



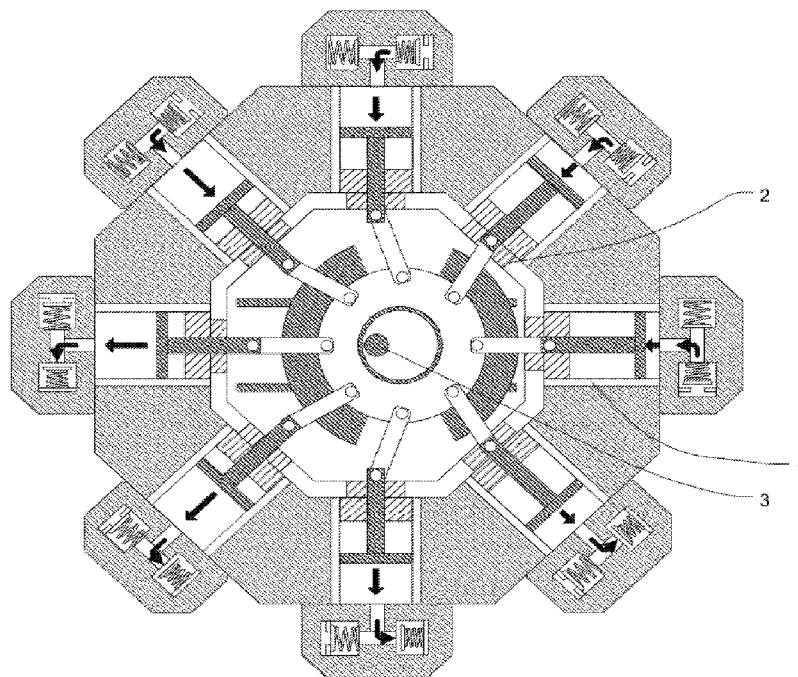
- (51) International Patent Classification:
F04B 9/04 (2006.01) *F04B 53/14* (2006.01)
F04B 49/12 (2006.01) *B01D 61/02* (2006.01)
- (21) International Application Number:
PCT/US2012/037572
- (22) International Filing Date:
11 May 2012 (11.05.2012)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
61/484,806 11 May 2011 (11.05.2011) US
- (71) Applicant (for all designated States except US): NEREID S.A. [CH/CH]; 5 ch des Tulipiers, CH-1208 Geneva (CH).
- (72) Inventors; and
- (75) Inventors/Applicants (for US only): THAT, Huy Ton [CH/CH]; 5 ch des Tulipiers, CH-1208 Geneva (CH). TOAVS, Philip [US/US]; 2410 5th St NW, Sidney, Montana 59270 (US).

- (74) Agents: JENSEN, Eric et al.; 209 Madison Street, Suite 500, Alexandria, Virginia 22314 (US).
- (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, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, 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, 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, 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, ML, MR, NE, SN, TD, TG).

[Continued on next page]

- (54) Title: A POSITIVE DISPLACEMENT MULTI-CYCLINDER PUMP

FIGURE 1 - RADIAL PUMP TOP VIEW



- (57) Abstract: A positive displacement multi-cylinder pump, or "radial pump" which cylinders are set in a radial configuration around a central crankcase. The radial pump has been especially designed for the seawater desalination using reverse osmosis (RO) membrane equipment. The pump acts as 1) a high pressure high flow positive displacement pump, 2) a brine energy recovery device, 3) a variable recovery system, and 4) a brine re-circulation system.

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *without international search report and to be republished
upon receipt of that report (Rule 48.2(g))*

A POSITIVE DISPLACEMENT MULTI-CYLINDER PUMP

BACKGROUND OF THE INVENTION

The versatility and high level of automation of the radial pump enables a virtually operator free operation with a minimum of maintenance. The pump is especially suited for the use in remote areas with limited operator skills. The radial pump can automatically adjust the production rate to the change of salinity of the feed water, while maintaining a constant power requirement and optimized efficiency. The constant power requirement is especially important when using a renewable energy source, as the size of the renewable energy equipment is rated as per the pump's power consumption. The automatic brine recirculation system allows a significant increase in the recovery ratio, hence reducing the number of reverse osmosis (RO) membranes and pre-filtration equipment required by the system.

The radial pump operates at very low speed, increasing its reliability and lifespan while dramatically reducing the noise and vibrations. The low speed operation also avoids the use of a pulsation dampener while requiring less pre-charge pressure. The radial pump utilizes primarily the variability of renewable resources such as solar thermal energy or the low velocity water currents in order to maximize the output flow potential that conventional positive displacement or centrifugal pumps cannot do efficiently.

By reversing its operation principle, the radial pump can also be used as a high torque low speed hydraulic motor. The integrated hydraulic motor drive is particularly adapted to be used with high torque low speed renewable power sources such as an ocean current power converters, windmills or solar thermal power blocks.

Thanks to its unique low speed/high flow output, the radial pump is also ideally suited for any irrigation or water pumping application using renewable energy. The applications include:

1. Water filtration and seawater desalination
2. Irrigation pumping
3. Water transportation
4. Open loop cooling circuit with hydrostatic pressure energy recovery
5. High pressure hydraulic transmission (when used as a hydraulic motor)

SUMMARY OF THE INVENTION

In one embodiment of the invention, a radial pump comprises a central drive plate mechanism which substantially reduces the lateral force generated by the piston rods by combining the effects of an eccentric bearing and a set of guided rails through the rotary movement of the main shaft. The resulting reduced lateral travel of the piston rods substantially alleviates the force exerted on the crankcase with

the advantage to reduce significantly its size, therefore the overall size of the pump. The reduced lateral travel of the piston rods also gives the opportunity to use more cylinders than a conventional radial pump, hence increasing the overall displacement. Unlike a combustion engine, the torque load exerted on the crankshaft and piston rods can be much higher when operating the pump at high pressures or with larger bores. The present invention has been especially designed to address this issue.

In a preferred embodiment of the invention, the radial pump comprises a timing valve for controlling the brine energy recovery process. The timing valve is comprised of only one moving part mounted on the piston rod of each cylinder. The timing of the energy recovery chambers ports opening /closing is entirely managed by the timing valve coupled to the stroke of the piston rod. The timing valve design avoids the use of complex valve mechanisms involving numerous springs and cams. It is an essential component for converting the radial pump into a hydraulic motor.

In yet another preferred embodiment of the invention, the radial pump comprises a variable volume brine recovery system. The system takes advantage of the multi-cylinder configuration of the radial pump to include a system which can increase or decrease the volume of the pressurized brine recovered from the RO membranes. A small brine recovery chamber is located in each cylinder of the pump. Each chamber is automatically activated in a sequence to increase or decrease the volume of recovered brine. A hydraulically actuated valve controls the opening / closing sequence of each variable recovery chamber. The process is entirely automated.

In yet a further preferred embodiment of the invention, the radial pump comprises an automatic brine recirculation system in which the brine is automatically re-circulated in the feed stream to achieve a higher recovery rate. The system automatically controls the flow of re-circulated brine. A higher recovery rate per given volume of feed water can be achieved without exceeding the membrane manufacturer's operating recommendations. As a consequence, less pre-treatment and less RO membranes are required as the system can handle a higher recovery rate, hence reducing the overall cost and maintenance of the equipment.

By way of these features, the invention presents an optimized system designed to function in remote areas as a standalone unit, requiring minimum human intervention. Its low speed high flow design has been optimized for the use with various renewable power sources such as thermal solar, water currents or wind. The radial pump in accordance with the invention can also be used as long distance water transportation relay pumping unit.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a radial pump top view.

FIG. 2 shows a central drive mechanism; FIGs. 2a-2d show the central drive mechanism in positions 1-4, respectively.

FIG. 3 shows a cylinder set side view; FIGs. 3a-3b show the cylinder in positions 1 and 2, respectively

FIG. 4 shows a side view of an embodiment of the timing valve as a rotary valve.

FIG. 5a diagrammatically illustrates the positioning of the rotary valve.

FIG. 5b diagrammatically illustrates another embodiment of the timing valve.

FIG. 6 shows the hydraulic control unit and brine recirculation valve; FIGs. 6a-b show positions 1 and 2, respectively.

FIG. 7 shows a variable brine recovery valve; FIGs. 7a-b show positions 1 and 2, respectively.

FIGs. 8a-8b shows a process overview, wherein the brine recirculation is opened (FIG. 8a) and the brine recirculation is closed (FIG. 8b).

10 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention refers to the design and peripheral/control equipment of a positive displacement multi-cylinder pump, or "radial pump" which cylinders **1** (see FIG. 1) are set in a radial configuration around a central crankcase **2**. The crankcase is of a polygonal design, closed at the top and bottom ends by first and second identical cover plates. A vertical axis central drive shaft **3** is mounted in the crankcase and vertically maintained by two ball bearings, each of them mounted in a circular opening in the center of each cover plate. The central drive shaft **3** can either be powered by an electric motor or directly coupled to a renewable energy source (such as a water current power converter). Inside the crankcase, the central shaft drives an eccentric bearing **4** (see FIG. 2) enclosed by a central drive plate **5**. The pistons' connecting rods **6** are connected to the central drive plate, secured by a vertical pin **7**.

