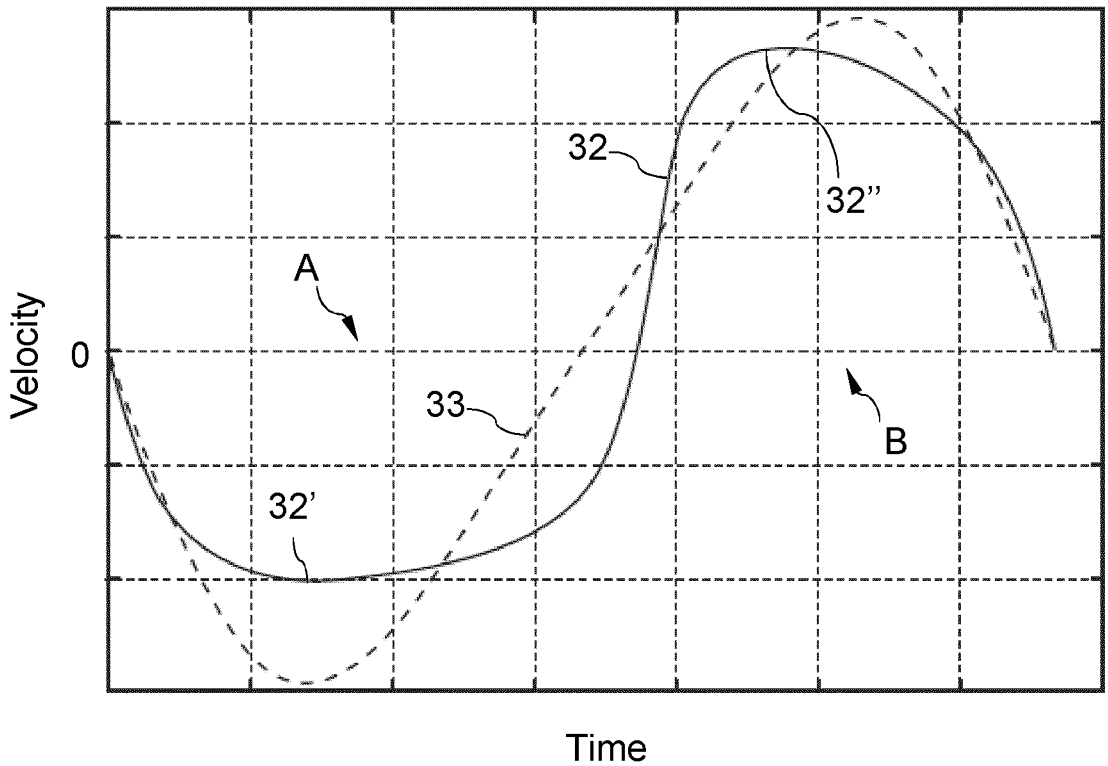

Fig. 3B

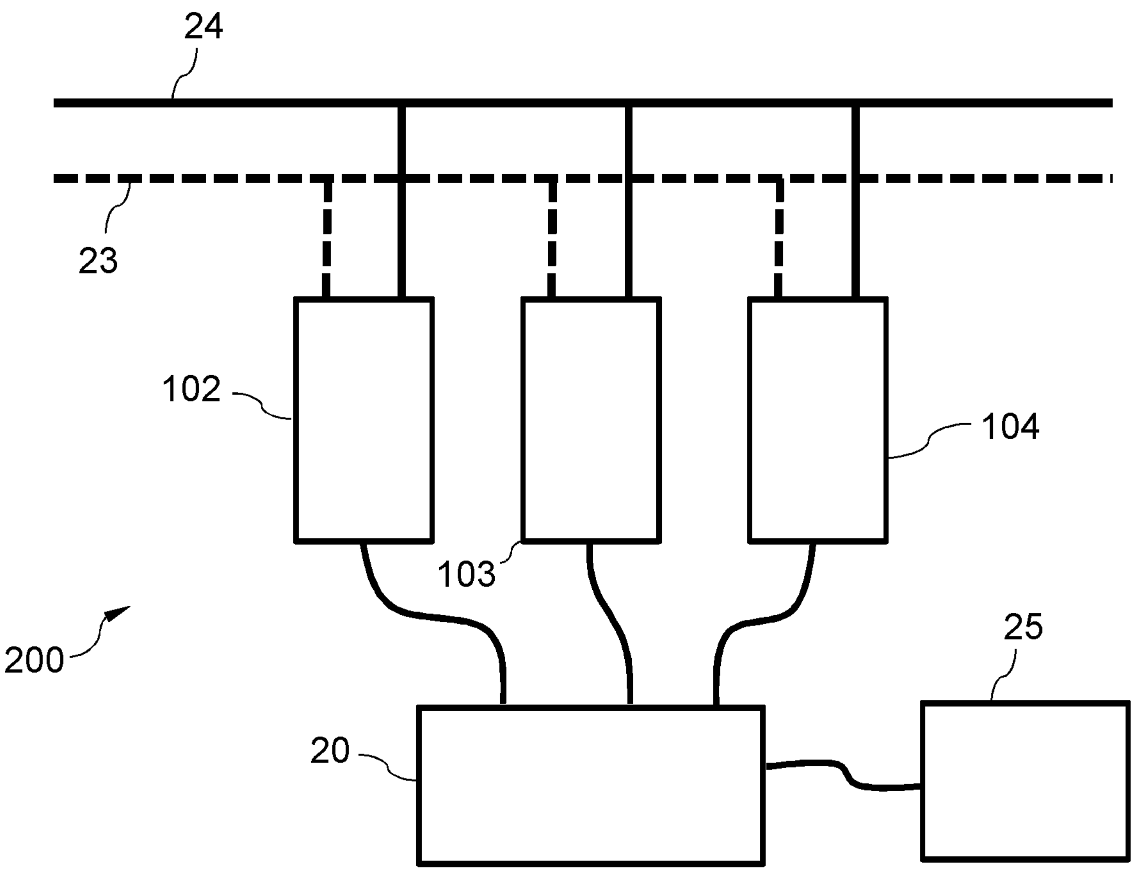

Fig. 4

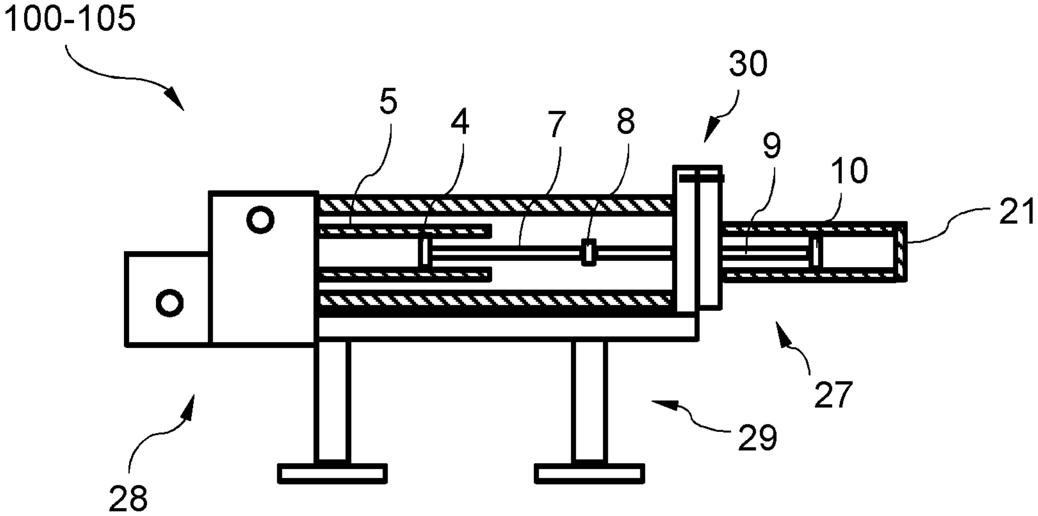

Fig. 5

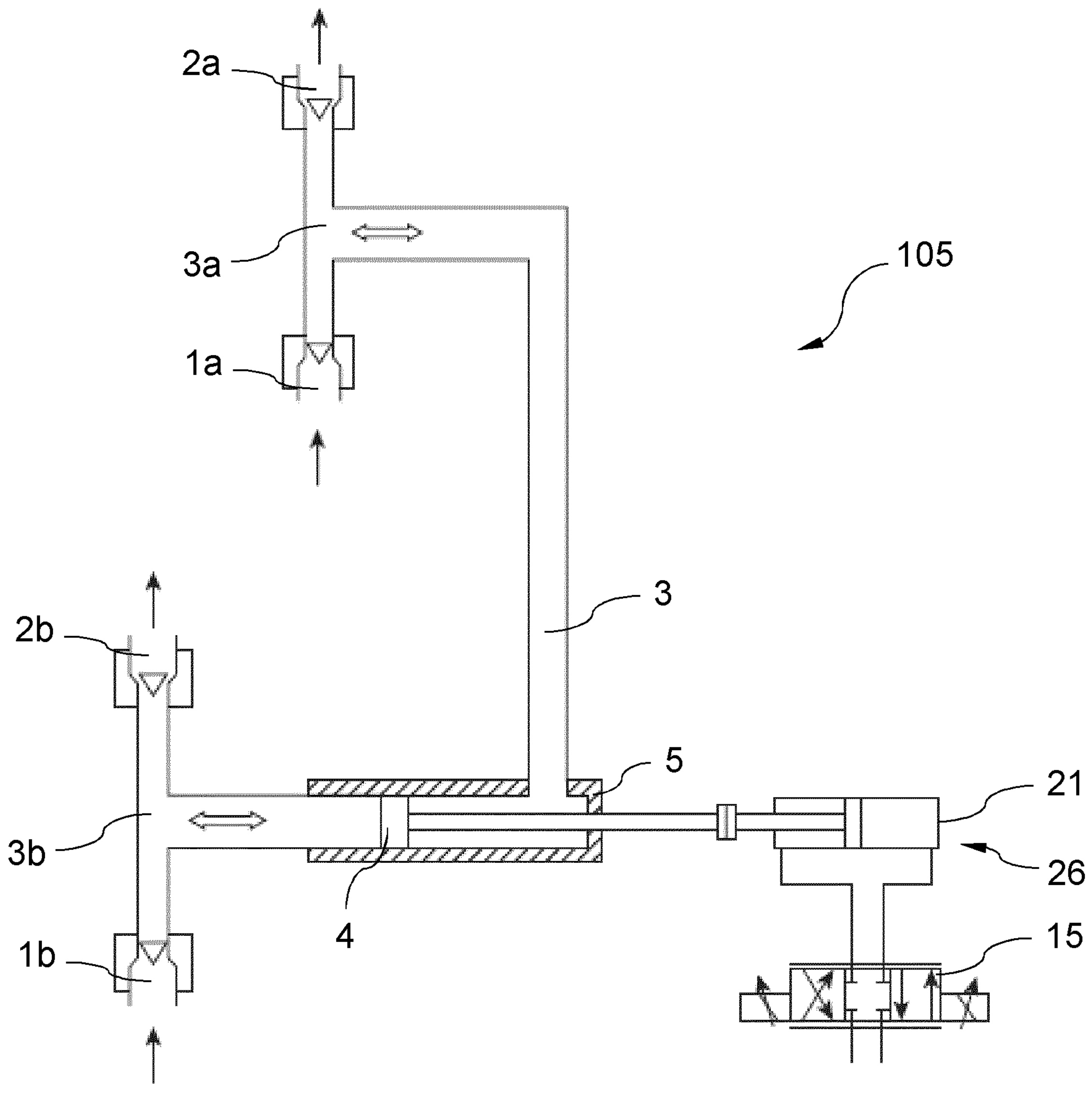

Fig. 6

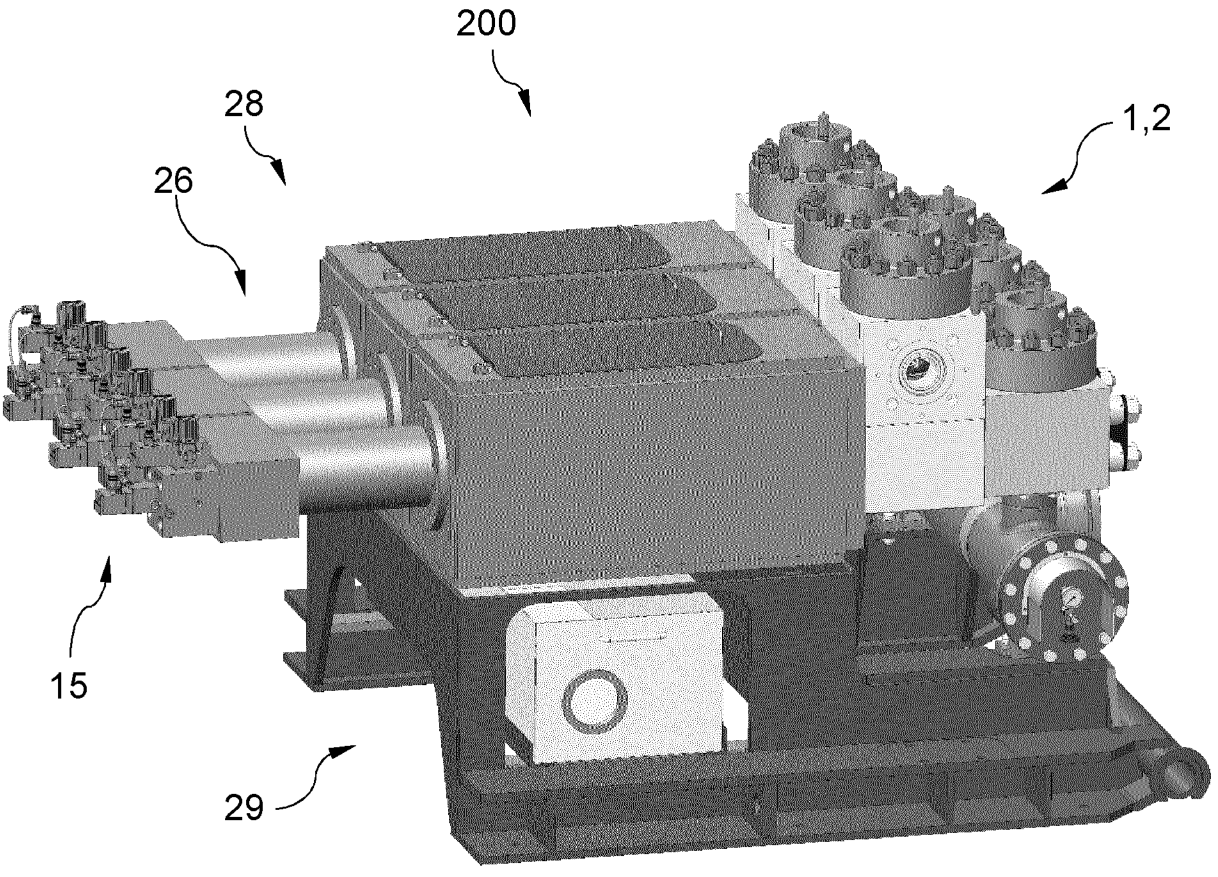

Fig. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2020/052991

A. CLASSIFICATION OF SUBJECT MATTER
INV. F04B9/105 F04B9/117 F04B43/067 F04B53/22
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F04B

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 4 990 058 A (ESLINGER DAVID M [US]) 5 February 1991 (1991-02-05) column 4, line 20 - column 5, line 30; figures 1,2	1-4,6-16 5
X A	EP 0 419 695 A1 (HOYA TAKESHI [JP]) 3 April 1991 (1991-04-03) column 2 - column 6; figures 1-8	1-3,5-7, 10-13 4,8,9, 14-16
