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(71) Applicant *(for all designated States except US)*: VAR DEVELOPMENTS LIMITED [GB/GB]; Landford Common Farm, Unit 18, New Road, Landford, Nr. Salisbury, Wiltshire SP5 2AZ (GB).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: HART, Bernard, Eaton [GB/GB]; Var Developments Limited, Landford Common Farm, Unit 18, New Road, Landford, Nr. Salisbury, Wiltshire SP5 2AZ (GB).

(74) Agent: PRICE, Nigel, John, King; J.A. Kemp & Co., 14 South Square, Gray's Inn, London WC1R 5LX (GB).

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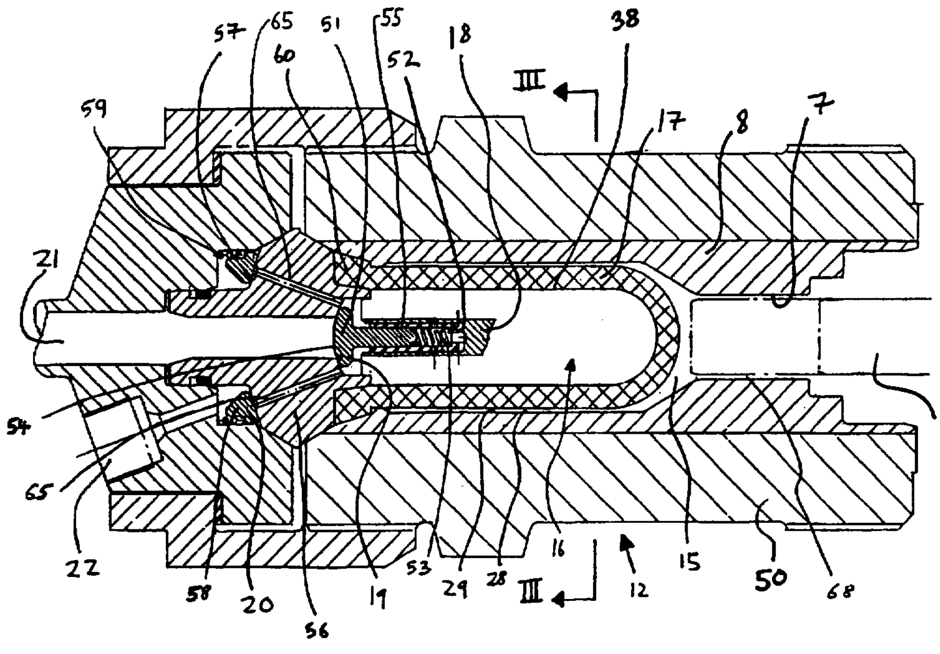

(57) Abstract

The diaphragm pump comprises pumping sections (12). Each pumping section comprises a cylinder (7), a pumping piston (11), a pressure chamber (15) adapted to contain hydraulic oil and subject, in use, to pressurization by movement of the pumping piston. Each pressure chamber (15) is separated from a water-containing pumping chamber (16) by a rubber diaphragm (17). The pumping sections are mounted within a housing. Each housing having a hollow cylindrical cavity in which each pumping section is inserted. This provides for a compact construction for the pump.

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DIAPHRAGM PUMP

This invention relates to diaphragm pumps.

Diaphragm pumps have been proposed previously - see, for example, GB-1,400,150. This known pump comprises a number of pumping sections radially disposed about a central drive shaft. Each of these pumping sections comprises a radial pumping cylinder, a radially reciprocatable pumping piston received in the pumping cylinder, an axially oriented pressure chamber adapted to be filed with pressurized liquid and an axially orientated flow channel disposed within the pressure chamber, the flow channel being bounded by a flexible diaphragm and having a one-way inlet valve and a one-way outlet valve. Each pressure chamber is defined by an axially oriented cylinder having a radial opening in its cylinder wall for communication with its respective radially oriented pumping cylinder/pumping piston. In practice, the pumping cylinder is commonly engaged with the cylinder wall by a screw thread at the opening. In use the pistons, which are mounted on an eccentric, are cyclically reciprocated in the cylinders. In each pumping cylinder the compression stroke of its piston causes the liquid to be pressurized to compress the diaphragm and so pressurize the liquid therein which is ejected through the one-way outlet valve of the respective flow channel. As the piston returns the pressure in the pressure chamber is relieved and the diaphragm returns to its original shape, drawing water through the respective one-way inlet valve.