The rotary movement of the drive shaft **3** is transmitted to the eccentric bearing **4** enclosed in the central drive plate **5**, which in turn transmits the push / pull movement to each piston's connecting rod **6**.

The number of cylinders is only limited by the size of the crankcase **2**. Each cylinder **1** is directly bolted on the side wall of the crankcase. A cylinder set **12** (see FIG. 3) is comprised of: a main cylinder **13** split into two distinct chambers (compression upper chamber **14**, and variable recovery lower chamber **15**), a cylinder head **16**, two pistons **17**, **18**, a piston connecting rod **6**, and a piston rod **19**. Both upper and lower chambers **14**, **15** have a dedicated piston **17**, **18**; however both pistons are connected to a same and unique piston rod **19**. The two chambers of a cylinder are separated by a bulkhead **20** in which is located an opening for the passage of the piston rod.

The compression upper chamber **14** delivers the required pumping flow and high pressure for the RO desalination process. Two check valves **16a**, **16b** located in each cylinder head **16** alternate the compression and feed cycles of an entire stroke. In a compression cycle, the feed check valve **16a** is closed while the exhaust check valve **16b** is opened to allow compressed water to exit the cylinder. In a feed cycle, the feed check valve **16a** opens to allow feed water to enter the cylinder while the exhaust check valve **16b** is closed. The above process is indefinitely repeated through the pumping operation.

The function of the energy recovery system and the variable recovery lower chamber will be described in detail further below.

1. Central drive plate – reduced lateral force generated on piston rods

Each piston of the pump is driven by a connecting rod 6 connected to the periphery of a central drive plate 5 (see FIG. 2). The central drive plate is enclosing an eccentric bearing 4 which is connected the
 5 central drive shaft 3. The central drive plate is also connected to a lower plate 8 via two connecting rods 9, each secured by 2 vertical pins 10 bolted to both central drive and lower plates. The lower plate is also mounted on two parallel rails 11 and can freely travel across the full length of the rails. As both
 10 central drive plate 5 and lower plate 8 are interconnected, the lower plate moves along with the upper plate while sliding on the rails 11. The 2 connecting rods linking the central drive plate to the lower plate have the function to control the lateral movement of the upper plate. The combined effect of the
 15 central drive plate 5 mounted on an eccentric bearing 4 and the lower plate 8 mounted on rails 11 results in a much reduced lateral travel of the piston rods throughout an entire piston stroke. It is important to note that unlike a conventional radial combustion engine, the force applied on a piston rod in a hydraulic radial pump is much more significant, especially when working with large bores. Excessive
 20 lateral force can weaken the crankcase structure at the cylinder base level and therefore cause a mechanical failure. It is the objective of this invention to substantially reduce the lateral force generated by the piston rods by combining the effects of an eccentric bearing and guided rails through the rotary movement of the main shaft. The resulting reduced lateral travel of the piston rods substantially alleviates the force exerted on the crankcase and also provides the advantage to reduce significantly the
 25 size of the latter, therefore the overall size of the pump. It also gives the opportunity to use more cylinders than a conventional radial pump, hence increasing the overall displacement of the pump.

2. Integrated energy recovery system with timing valve

Underneath the main piston 17 of the compression chamber of a cylinder 13 is the energy recovery
 25 chamber 21 designed to recover a fixed volume percentage of the brine released by the RO membranes (see FIG. 3). In a pumping process, the main piston 17 moves upwards so the upper chamber 14 can generate high pressure feed water. Simultaneously, the brine exiting the RO membranes is redirected towards the energy recovery chamber 21 under the piston 17 to contribute to the pushing effect, therefore reducing the power required on the pump's main drive shaft 3. It is to be noted that the
 30 volume of recovered brine in the energy recovery chamber 21 is determined by the size of the piston rod 19 which cannot vary. Therefore the brine recovered in the energy recovery chamber is a fixed ratio.

The feed / exhaust cycle of each energy recovery chamber 21 is controlled by the rotary timing valve 59, mounted on the piston rod's 19 section between the crankcase 2 and the main cylinder 13. By using the piston rod's vertical travel, the rotary timing valve 59 mechanically alternates the feed and exhaust
 35 cycles of the energy recovery chamber 21 of each cylinder.

Each energy recovery chamber 21 of a cylinder is connected to the rotary timing valve 59 with a high pressure piping 69. The rotary timing valve (see FIG. 4) is comprised of a rotating cylinder 60a mounted

around the piston rod **19** in the section between the crankcase **2** and the main cylinder **13**. On the inside wall of the rotating cylinder **60a** is located a driving groove **61** with a trapezoidal shape. A driving peg **62** is perpendicularly mounted to the piston rod **19**. The driving peg **62** is positioned to travel inside the driving groove **61** and has a function to position the rotating cylinder **60a** depending on the stroke of the piston rod **19**. An island **65** in the center of the driving groove **61** prevents any lateral movement of the driving peg **62** during its ascending or descending stroke.

A flange **63** is mounted on the upper end circumference of the rotating cylinder **60a**. A hole **64** drilled in the flange, or driving hole, has the function to control the brine inlet and outlet flow.

An outer cylinder **24** statically mounted around the rotating cylinder **60a** physically connects the crankcase **2** to the main cylinder **13**. A metal plate **23** mounted inside the outer cylinder **24** has the function to clamp the flange **63** of the rotating cylinder against the bottom wall of the main cylinder **13**.

Two portholes are drilled in the outer cylinder **24**, one to allow the passage to the pressurized brine inlet conduit **67** and the second to the depressurized brine outlet conduit **68**. The inlet and outlet conduits **67** and **68** are aligned with the rotating cylinder's driving hole **64**. The diameter of both inlet and outlet conduits **67**, **68** and the rotating cylinder's driving hole **64** are the same.

The high pressure conduit **69** connects the energy recovery chamber **21** to the conduits **67**, **68** via the driving hole **64**. The conduit **69** is split into two conduits just before its junction with the driving hole **64** in order to receive the alternate flow from conduits **67** and **68**. The driving hole's **64** function is to alternate the closing and opening of conduits **67** and **68**. The conduit **69** has the function to alternate the pressurized and depressurized brine flow of the energy recovery chamber **21**.

In order to ensure an efficient sealing of the rotary valve system, the valve design provides a pair of compression seals **70**, **71**, installed on both side of the flange **63**, and both facing the driving hole **64**. Each compression seal **70**, **71** contains a seal spring (not shown) which both provides a spring force to force the sliding seal against the valve outer, and also seal the water path around the rear of the sliding seal. It is to be noted that different sealing technologies can be used in this configuration. The various commercial sealing technologies are well known in the rotary valve industry.

As described above, the main function of the rotating cylinder's driving groove **61**, actuated by the driving peg **62**, is to alternate the opening and closing of the pressurized brine inlet conduit **67** and the depressurized brine outlet conduit **68** through the ascending and descending stroke of the piston.

A functional diagram of the rotary valve is shown in FIG. 5a. When a piston **17** of the pump is in its compression (ascending) stroke, the vertical movement of the piston rod **19** takes the driving peg **62** in an ascending movement.

The rotating cylinder's driving groove **61** in which the driving peg **62** travels is designed in such a manner to position the rotating cylinder **60a** and its connected flange **63** in a position allowing its driving hole **64** to be aligned with the pressurized brine inlet conduit **67** during the entire ascending stroke. In this

position, the pressurized brine can enter the energy recovery chamber **21** via the conduit **69**. The energy recovery chamber **21** is therefore filled up with the pressurized brine and contributes to push the piston **17** upwards.

- 5 Close to the end of the ascending stroke, the shape of the rotating cylinder's driving groove **61** is designed in such a manner that the ascending movement of the driving peg **62** forces the rotating cylinder **60a** to rotate counter-clockwise and therefore, position its connected flange **63** in a position allowing its driving hole **64** to be aligned with the depressurized brine outlet conduit **68**. At that point, the piston **17** of the pump begins its descending stroke. The depressurized brine is expelled from the energy recovery chamber **21** via the conduit **69** during the entire descending stroke of the piston **17**.
- 10 Close to the end of the descending stroke of the piston **17**, the shape of the rotating cylinder's driving groove **61** is designed in such a manner that the descending movement of the driving peg **62** forces the rotating cylinder **60a** to rotate clockwise and reposition its connected flange **63** in a position allowing its driving hole **64** to be aligned with the pressurized brine inlet conduit **67**. At that point, the piston **17** of the pump begins its ascending stroke and the entire cycle is repeated.
- 15 The timing of the brine pressurizing and exhaust cycles for each cylinder can be very precisely adjusted by fine tuning the design of the driving groove **61**.

The driving groove **61** and the driving peg **62** are lubricated by a low pressure oil circuit. Due to the low speed of the pump running only at 150 rpm, the rotary valve requires very basic lubrication for its operation. A circular plate **66** mounted on the driving peg **62** prevents the oil to touch the piston rod **19**.