X A	DE 197 36 337 A1 (INDUSTRIEANLAGEN BETRIEBSGES [DE]) 25 February 1999 (1999-02-25) columns 2-4; figure 1	1-4, 6-10,13, 14 11,12, 15,16

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

"P" document published prior to the international filing date but later than the priority date claimed

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

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 April 2020	07/05/2020

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Ziegler, Hans-Jürgen

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	EP 2 881 370 A1 (ZHU RONGHUI [CN]) 10 June 2015 (2015-06-10) paragraphs [0036] - [0047]; figures 1-3	1-4,6-9, 11-16 5,10
X	DE 12 21 028 B (MICHEL PEQUIGNOT) 14 July 1966 (1966-07-14) figure 1	1-5
A	FR 3 012 538 A1 (DOSATRON INTERNATIONAL [FR]) 1 May 2015 (2015-05-01) figure 1	8,9
A	WO 2017/174719 A1 (DOSATRON INTERNATIONAL [FR]) 12 October 2017 (2017-10-12) figure 1	8,9

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2020/052991

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4990058 A	05-02-1991	NONE	
EP 0419695 A1	03-04-1991	EP 0419695 A1	03-04-1991
		JP 2671216 B2	29-10-1997
		JP H01305176 A	08-12-1989
DE 19736337 A1	25-02-1999	DE 19736337 A1	25-02-1999
		EP 1005607 A1	07-06-2000
		WO 9910640 A1	04-03-1999
EP 2881370 A1	10-06-2015	CN 102838186 A	26-12-2012
		CN 202808438 U	20-03-2013
		EP 2881370 A1	10-06-2015
		US 2015298062 A1	22-10-2015
		WO 2014019272 A1	06-02-2014
DE 1221028 B	14-07-1966	NONE	
FR 3012538 A1	01-05-2015	AR 098252 A1	18-05-2016
		AU 2014343342 A1	19-05-2016
		CA 2926684 A1	07-05-2015
		CN 105683570 A	15-06-2016
		EA 201690875 A1	31-08-2016
		EP 3063406 A1	07-09-2016
		FR 3012538 A1	01-05-2015
		JP 6563913 B2	21-08-2019
		JP 2016536507 A	24-11-2016
		UA 116818 C2	10-05-2018
		US 2016305424 A1	20-10-2016
		WO 2015063668 A1	07-05-2015
WO 2017174719 A1	12-10-2017	AR 108190 A1	25-07-2018
		AU 2017248041 A1	15-11-2018
		BR 112018070360 A2	29-01-2019
		CA 3019249 A1	12-10-2017
		CN 109072890 A	21-12-2018
		EA 201892263 A1	29-03-2019
		EP 3440353 A1	13-02-2019
		FR 3049992 A1	13-10-2017
		JP 2019513934 A	30-05-2019
		KR 20180127409 A	28-11-2018
		SG 11201808417S A	30-10-2018
		US 2019120226 A1	25-04-2019
		WO 2017174719 A1	12-10-2017