These known pumps are suitable for pumping liquids, such as water, at pressures up to around 5,000 to 10,000 p.s.i. If higher pressures are generated, then components in these types of pump tend to suffer from problems of fatigue. Because of the increased pressure in the pressure chambers, the internal hoop stresses in the walls of the cylinders defining the pressure chambers are correspondingly higher. This can lead very rapidly to fatigue failure, particularly where the cylinder wall stress concentration is at its highest around its opening to its associated pumping cylinder/piston. When run at approximately 15,000 p.s.i. output pressure, a pump of the sort disclosed in GB-A-1,400,150 will experience fatigue failure of the cylinder wall after around 200 hours running.

A further disadvantage of these pumps is that their construction makes them bulky and heavy. The construction requires that, moving radially outwardly from the pump drive shaft, each pumping section has a pumping cylinder and piston and a pressure chamber. Each pumping section thus, necessarily, has a large extent in the radial direction of the pump, causing the pump to have a large overall diameter.

According to the present invention there is provided a diaphragm pump comprising a plurality of pumping sections, each pumping section comprising:

a rigid elongate tubular body having first and second opposite ends;

a flexible diaphragm received in the interior of the tubular body and dividing the interior into a pressure chamber and a pumping chamber;

an opening in the first end of the tubular body for filling the pressure chamber with a first liquid and for pressurization of the first liquid in the pressure chamber; and

a one-way inlet valve and a one-way outlet valve provided in the second end of the tubular body for the flow into and out from the pumping chamber of a second liquid;

whereby, in use, upon pressurization of the first liquid in the pressure chamber via the opening, the diaphragm will deflect to reduce the volume of the pumping chamber to displace second liquid therefrom via the one-way outlet valve.

Preferably the tubular body has an unbroken cylindrical inner wall.

By providing the pressure and pumping chambers within an elongate tubular body and having the first and second liquids flow into and from the chambers via the ends of the body, weakening of the body walls by forming apertures therein can be avoided, reducing stress concentrations in the tubular body. This reduces the likelihood of fatigue failures developing as a result of such stress concentrations.

Although the first and second liquids are intended to be incompressible, the high pressures at which this pump is intended to be capable of operation means there may be some reduction in the volume of these liquids upon their pressurization. The effects of this can be minimised by restricting the volume of the pressure chamber by internally lining the tubular body with a liner having an irregular inner wall surface.

In order to further reduce the adverse effects of hoop stresses in the rigid elongate tubular body during operation of the pump, the body may be pre-stressed or autofrettaged. This means that the inner part of the tubular body has a residual compressive stress and the outer part has a residual tension.

The diaphragm, which is preferably of closed-end construction, is formed over a mandrel. The mandrel may be shaped such that as the diaphragm is repeatedly compressed and relaxed around it, the mandrel rotates within the diaphragm. This ensures that over time the diaphragm is loaded in different positions, thus preventing repeated stressing of the same points of the diaphragm, which can lead to premature failure of the diaphragm.

In a preferred construction the diaphragm pump of the present invention is a swash plate pump in which the cylinders of the pumping sections are arranged generally parallel to one another around a central axis of the pump, which axis is coincident with the axis of rotation of the swash plate. This further reduces the radial dimension of the pump relative to that disclosed in GB-1,400,150.

An embodiment of a pump in accordance with the present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a longitudinal cross section of an embodiment of the pump through one of pumping sections along the line I-I in Figure 3; showing the piston of that pumping section at the start of its delivery stroke;

Fig. 2 is an enlarged view of the pumping section of Figure 1 viewed along the line II-II in Figure 3; and

Fig. 3 is an axial cross section through the plane III-III in Figures 1 and 2.

The pump comprises a main body 1 to which is connected (by means not shown) a housing 2 for its drive arrangement 3. In the illustrated embodiment the drive arrangement comprises a swash plate 4 which is, in use, rotatably driven about an axis 5 by drive means (not shown) such as a motor or engine. The swash plate is rotatably supported by bearings 6.

The illustrated embodiment of pump comprises three substantially identical pumping sections, spaced around its axis at 120° intervals and all driven by the same swash plate 4. Other numbers of pumping sections may be employed. Only one pumping section is shown in the figures.

The illustrated pumping section comprises a rigid, elongate tubular body 50. This body 50, which is cylindrical, may typically be made of high tensile steel. Lightly shrunk fit into the body 50 is an irregularly shaped liner 8, which may typically be made of stainless steel.

A flexible diaphragm 17 is provided internally of the tubular body 50 and liner 8. This diaphragm, which may be made of elastomeric material such as approximately 6-7 mm thick rubber, divides the interior of the tubular body 50 and liner 8 into a pressure chamber 15 and a pumping chamber 16.