- 20 The above piston stroke driven timing valve design requires reduced component count when compared with a poppet valve system driven by a camshaft and rocker arms.

It is to be noted that in a cycle of a **10** piston configuration for example, there are always 5 pistons in compression mode and 5 pistons in discharge mode.

- 25 In another embodiment, the rotary valve may be replaced with a valve built on a flat surface **60b** (instead of a cylindrical design; see FIG. 5b) where the driving peg **62** travelling inside the groove **61** carved in the flat surface would imprint a lateral movement to the valve. The flat valve **60b** would slide laterally to control the movement of the driving hole **64**. It is the same principle, easier to build but requires a base on which the flat valve can slide.

3. Variable recovery system

30 3.a. Variable recovery chamber

- Underneath the compression chamber **14** of each cylinder (see FIG.3) is a lower chamber **15** designed to increase/decrease the brine recovery ratio. As mentioned in the above description of the rotary valve **59**, the energy recovery chambers **21** can only handle a fixed volume of recovered brine coming from the RO membranes. However, the ability to change the brine recovery rate, hence the permeate
- 35 production ratio of a RO system represents a significant advantage in areas where feed water salinity or

TDS (total dissolved solids) can rapidly change, for example in well-fed systems. Energy recovery devices which can handle such a variable recovery rate are mainly turbine type devices such as the TurboBooster. Besides, isobaric pressure exchangers such as ERI's PX are severely restricted by their flow limits. It is one object of the invention to integrate to the radial pump a variable brine recovery system based on a positive displacement operation principle.

On each cylinder of the pump, a second positive displacement chamber **15** is placed underneath the main compression **14** chamber as described above in point 2. This lower chamber **15** has a smaller bore than the upper chamber **14**, and is separated from the upper chamber by a bulkhead **20**. Both chambers share the same piston rod **19** (therefore the same stroke) which travels through a central opening located in the bulkhead **20**. As for the upper chamber, the lower chamber has a smaller diameter piston **18** mounted on the rod **19**, with the difference that the piston of the upper chamber **17** is mounted at the end of the rod, while the lower chamber's smaller piston **18** is mounted on a lower section of the rod (the rod is extended towards the upper chamber).

As for the energy recovery chamber **21** described above in point 2, the variable energy recovery chamber **22** is positioned underneath the piston **18** of the lower chamber **15**. The variable energy recovery chamber **22** functions the same way as the energy recovery chamber **21**, with the difference that the volume of the variable chamber is smaller.

The concept of a variable displacement energy recovery in a positive displacement pump requires the system to progressively increase or decrease the volume of recovered brine in addition or subtraction to the fixed volume already recovered by the energy recovery chambers **21**. The present invention takes the advantage of a multi-cylinder configuration (i.e. 10 cylinders), where each cylinder with a smaller variable recovery chamber **22** can be activated or de-activated in sequence in order to progressively increase / decrease the volume of recovered brine. The combined volume of both main energy recovery chamber **21** and smaller energy recovery chamber **22** represents 100% of the pump's displacement.

The total volume of the smaller recovery chambers **21** represents the variable volume of recovered brine that the pump can handle.

Example: in a 10 cylinders configuration, let's presume that the fixed brine recovery ratio of the upper recovery chambers **21** is 60% of the displacement. It is assumed that the brine recovery ratio of the system can be increased up to 90%. The variable volume would therefore represent 30% of the total displacement. This additional volume of 30% would then be absorbed by the variable recovery chamber **22** of a cylinder. However the increase of brine recovery from 60% to 90% can be done incrementally by opening the variable recovery chambers one by one, in a sequence.

In a sequence determined by the variable recovery valve **72**, pressurized brine enters the variable recovery chamber **22** of each cylinder, one after the other, increasing progressively the recovered brine volume, hence reducing the energy required on the main drive shaft **3**. As both pistons **17**, **18** of the lower and upper chambers are linked to the same rod **19**, the pushing effect of the variable energy recovery chamber **22** on the secondary piston **17** is directly transmitted to the upper piston **18**, hence

contributing to the pumping energy. It is noted that for best performance the variable recovery chambers **22** should be pressurized in the same sequence as the main energy recovery chambers **21**.

5 **3.b. Variable recovery valve**

The variable recovery valve's function (see FIG. 7) is to open / close following a predetermined sequence the variable recovery chambers **22** of each cylinder of the pump in order to progressively increase / decrease the brine recovery volume. The variable recovery valve **72** is actuated by the hydraulic control unit **29** described further below. The variable recovery valve is comprised of a closed ended cylinder **73**
 10 in which a rod **74** can freely travel. The rod **74** is hydraulically driven by a high pressure line **75** connected to one end of the cylinder **73**. From the same cylinder's end, a small diameter pipe **76** is extended inside the cylinder, then through a borehole in the center axis of the rod **74** in order to convey the high pressure fluid. This high pressure fluid forces the rod to move forward in the bore of the cylinder. Still from the same end of the cylinder, a spring **77** is connected to the rod **74** in order to
 15 retract the latter once the high pressure line is depressurized.

Two adjacent rows of hydraulic valves **78** are perpendicularly mounted on the side walls of the variable recovery valve cylinder **73**. The number of hydraulic valves **78** is equal to the number of cylinders on the pump. The function of the hydraulic valves is to control the flow coming in and out of the variable recovery chambers **22**.

20 Each hydraulic valve **78** is comprised of a small cylinder **79** in which a spring loaded piston **80** can freely travel. The small cylinder **79** is closed at the top end (where the spring **81** is seated) and opened with a flange at the bottom end where it is perpendicularly mounted on the variable recovery valve cylinder **73**.

25 A hole **82** perpendicularly drilled in the recovery valve cylinder wall **73** at the flange mounting spot of each hydraulic valve allows the spring loaded piston head **83** to expand inside the cylinder **73**. The pistons head **83** are of a rounded shape.

As a functional process, the high pressure fluid coming from the hydraulic line **75** pushes the rod **76** through the variable recovery valve cylinder **73**. As a result, the rod actuates in a sequence the rounded piston heads **82** of each small hydraulic valve **78** perpendicularly mounted in adjacent rows. Each spring
 30 loaded piston **80** of a small hydraulic valve is pushed back in a sequence, and therefore changes its position within the small cylinders **79**. As a consequence, this mechanical actuation pressurizes the hydraulic fluid contained in the small cylinder **79**. The pressure is sent out to the hydraulic line **84** then to the 3 way spool **28** located inside the cylinder set **12**. The reverse process happens when the hydraulic high pressure line **75** is depressurized. The rod **74** moves backwards, retracted by its axial
 35 spring **77**, allowing the spring loaded pistons **80** of each small hydraulic valve **78** to come back to their initial position, hence depressurizing the hydraulic fluid in cylinder **79**.

Each variable recovery chamber 22 of the pump is connected via a high pressure piping 84 to its respective hydraulic valve 78 mounted on the variable recovery valve cylinder 73.

When the spring loaded piston 80 of a hydraulic valve 78 is extended (default position), the hydraulic fluid in the line 84 is depressurized, hence the 3 way spool 28 is not actuated. The inflow and outflow of the variable recovery chamber 22 of a same cylinder is connected to open flow via port 27. The variable recovery chamber is not pressurized and freely absorbs and release ocean water at ambient pressure. As soon as the spring loaded piston 80 is compressed by the hydraulically actuated rod 74, the hydraulic fluid in line 84 is pressurized and the 3 way spool 28 is actuated. The inflow and outflow of the variable recovery chamber 22 is then directly connected to the energy recovery chamber 21 of a same cylinder via the line 25 and 26. As the main recovery chambers 21 and the variable recovery chamber 22 are now interconnected, the inflow and outflow timing of the recovered brine is entirely managed by the rotary valve 59.

It is to be noted that the above configuration is only an example of embodiment. The small cylinders 79 can also be setup in a radial configuration where they would be actuated by a hydraulically powered radial cam.

3.c. Variable recovery valve hydraulic control unit

The hydraulic fluid controlling the movement of the rod 74 inside the variable recovery valve 72 is regulated by the hydraulic control unit 29 (see FIG.6). The hydraulic control unit is connected to the pump's main high pressure feed line 39 (between the pump and the RO membranes). The unit uses the fluctuation of the pressure delivered to the RO membranes to hydraulically actuate/release the rod 74 inside the variable recovery valve 72.

The pressure delivered by the pump to the RO membranes (or service pressure) can increase or decrease due to the following reasons: a) increase or decrease of salinity or TDS in the feed water b) RO membrane fouling.

In the event that the pressure increases, additional power is required from the pump to maintain a constant fresh water production rate. However the present system is mainly intended to function on renewable energies systems (solar thermal, water currents) which are rated to produce only a constant or limited power output and are subject to fluctuations. In order to avoid any waste of energy, the hydraulic control unit 29 automatically increases the brine recovery ratio, hence preventing any increase of the service pressure due to membrane fouling or higher salinity / TDS level. By doing so, the system automatically reduces the production output by increasing the brine recovery ratio, while preserving the overall energy efficiency. It is to be noted that an energy recovery turbine such as the Turbo Booster can do the same work but with much less efficiency than a positive displacement system.

The hydraulic control unit 29 can also be manually shunted if the operator wishes to maintain a constant fresh water production rate, hence a constant brine recovery. In this case the variable brine recovery

system is deactivated by unscrewing the adjustable knob 40. Pressure in the RO membranes will progressively buildup, hence requiring from the electric motor an increase of power output.

The hydraulic control unit 29 (see FIG. 6) is comprised of a dual chamber cylinder 32 separated by a bulkhead 33 in its mid-section. The dual chamber cylinder is closed at its top and bottom ends. A piston is installed in each chamber (upper chamber 36 and lower chamber 37). Both pistons 34, 35 are connected together with a piston rod 38 running across the mid-section bulkhead 33 through an opening in its center. A hydraulic port 39 located at the bottom of the cylinder is directly connected to the pump's high pressure main feed line (between the pump and the RO membranes). Above the piston 34 in the upper chamber 36, a spring 31 mounted at the top end of the cylinder maintains a constant pressure on the upper piston 34 by pushing it downwards.. The high pressure chamber 43 above the upper piston 34 is filled up with hydraulic fluid used to actuate the rod 74 in the variable brine recovery valve 72. A high pressure line 44, connected via a port through the cylinder side walls, connects the high pressure chamber 43 to the port 75 of the variable brine recovery valve 72. The adjustable knob 40 is comprised of a threaded screw 41 screwed inside the cylinder 32 at its top.

As a functional process, the secondary piston 35 is pushed upwards when the service pressure in the pump's high pressure main feed line increases. At the opposite top end of the cylinder 32, the spring 31 exerts a counter pressure against the upper piston 34. The spring 31 is calibrated in a manner that both upper and lower forces acting against pistons 34 and 35 are balanced at the normal service pressure of the pump. As soon as the service pressure increases, the piston assembly 34, 35, 38 progressively rise since the service pressure becomes higher than the pressure exerted by the spring 31. As a consequence, the hydraulic fluid in the high pressure chamber 43 is compressed and a volume of compressed fluid is transferred to the variable recovery valve 72 via the pressure line 44 to actuate the rod 74. The rod then actuates in a sequence the variable brine recovery hydraulic valves 78. The above process applies in the exact reverse order as soon as the service pressure of the pump decreases.

It is to be noted that in the above configuration, the actuation of the variable brine recovery valve 72 is an automatic process which doesn't require a manual intervention, unless the operator wishes to shunt the variable recovery process during operation. In order to deactivate the hydraulic control system, the operator has to unscrew the knob 40 mounted on the threaded screw 41. This will provide more volume to the high pressure chamber 43, hence prevents the actuation of the rod 74. As the rod 74 in the variable recovery valve 72 is retained by the retainer spring 77, it cannot expand since any volume of hydraulic fluid expelled from the high pressure chamber 43 is taken by the additional space 42 resulting from the opening of the knob 40. Spring load must be adjusted in a way that it can maintain a static position of the piston assembly 34, 35, 38 at a nominal service pressure. It is also to be noted that the sensitivity of this hydraulic actuation system depends on an accurate selection of all the springs involved in the process, namely the rod's retainer spring 77 and the small hydraulic valves springs 81.

4. Automatic brine recirculation system

Conventional reverse osmosis (RO) technology is based on hydrodynamic principles. A pressurized feed flow stream is divided into permeate flow and pressurized brine flow. The ratio of the permeate flow rate to the feed flow rate, known as the recovery rate, is typically lower than 45% in normal salinity conditions. Higher recovery can be achieved with multiple RO stages, often with additional pressurization between stages. The recovery in each stage is limited by the requirement to maintain sufficient brine flow across each membrane element. In high recovery systems, the energy in the pressurized brine is typically not recovered.

The present automatic brine recirculation technology is based on an automated recirculation process in which the brine is re-circulated in the feed stream to achieve a higher recovery rate. The higher the salinity in the feed water, the less permeate recovery can be achieved due to increased osmotic pressure in the system. Depressurized brine is re-circulated until the permeate flow rate falls under a predetermined level. As the system is of a positive displacement design, the recovered brine volume increases proportionally along with the permeate flow decrease. The variable brine recovery system handles the additional brine to be recovered until it reaches its maximum capacity (i.e. 90% of the displacement when the permeate flow falls to 10%). At that point, the hydraulic control unit 29 (see FIG.6) closes the brine recirculation valve 45 so only ocean feed water (with much less salinity) feeds the RO membranes. As a consequence the service pressure progressively diminishes which results in increased permeate flow rate. The service pressure progressively diminishes to come back to the initial service pressure. At that point the hydraulic control unit 29 opens the brine recirculation valve 45 so only recycled brine (with higher salinity) feeds the RO membranes. This automated cycle is indefinitely repeated through the desalination operation.

In terms of advantages, a higher recovery rate per given volume of feed water can be achieved without exceeding the membrane manufacturer's operating recommendations. As a consequence, less pre-treatment and less RO membranes are required as the system can handle a higher recovery rate, hence reducing the overall cost and maintenance of the equipment.

The brine recirculation valve 45 is directly connected to the main feed water line 30 between the pre-filtration membranes and the radial pump's feed port. Depressurized brine coming from the timing valve's brine outlet 68 is directed to the brine recirculation valve via the depressurized brine port 53. The brine recirculation valve is comprised of a cylinder 46, two pistons 47, 48 and a piston rod 49. The first piston 48 is mounted at the lower end of the rod 49, while the second piston 47 is mounted at the mid-section of the rod 49. The cylinder 46 has three distinct chambers: an upper chamber 50, a mid-section chamber 51 and a lower chamber 52. The bottom end of the lower chamber 52 is directly connected to the RO main feed water line 30, and the depressurized brine port 53 is connected on its side wall. The mid-section chamber 51, built with a larger diameter than the lower chamber 52 has the brine release port 54 connected on its side wall. Note that both lower and mid-section chambers are not separated by any bulkhead so water can freely flow through both chambers. The upper chamber 50 is separated from the mid-section and lower chambers by a bulkhead 55. The piston rod 49 runs vertically across all three chambers. An opening in the center of the upper chamber bulkhead 55 maintains the

rod in place. The section of the piston rod 49 in the upper chamber 50 has a vertical groove 56 drilled in its side wall. The vertical groove 56 hosts a horizontal pilot pin 57 connected to the piston rod 38 of the hydraulic control unit 29 at its lower chamber 37 level. The horizontal pin 57 can travel freely across the vertical length of the groove 56 until it reaches the bottom or top end of the groove. It is noted that in this configuration, both hydraulic control unit 29 and brine recirculation valve 45 have to be mounted side by side, with a horizontal opening 58 between both units in order to allow the free operation of the horizontal pilot pin 57.

As a functional process, the brine recirculation valve 45 is initially set so that the lower chamber's piston 48 is positioned below the bottom end opening of the lower chamber 52 connected to the pump's main feed water line 30. Depressurized brine coming from the side port 53 of the lower chamber 52 can therefore freely flow through the bottom end opening of the lower chamber 52 into the pump's main feed water line 30. The mid-section chamber's piston 47 connected to the same piston rod 49 is also positioned at the bottom of the mid-section chamber 51 so water from the lower chamber 52 cannot flow upwards. In that position the brine recirculation process is operational.

As the brine is re-circulated in the main feed line 30, the service pressure starts to increase. As a result, the hydraulic control unit's rod 38 starts to rise along with the piston assembly 47, 48, 49 in the hydraulic control unit 45. As described above, the horizontal pilot pin 57 is hard mounted on the hydraulic control unit's rod 38 and also inserted in the vertical groove 56 of the brine recirculation valve's rod 49. As soon as the rising horizontal pin 57 enters in contact with the top of the groove 56, the brine recirculation valve's rod 49 is raised along with the ascending movement of the hydraulic control unit's rod 38. As a result of the ascending movement of the rod 49, the piston 48 of the lower chamber closes the access of the depressurized brine to the main feed water line 30. Simultaneously the ascending piston 47 in the mid-section chamber 51 opens the access of the brine release port 54 to the depressurized brine coming from port 53. In that position the brine recirculation process is stopped and the pump is only fed with lower salinity feed water coming from the ocean. This will result in a progressive decrease of the service pressure until the point that the descending movement of the piston assembly 47, 48, 49 will reposition the brine recirculation valve's to its initial point. This will reopen the brine recirculation valve and the process is indefinitely repeated through the desalination operation. It is to be noted that the above described brine recirculation system is an optional feature intended to increase fresh water recovery efficiency and does not represents a component without which the pump cannot operate. The foregoing description of the present invention, and the Figures to which the description refers, are intended as examples only, and are not intended to limit the scope of the invention. It is anticipated, for example, that one skilled in the art will likely realize additional alternatives that are now apparent from this disclosure. Accordingly, the scope of the invention should be determined solely from the following claims and limitation should be inferred by the foregoing description or the Figures.