By using an irregularly shaped liner 8 in the cylindrical tubular body 50, the tubular body 50 can have a plain faced (i.e. constant diameter) cylindrical shape, yet the wall defining the pressure chamber 15 can be irregularly shaped, e.g. have a non-constant diameter. The plain faced cylindrical shape for the tubular body 50 is preferred as it avoids undue stress concentrations in the tubular body 50. As will be explained at the end of the specific description below, the irregular shape for the inner wall surface of the liner 8 assists the volumetric efficiency of the pump.

The liner 8, does not suffer the same hoop stresses, in use, as the wall of the tubular body 50, because it is restrained annularly by the tubular body. As a result the material from which it is made is not critical in terms of strength. Of the tubular body 50 and liner 8, the dominant load bearing item is the tubular body.

By making the internal wall of the tubular body 50 a plain faced cylindrical shape, the tensile hoop stress induced in the inner wall surface of the tubular body is evenly distributed avoiding stress concentrations which could lead to premature failure of the tubular body and hence the pump. Nevertheless, the tensile hoop stresses in the tubular body 50 at the high pressures (for example, 20,000 p.s.i.) at which the pump may be used will still be very high, particularly at the inner wall of the body. As a result, to reduce the maximum tensile hoop stress to which the inner wall of the tubular body is subjected in use (i.e. when internally pressurized), prior to assembly into the pump, the tubular body 50 may advantageously be pre-stressed or autofrettaged to leave it with a residual compressive stress at its inner wall. In such a condition, the radially innermost parts of the wall of the tubular body are pre-stressed such that they have a permanent, residual compressive stress before the body is internally pressurized. Therefore, when the pumping chamber is pressurized in use and tensile hoop stresses are induced in the tubular body, the tensile hoop stress at the inner part of the wall is reduced by an amount equal to the compressive stress previously induced in the inner wall by autofrettage. The net result is to reduce the resultant tensile stress at the inner wall of the tubular body 50.

Autofrettaging may typically be achieved by internally pressurising the tubular body, prior to its inclusion in the pump, to a pressure of the order of 60,000 psi. This stresses the inner part of the wall of the tubular body 50 into the plastic range so that, when the pressure is relieved, there is residual compression in the inner part of the wall of the tubular body 50 and residual tension in the outer part.

A pumping piston 11 is reciprocable within the end portion of the cylinder 7 of the liner 8. The pumping piston 11 is slidable along the central longitudinal axis of the cylinder 7. The driven end of the piston 11 is formed into a ball of a conventional ball/socket arrangement 13. The socket is slidable over the face of the swash plate 4 upon rotation of the swash plate to transmit mechanical drive to the piston 11.

The pumping piston 11 is slidably mounted in a bore 14 formed in the main body 1 of the pump. The bore 14 is aligned with the bore of its associated cylinder 7. Running clearances between the relatively slidable cylindrical surfaces of the pumping piston 11 and bore 14 may be of the order of 20-30 micrometres.

Each similar pumping section 12 is provided with a pressure chamber 15. Each chamber 15 is, in use, filled with a first liquid, such as hydraulic oil, and is subject to pressurization by the reciprocating movement of its associated pumping piston 11. Each pressure chamber 15 is separated from its associated pumping chamber 16 by the flexible diaphragm 17. In the illustrated embodiment the diaphragm 17 takes the form of a resiliently deflectable closed-end (thimble-shaped) rubber diaphragm formed over a supporting mandrel 18. The diaphragm has an elongate portion and a generally dome-shape end portion to form the closed end. The mandrel 18 is an elongate structure having angularly spaced radially projecting supporting surfaces 38 protecting from its centre to support the diaphragm. Although, in the illustrated embodiment, the support surfaces 38 extend longitudinally, they may be provided with a slight twist over their length to be generally helical. In addition, the mandrel 18 is advantageously not prevented from rotating relative to the diaphragm 17 so that, over a large number of cycles, different portions of the diaphragm will be in contact with the mandrel's support surfaces avoiding repetition of the stress pattern in the diaphragm. This helps to prolong the life of the diaphragm and hence the operating life of the pump.

In the illustrated embodiment the diaphragm projects into the pressure chamber 15 from the second (left hand) end of the tubular body 50, enclosing the pumping chamber 16 and the mandrel 18, and is repeatedly compressed to pump liquid from the pumping chamber 16. In an alternative arrangement (not shown) the diaphragm may project into the tubular body 50 from the first (right hand) end and enclose the pressure chamber and mandrel therein and be repeatedly tensioned to pump liquid from a pumping chamber radially outwardly thereof.

In the illustrated embodiment, the mandrel is shown as having four support surfaces 38, but this number may be increased or reduced according to the specification of the diaphragm pumping pressure and liquids involved.