What is claimed is:

1. A radial piston pump, comprising:

a central crankcase (2), including a central drive shaft (3) extending longitudinally along a central axis, a cover plate, and a central drive plate (5), the central drive shaft (3) configured to rotate about the central axis, and the central drive plate (5) enclosing an eccentric bearing (4) in connection with the drive shaft (3) such that the central drive plate rotates with a rotation of the drive shaft (3);

a plurality of cylinder sets (1) positioned in a plane perpendicular to the central axis and arranged in a radial configuration around the central crankcase (2), each cylinder set (1) comprising a piston connecting rod (6) connected to a peripheral portion of the central drive plate (5); and

a secondary plate slidingly mounted on a horizontal rail affixed to the cover plate, a peripheral portion the secondary plate connected to the peripheral portion of the central drive plate (5) via a plate connecting rod (9), the plate connecting rod configured to cause the secondary plate to slide along the rail with a rotation of the central drive plate.

2. The radial piston pump according to claim 1,

wherein each cylinder set (1) comprises a main cylinder and a primary piston (17), the primary piston (17) connected by a piston rod (19) to the piston connecting rod (6), the piston rod (19) attached to a bottom surface of the primary piston (17), a portion of the main cylinder delimited by a top surface of the primary piston (17) forming an upper chamber (14), and a portion of the main cylinder delimited by the bottom surface of the primary piston (17) forming an primary energy recovery chamber (21), the primary energy recovery chamber (21) configured to receive pressurized fluid during a compression cycle of the upper chamber (14), and configured to exhaust fluid during a feed cycle of the upper chamber (14), and

wherein each cylinder set (1) further comprises a valve configured to allow feed fluid to enter the upper chamber (14) in the feed cycle, and to allow compressed fluid to exit the upper chamber (14) in the compression cycle.

3. The radial piston pump according to claim 2, wherein each cylinder set (1) further comprises a timing valve (59) configured to mechanically alternate between feed and exhaust cycles of the primary energy recovery chamber (21).

4. The radial piston pump according to claim 3, wherein the timing valve comprises a rotatable cylinder (60a) mounted around the piston rod (19) and a driving peg (62)

perpendicularly mounted to the piston rod (19) and positioned to travel inside a driving groove (61) on an inside wall of the rotatable cylinder (60a) for rotating the rotatable cylinder (60a) in accordance with a reciprocal motion of the piston rod (19), thereby to regulate a position of a control portion of the rotatable cylinder to either i) allow passage of fluid from a first conduit into the primary energy recovery chamber (21) or ii) allow passage of fluid out from the primary energy recovery chamber (21) through a second conduit.

5. The radial piston pump according to claim 3, wherein the timing valve comprises a flat member (60b) and a driving peg (62)-perpendicularly mounted to the piston rod (19) and positioned to travel inside a driving groove (62) on an inside wall of the flat member (60b) for sliding the flat member (60b) in accordance with a reciprocal motion of the piston rod (19), thereby to regulate a position of a control portion of the flat member (60b) to either i) allow passage of fluid from a first conduit into the primary energy recovery chamber (21) or ii) allow passage of fluid out from the primary energy recovery chamber (21) through a second conduit.

6. The radial piston pump according to any of claims 2, 3, 4 or 5, further comprising:
a variable recovery valve (72); and
a hydraulic control unit (29) in communication with the variable recovery valve (72) for controlling the variable recovery valve (72),
wherein each cylinder set (1) further comprises a secondary cylinder separated from the main cylinder by a bulkhead (20), the secondary cylinder having provided therein a second piston (18) connected to the piston rod (19), a portion of the secondary cylinder delimited by a top surface of the secondary piston (18) forming a lower chamber (15), and a portion of the secondary cylinder delimited by the bottom surface of the secondary piston (18) forming a secondary energy recovery chamber (22),
wherein each cylinder set (1) yet further comprises a 3-way spool (28) that, in an actuated mode, establishes a direct fluid connection between the primary energy recovery chamber (21) and the secondary energy recovery chamber (22), and in a non-actuated mode, prevents fluid connection between the primary energy recovery chamber (21) and the secondary energy recovery chamber (22), and
wherein, responsive to an increase in pressure in a fluid line carrying fluid exiting the upper chamber (14) in the compression cycle, the hydraulic control unit causes the variable recovery valve to actuate one or more 3-way spools (28) of the plurality of cylinder sets (1).

7. The radial piston pump according to claim 6, wherein the hydraulic control unit (29), in a first mode, receives an output fluid out from the primary energy recovery chamber (21) and recirculates the output fluid into a line supplying the feed fluid to the upper chamber (14), and in a second mode, receives the output fluid out from the primary energy recovery chamber (21) and directs the output fluid to a release port (54).

8. The radial piston pump according to any of claims 6 or 7,
wherein the variable recovery valve (72) comprises a closed ended cylinder (73) and a rod (74) slidably mounted within the closed ended cylinder (73) and a spring mounted to an end of the closed ended cylinder (73), the closed ended cylinder (73) comprising hydraulic valves (78) perpendicularly mounted on a side wall of the closed ended cylinder (73), each hydraulic valve (78) comprising a valve cylinder (79) and a spring-loaded piston (80) slidably mounted therein, each valve cylinder (79) in fluid connection with one 3-way spool of a one cylinder set (1),

wherein the spring biases the rod (74) into a home position where the rod (74) is free of contact with any of the spring-loaded pistons (80) of the hydraulic valves (78), and

wherein the closed ended cylinder (73) is in fluid communication with the hydraulic control unit (29), the hydraulic control unit (29) configured to, in response to an increase in pressure in the fluid line carrying fluid exiting the upper chamber (14) in the compression cycle, cause the spring-loaded piston (80) to move from the home position, thereby to actuate one or more of the hydraulic valves (78) and consequently actuate a corresponding 3-way spool of a corresponding cylinder set (1).

9. The radial piston pump according to any of claims 7 or 8, wherein the hydraulic control unit (29) further comprises a user-adjustable control for forcing the hydraulic control unit (29) to remain in one of the first or second modes.

10. A radial piston pump, the radial piston pump comprising:
a central crankcase (2), including a central drive shaft (3) extending longitudinally along a central axis, a cover plate, and a central drive plate (5), the central drive shaft (3) configured to rotate about the central axis, and the central drive plate (5) enclosing an eccentric bearing (4) in connection with the drive shaft (3) such that the central drive plate rotates with a rotation of the drive shaft (3); and

a plurality of cylinder sets (1) positioned in a plane perpendicular to the central axis and arranged in a radial configuration around the central crankcase (2), each cylinder set (1) comprising a piston connecting rod (6) connected to a peripheral portion of the central drive plate (5),

wherein each cylinder set (1) comprises a main cylinder and a primary piston (17), the primary piston (17) connected by a piston rod (19) to the piston connecting rod (6), the piston rod (19) attached to a bottom surface of the primary piston (17), a portion of the main cylinder delimited by a top surface of the primary piston (17) forming an upper chamber (14), and a portion of the main cylinder delimited by the bottom surface of the primary piston (17) forming an primary energy recovery chamber (21), the primary energy recovery chamber (21) configured to receive pressurized fluid during a compression cycle of the upper chamber (14), and configured to exhaust fluid during a feed cycle of the upper chamber (14), and

wherein each cylinder set (1) further comprises a valve configured to allow feed fluid to enter the upper chamber (14) in the feed cycle, and to allow compressed fluid to exit the upper chamber (14) in the compression cycle.

11. The radial piston pump according to claim 10, wherein each cylinder set (1) further comprises a timing valve (59) configured to mechanically alternate between feed and exhaust cycles of the primary energy recovery chamber (21).

12. The radial piston pump according to claim 11, wherein the timing valve comprises a rotatable cylinder (60a) mounted around the piston rod (19) and a driving peg (62) perpendicularly mounted to the piston rod (19) and positioned to travel inside a driving groove (61) on an inside wall of the rotatable cylinder (60a) for rotating the rotatable cylinder (60a) in accordance with a reciprocal motion of the piston rod (19), thereby to regulate a position of a control portion of the rotatable cylinder to either i) allow passage of fluid from a first conduit

into the primary energy recovery chamber (21) or ii) allow passage of fluid out from the primary energy recovery chamber (21) through a second conduit.

13. The radial piston pump according to claim 11, wherein the timing valve comprises a flat member (60b) and a driving peg (62) perpendicularly mounted to the piston rod (19) and positioned to travel inside a driving groove (61) on an inside wall of the flat member (60b) for sliding the flat member (60b) in accordance with a reciprocal motion of the piston rod (19), thereby to regulate a position of a control portion of the flat member (60b) to either i) allow passage of fluid from a first conduit into the primary energy recovery chamber (21) or ii) allow passage of fluid out from the primary energy recovery chamber (21) through a second conduit.

14. The radial piston pump according to any of claims 10, 11, 12 or 13, further comprising:

a variable recovery valve (72); and

a hydraulic control unit (29) in communication with the variable recovery valve (72) for controlling the variable recovery valve (72),

wherein each cylinder set (1) further comprises a secondary cylinder separated from the main cylinder by a bulkhead (20), the secondary cylinder having provided therein a second piston (18) connected to the piston rod (19), a portion of the secondary cylinder delimited by a top surface of the secondary piston (18) forming a lower chamber (15), and a portion of the secondary cylinder delimited by the bottom surface of the secondary piston (18) forming a secondary energy recovery chamber (22),

wherein each cylinder set (1) yet further comprises a 3-way spool (28) that, in an actuated mode, establishes a direct fluid connection between the primary energy recovery chamber (21) and the secondary energy recovery chamber (22), and in a non-actuated mode, prevents fluid connection between the primary energy recovery chamber (21) and the secondary energy recovery chamber (22), and

wherein, responsive to an increase in pressure in a fluid line carrying fluid exiting the upper chamber (14) in the compression cycle, the hydraulic control unit causes the variable recovery valve to actuate one or more 3-way spools (28) of the plurality of cylinder sets (1).

15. The radial piston pump according to claim 14, wherein the hydraulic control unit (29), in a first mode, receives an output fluid out from the primary energy recovery chamber (21) and recirculates the output fluid into a line supplying the feed fluid to the upper chamber (14), and in a second mode, receives the output fluid out from the primary energy recovery chamber (21) and directs the output fluid to a release port (54).

16. The radial piston pump according to any of claims 14 or 15, wherein the variable recovery valve (72) comprises a closed ended cylinder (73) and a rod (74) slidably mounted within the closed ended cylinder (73) and a spring mounted to an end of the closed ended cylinder (73), the closed ended cylinder (73) comprising hydraulic valves (78) perpendicularly mounted on a side wall of the closed ended cylinder (73), each hydraulic valve (78) comprising a valve cylinder (79) and a spring-loaded piston (80) slidably

mounted therein, each valve cylinder (79) in fluid connection with one 3-way spool of a one cylinder set (1),

wherein the spring biases the rod (74) into a home position where the rod (74) is free of contact with any of the spring-loaded pistons (80) of the hydraulic valves (78), and

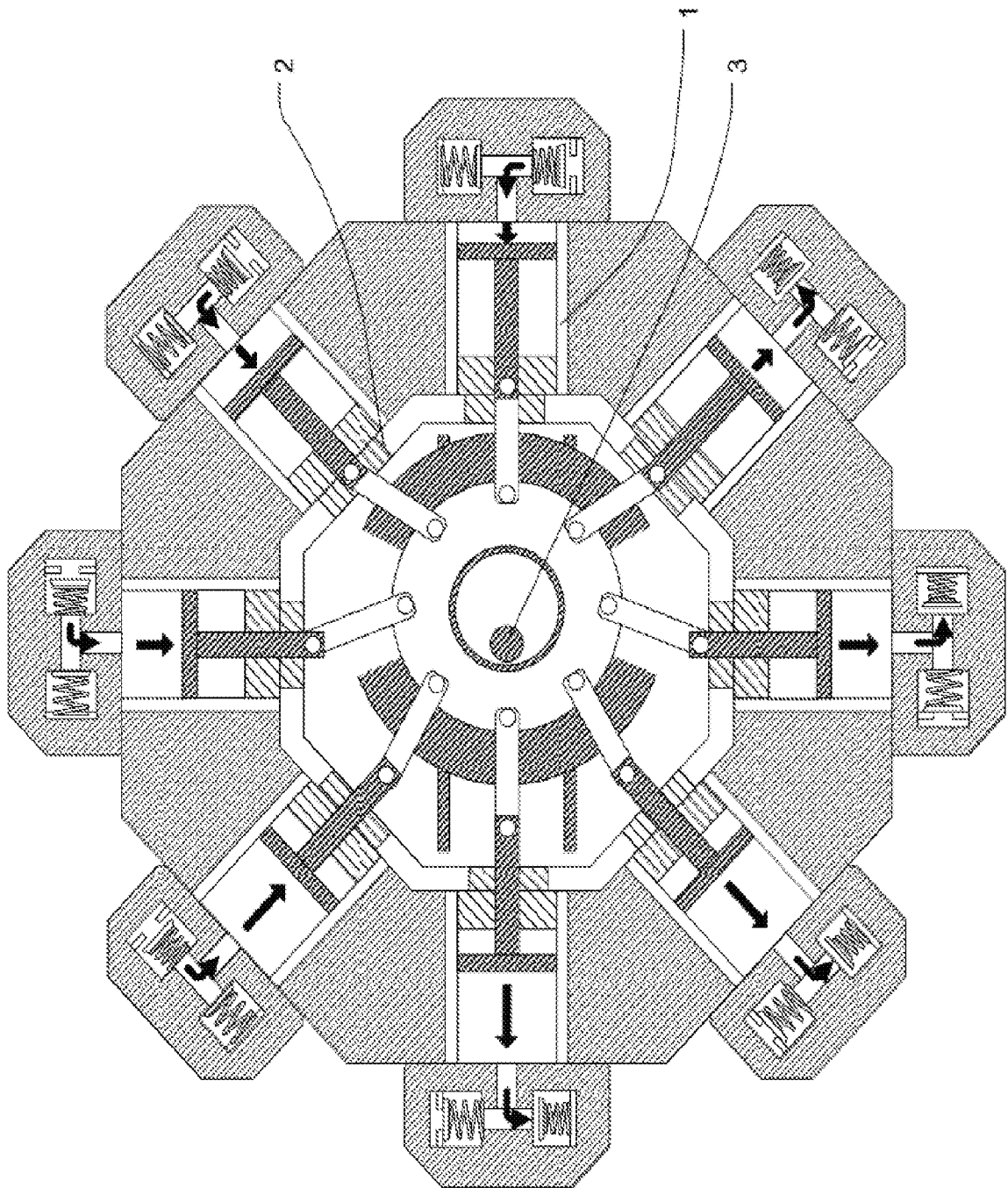
- 5 wherein the closed ended cylinder (73) is in fluid communication with the hydraulic control unit (29), the hydraulic control unit (29) configured to, in response to an increase in pressure in the fluid line carrying fluid exiting the upper chamber (14) in the compression cycle, cause the spring-loaded piston (80) to move from the home position, thereby to actuate one or more of the hydraulic valves (78) and consequently actuate a corresponding 3-way spool of a
- 10 corresponding cylinder set (1).

17. The radial piston pump according to any of claims 15 or 16, wherein the hydraulic control unit (29) further comprises a user-adjustable control for forcing the hydraulic control unit (29) to remain in one of the first or second modes.

- 15 18. The radial piston pump according to any of claims 10 to 17, further comprising:
a secondary plate slidably mounted on a horizontal rail affixed to the cover plate, a peripheral portion the secondary plate connected to the peripheral portion of the central drive plate (5) via a plate connecting rod (9), the plate connecting rod configured to cause the
- 20 secondary plate to slide along the rail with a rotation of the central drive plate.