Even when not subjected to pressure by the first liquid in the pressure chamber 16, the diaphragm may optionally be lightly tensioned over the mandrel 18. This can enable the pump to run at a higher cycling speed, by assisting recovery of the diaphragm following its compression during a delivery stroke of the piston 11.

Each of the pumping chambers 16 is provided with a one-way inlet valve 19 and a one-way outlet valve 20, as is conventional. The inlet conduit 21 for the liquid to be pumped (second liquid) is common to the inlet valves 19 of all of the pumping sections.

In the illustrated embodiment, the inlet valve takes the form of an inlet valve member 51 generally in the shape of a mushroom, whose stalk is slidably mounted in a guide bore 52 provided in the centre of the mandrel 18. The valve member 51 is biased by a spring 53 into contact with an annular valve seat 54. In the illustrated embodiment the guide bore is lined with a bush 55 pinned into place. This bush may, for example, be made of acetyl resin.

The outlet conduit 22 for the pumped liquid is linked to a loop common to the outlet conduits 22 and valves 20 of the other pumping sections (not shown), as is also conventional.

In the illustrated embodiment the second end of the tubular body 50 is closed by a plug member 56, on the front face of which the inlet valve seat 54 is formed. On a rear surface of the plug member an annular outlet valve seat 57 is provided. A plurality of passages 65 pass through the plug member 56 from the pumping chamber 16 to the outlet valve seat 57, which passages open into an annular groove on the face surface of the seat 57. The outlet valve member 58 takes the form of an annular ring biased into contact with the valve seat 57 by a spring 59.

In use, the (second) liquid to be pumped (for example, water) reaches the pump via conduit 21 and enters the pumping chamber 16 via inlet valve 19. As a result of the compression of the diaphragm 17 caused by the reciprocatable pumping action of the pumping piston 11, liquid from the pumping chamber 16 is ejected past the outlet valves 20 into the outlet conduit 22. This occurs sequentially with operation of the other similar pumping chambers (not shown) of the pump.

The plug member 56 and liner 8 are shaped such that an annular groove 60 is formed between them at the second (left hand) end of the tubular body 50. In this groove a bead formed on the open (left hand) end of the diaphragm 17 is retained to locate the diaphragm 17.

The pump is further provided with an auxiliary circuit. In the illustrated embodiment, this auxiliary circuit includes an auxiliary oil pump 25 driven by a shaft 26 extending along the central axis of the pump from the main swash plate drive arrangement 3. Hydraulic oil is pumped by the auxiliary oil pump 25 along a first flow section of the auxiliary circuit. Hydraulic oil is supplied to the housing 2 for the drive arrangement 3 via part 65, fully to flood the chamber 27 of the housing, before exiting from the housing. The hydraulic oil in the housing 2 acts to cool and lubricate the drive arrangement 3, as well as to prevent air from entering the pressure chambers 15 from the housing chamber 27. In the illustrated embodiment, the hydraulic oil exiting from the housing via a port 66 is passed through a filter (not shown) into an oil reservoir (not shown), from which reservoir the hydraulic oil is fed back to the auxiliary oil pump 25 via a third section of the auxiliary circuit.

From the pumping section 12 illustrated in Figure 1, it will be noted that the pumping piston 11 is provided with radial ports 34, which ports are positioned to open into the interior 27 of the housing 2 at the start of the delivery stroke of a respective pumping piston. The ports 34 allow for small flows of hydraulic oil therethrough, for example to accommodate expansion of the hydraulic oil (first liquid) in the pressure chambers 15 and/or to accommodate losses of that liquid from the pressure chambers, for example due to leakage between the sliding surfaces of the driving pistons 11 and their associated bores 14.

The illustrated embodiment of the pump will now be described in operation.

With the diaphragm pump primed, on rotation of the swash plate at an operating speed, for example in the range of 500-1500 rpm, for instance 1000 rpm, the pumping pistons 11 are caused to reciprocate in sequence. In reciprocating, each pressure chamber 15 (after closure of the ports 34) contains a fixed amount of hydraulic liquid (first liquid) and is subjected to pressurization by movement of its pumping piston, causing its associated diaphragm 17 to be deflected inwardly against its supporting mandrel 18 into the spaces between the mandrel's support surfaces 38. In so doing, the diaphragm reduces the volume of its associated pumping chamber 16. When the pressure of the second liquid (e.g. water) in the pumping chamber 16 reaches the pressure in the outlet conduit 22, the outlet valve member 59 is moved away from its valve seat 57. With the outlet valve 20 open the liquid from the pumping chamber 16 is expelled into the outlet conduit 22. A desirable flow rate for the pump may be of the order of 10 litres/minute, at about 20,000 psi delivery pressure.

On movement of a pumping piston 11 through its full delivery stroke, a volume V_1 of its associated pressure chamber 15 is swept. At the high pressures experienced in the pressure chamber 15, even normally incompressible hydraulic liquid (first liquid) and water (second liquid) suffers a reduction in volume of approximately 3% at 10,000 p.s.i. Consequently, the diaphragm is displaced slightly less than volume V_1 and hence the amount of the second liquid pumped from the pumping chamber out of the outlet valve is correspondingly reduced. This has the overall effect of reducing the overall flow rate of the pump.

In the illustrated embodiment of the apparatus this effect is minimised by keeping the radial gap 28 between the circumferential surface of the diaphragm and the inner wall 29 at the left hand end of the liner 8 small so the volume of the hydraulic liquid contained therein is minimised, whilst maintaining a sufficient clearance to allow adequate flow along the length of the cylinder. Similarly, the radial gap 68 between the extended piston 11 and the inner wall 29 at the right hand end of the liner 8 is kept small; the position of the piston 11 when extended at the end of its delivery stroke is shown in a broken line in Figure 2. Keeping both of these gaps 28,68 small helps to reduce the unswept volume of the pressure chamber 15. These small gaps 28,68 are achieved by the provision of the irregularly shaped liner 8 having two main cylindrical sections of differing diameter connected by a portion which may, as shown, have a frustoconical surface. These cause the radial wall thickness of the liner 8 to be non-constant along the length of the liner. The outer surface of liner 8 has a cylindrical shape to match the dimensions and shape of the inner wall of the tubular body 50. The wider cylindrical section of the liner (left hand end in Figs. 1 and 2) contains the diaphragm 17. The other cylindrical section forms a reservoir from which first liquid in the pressure chamber 15 is forced by the pumping piston 11. Where a similarly shaped internal surface is required, but the pump is not required to run at high pressures, the liner 8 may be omitted and the internal wall of the tubular body 50 itself may be approximately shaped. However, where the pump is required to run at high pressures (e.g. 20,000 p.s.i.) it is preferred for the arrangement to be as shown, namely for a strong, plain faced cylindrical tubular body 50 to be provided for maximum strength, and for a liner 8 to be used to provide the required internal shape for the pressure chamber.

Compression of the first and second liquids does lead to somewhat reduced volumetric efficiency. However the energy required to compress the liquids which does not provide any useful pumping work, is returned to the swash plate during the relaxation stroke of the piston. Furthermore, this compression of the liquids leads to a more constant power consumption across a broad range of flow rates. This can be beneficial if a fixed power motor is being used to drive the pump.

CLAIMS

1. A diaphragm pump comprising a plurality of pumping sections, each pumping section comprising:

a rigid elongate tubular body having first and second opposite ends;

a flexible diaphragm received in the interior of the tubular body and dividing the interior into a pressure chamber and a pumping chamber;

an opening in the first end of the tubular body for filling the pressure chamber with a first liquid and for pressurization of the first liquid in the pressure chamber; and

a one-way inlet valve and a one-way outlet valve provided in the second end of the tubular body for the flow into and out from the pumping chamber of a second liquid;

whereby, in use, upon pressurization of the first liquid in the pressure chamber via the opening, the diaphragm will deflect to reduce the volume of the pumping chamber to displace second liquid therefrom via the one-way outlet valve.

2. A pump as claimed in claim 1, wherein the tubular body has an unbroken cylindrical inner wall surface.

3. A pump as claimed in claim 1 or claim 2, wherein the tubular body has been autofrettaged to provide it with a residual compressive stress at its inner wall surface.

4. A pump as claimed in any one of the preceding claims, wherein the tubular body is lined internally with a liner having an irregular inner wall surface.

5. A pump as claimed in claim 4, wherein the irregular inner wall surface of the liner has two generally cylindrical surface portions of different diameters.

6. A pump as claimed in any one of the preceding claims, wherein the diaphragm is made of elastomeric

material.

7. A pump as claimed in any one of the preceding claims, wherein a mandrel is located within the diaphragm to provide support therefor.

8. A pump as claimed in claim 7, wherein the one-way inlet valve comprises a valve member displaceable axially, away from and towards a valve seat, in a guide bore provided in the mandrel.

9. A pump as claimed in claim 7 or claim 8, wherein the mandrel provides a plurality of angularly spaced support surfaces for supporting the diaphragm.

10. A pump as claimed in claim 9, wherein the support surfaces are generally helical in shape.

11. A pump as claimed in any one of the preceding claims, wherein the diaphragm is generally thimble-shaped, having an elongate cylindrical portion and a closed, domed end portion.