1/20

FIGURE 1 - RADIAL PUMP TOP VIEW



2/20

FIGURE 2 – CENTRAL DRIVE MECHANISM

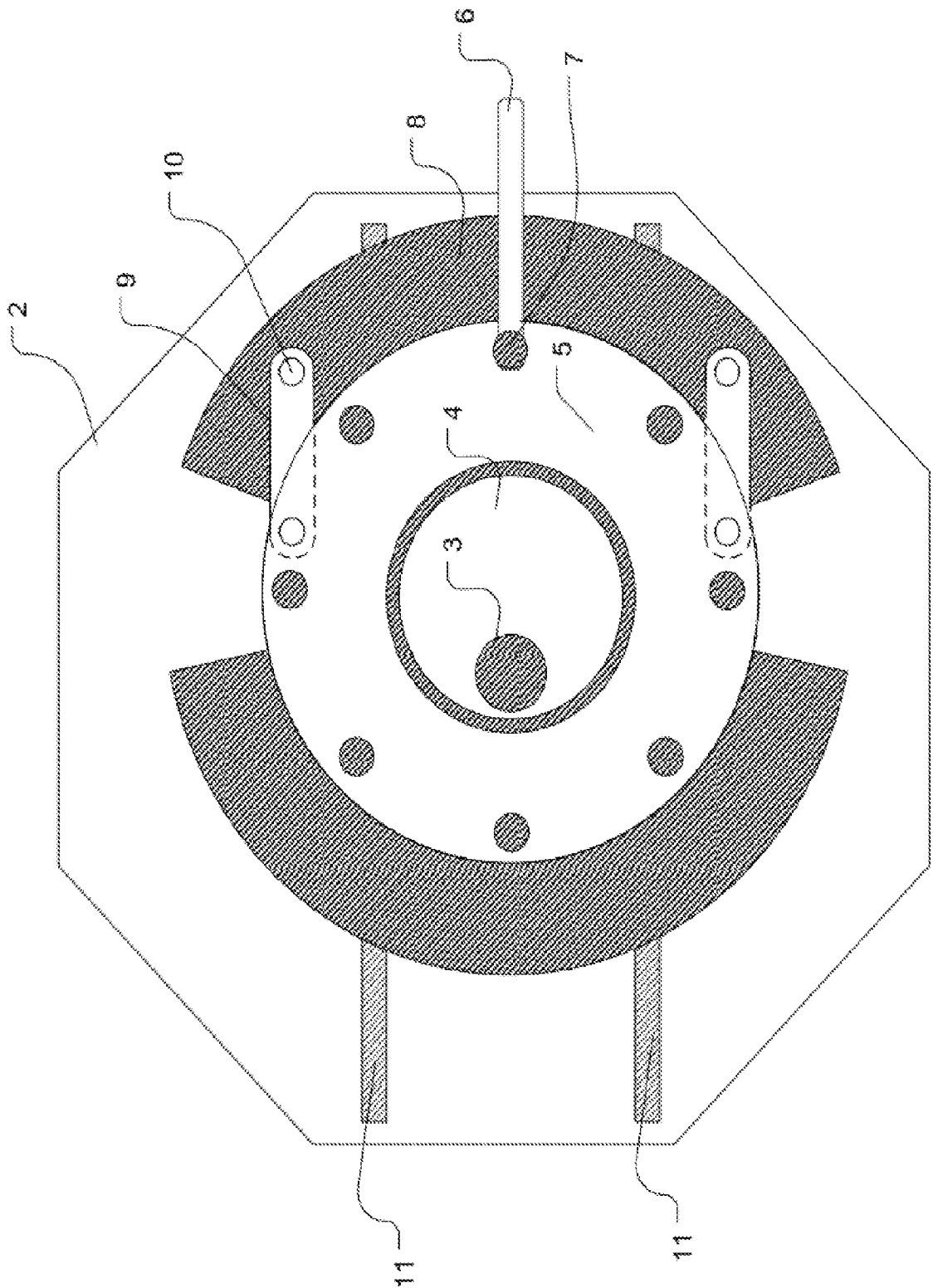
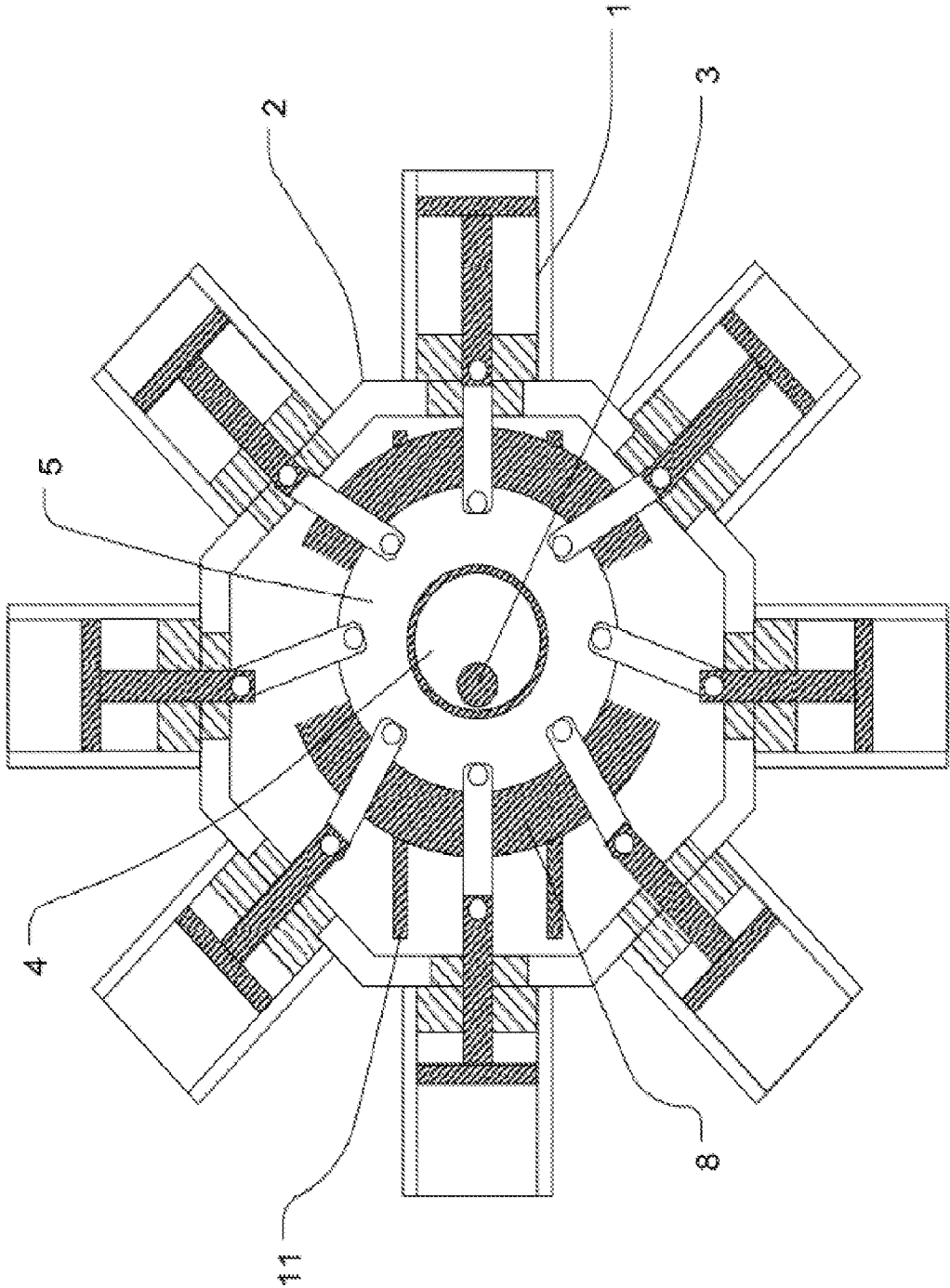
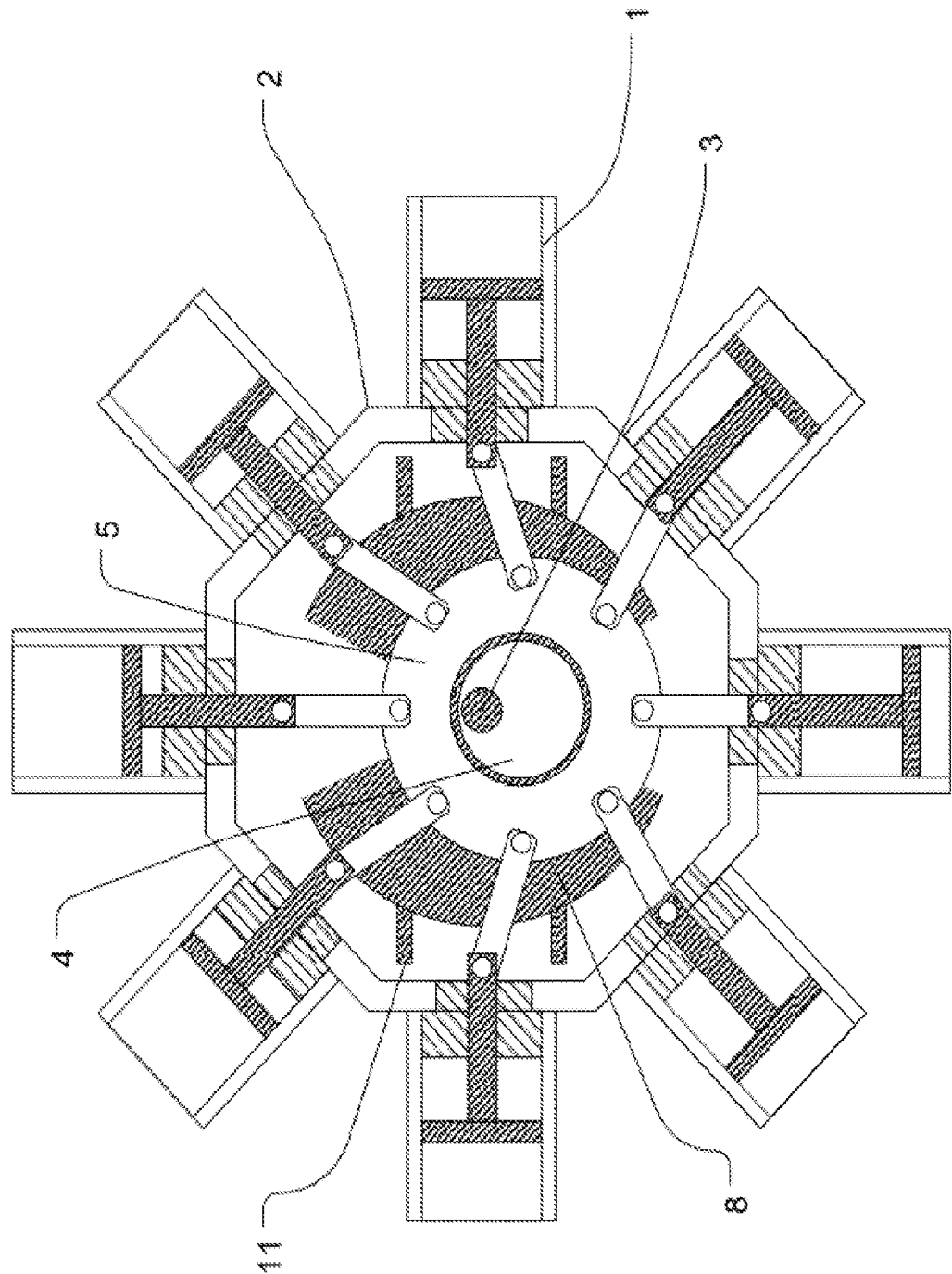