12. A pump as claimed in claim 11 only when dependent upon any one of claims 7-10, wherein the mandrel also has an elongate portion and a domed end portion.

13. A pump as claimed in claim 11 or 12, wherein the thimble-shaped diaphragm extends into the interior of the tubular body from the second end of the tubular body and defines the pumping chamber therein.

14. A pump as claimed in claim 13, wherein the mandrel extends from the second end of the tubular body into the pumping chamber defined within the diaphragm.

15. A pump as claimed in any one of claims 12-14, wherein the mandrel and diaphragm are arranged such that, in use, the mandrel is rotatable relative to the diaphragm.

16. A pump as claimed in any one of the preceding claims, wherein flow passages of the one-way inlet and outlet valves are both provided in a plug member positioned to close the second end of the tubular body.

17. A pump as claimed in claim 16, wherein the one-way outlet valve comprises an axially displaceable annular

ring biased into contact with a valve seat provided on a rear surface of the plug member, the plug member being provided with at least one passage therethrough to the valve seat from the pumping chamber.

18. A pump as claimed in claim 16 or claim 17, wherein part of the diaphragm is seated on the plug member.

19. A pump as claimed in claim 18 when dependent upon claim 4, wherein the diaphragm is provided with an annular bead and this bead is retained in an annular groove formed by the plug member and by one end of the liner.

20. A pump as claimed in any one of the preceding claims, further comprising a piston received in the first end of the tubular body and reciprocatable repeatedly to pressurize the first liquid in the pressure chamber.

21. A pump as claimed in any one of the preceding claims, wherein the tubular bodies of the plurality of pumping sections are arranged generally parallel to one another around a central pump axis.

22. A pump as claimed in claim 21 when dependent upon claim 20, wherein the pump includes a drive arrangement for reciprocating the pistons of the pumping sections, this drive arrangement including a swash plate, the axis of rotation of the swash plate being said central axis of the pump.

23. A pump as claimed in claim 22, wherein the swash plate is housed in a casing filled, in use, with a third liquid, the pressure chamber of each pumping section being arranged to open into the casing at the start of the delivery stroke of its pumping piston to allow for any flow, between the casing and its pressure chamber, of the first and third liquids contained therein.

24. A pump as claimed in claim 23, wherein a wall of each pumping piston is provided with a port, said port being positioned to open into the casing at the start of the delivery stroke of the pumping piston to allow for said flow of the first and third liquids.

25. A pump as claimed in any one of the preceding claims, wherein the first liquid is hydraulic oil.

26. A pump as claimed in any one of the preceding claims, wherein the second liquid is water.

27. A diaphragm pump substantially as described herein with reference to the accompanying drawings.

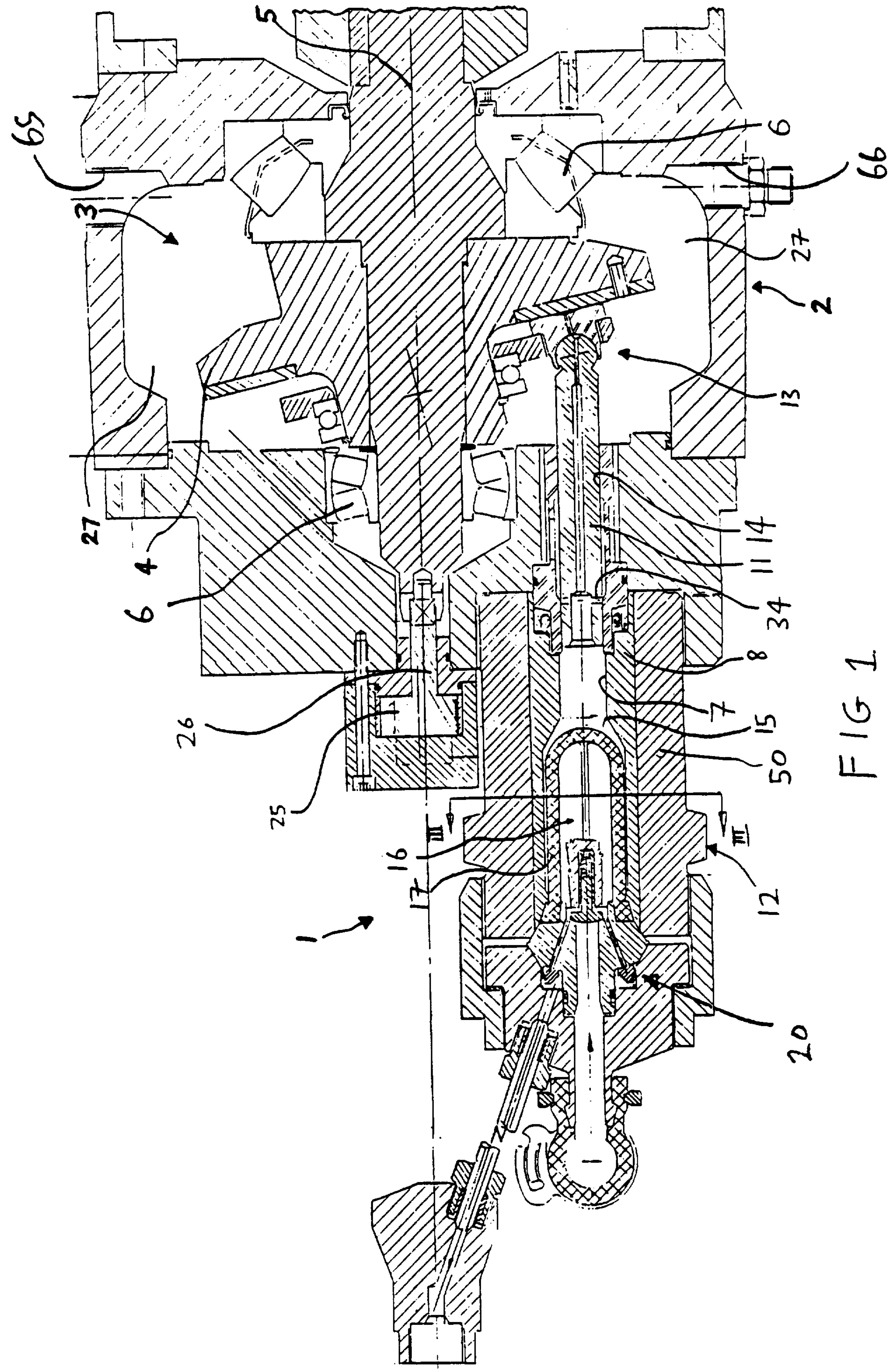

FIG 1

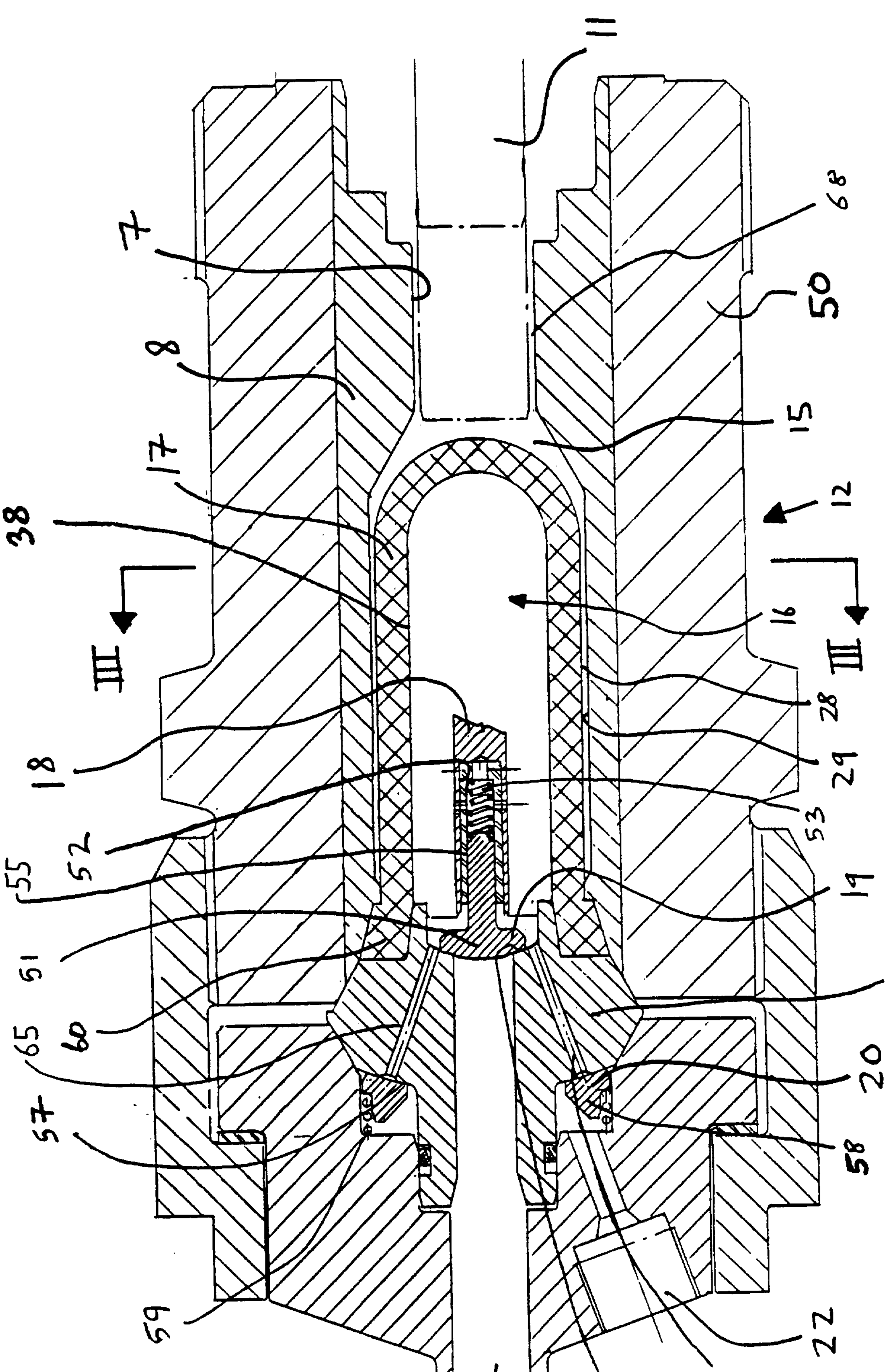
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FIG 2.

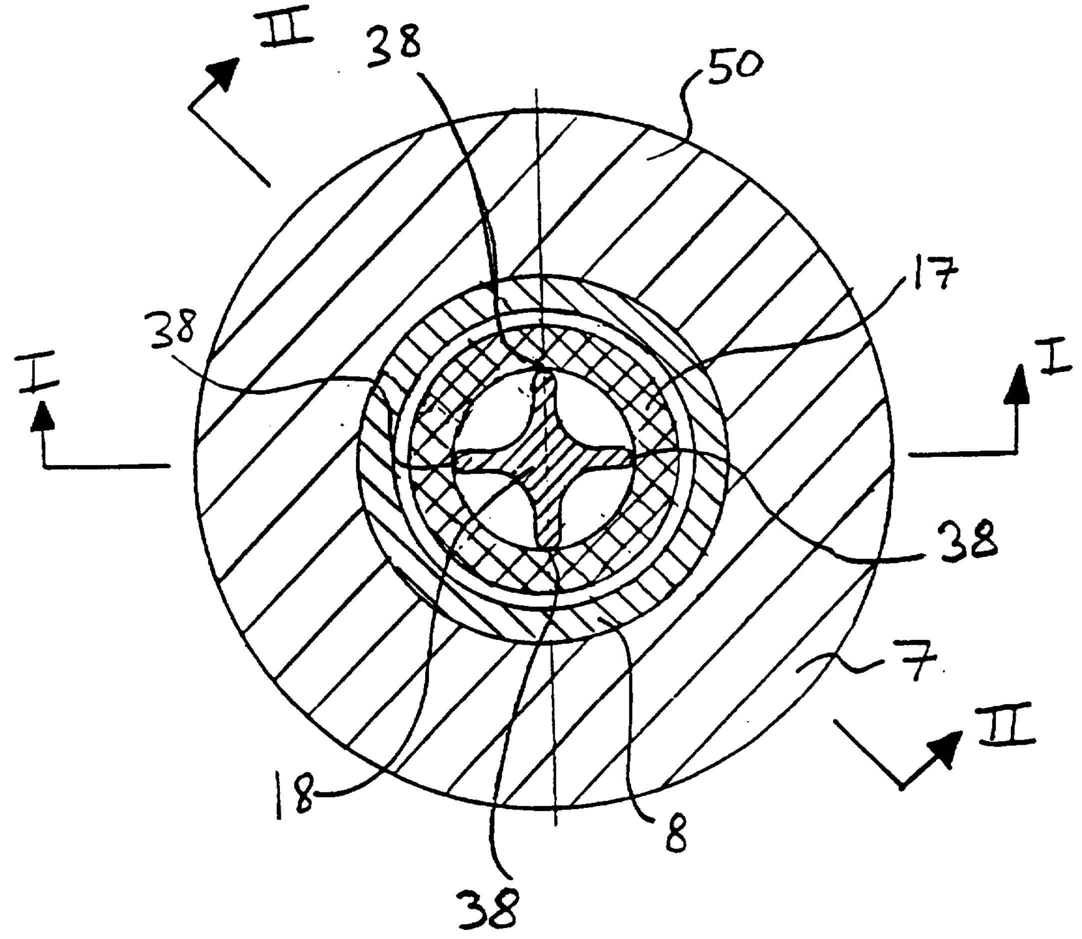

FIG. 3