FIGURE 2 (a) -- CENTRAL DRIVE MECHANISM -- POSITION 1



4/20

FIGURE 2 (b) -- CENTRAL DRIVE MECHANISM -- POSITION 2



5/20

FIGURE 2 (c) – CENTRAL DRIVE MECHANISM – POSITION 3

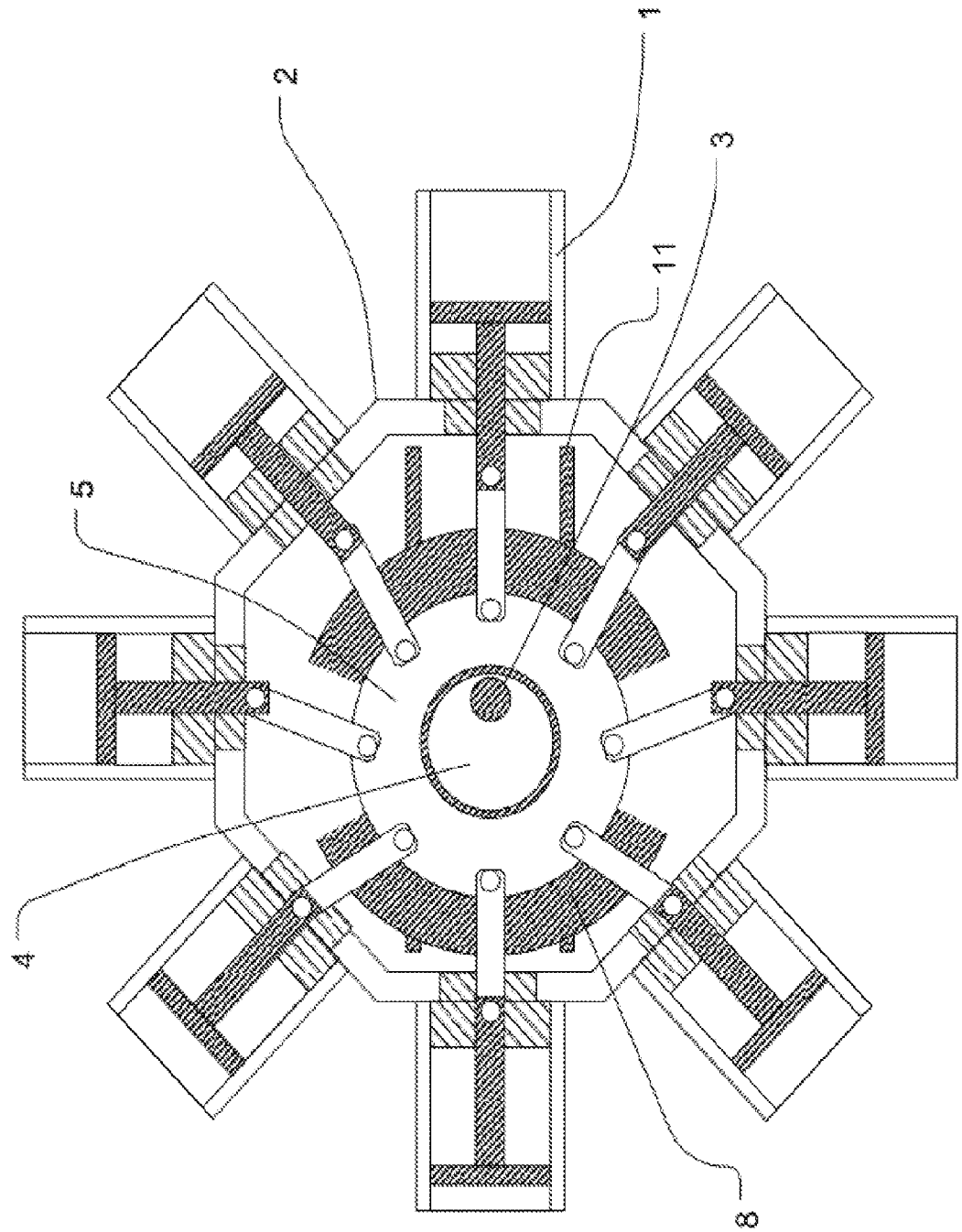


FIGURE 2 (d) – CENTRAL DRIVE MECHANISM – POSITION 4

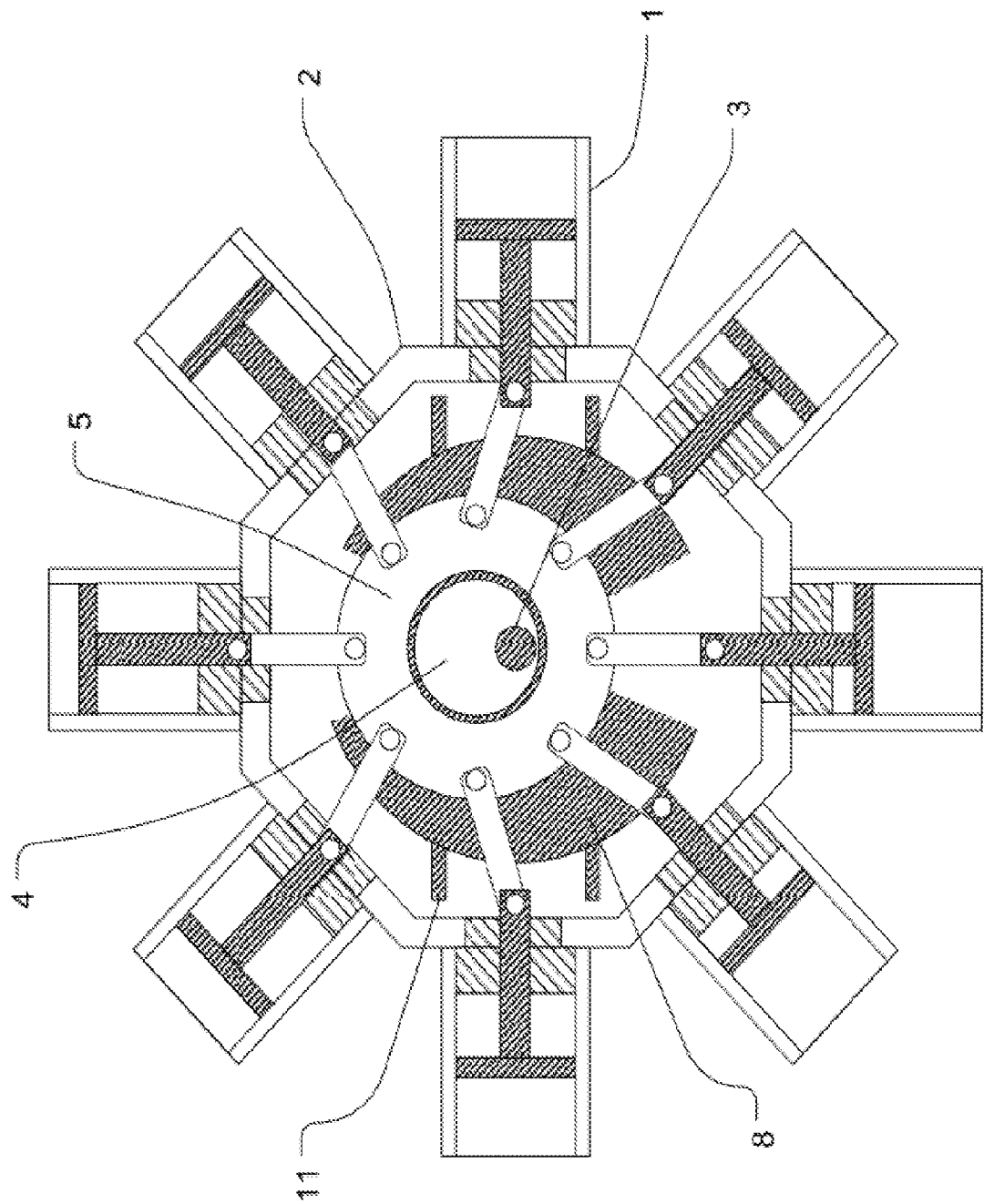


FIGURE 3 - CYLINDER SET SIDE VIEW

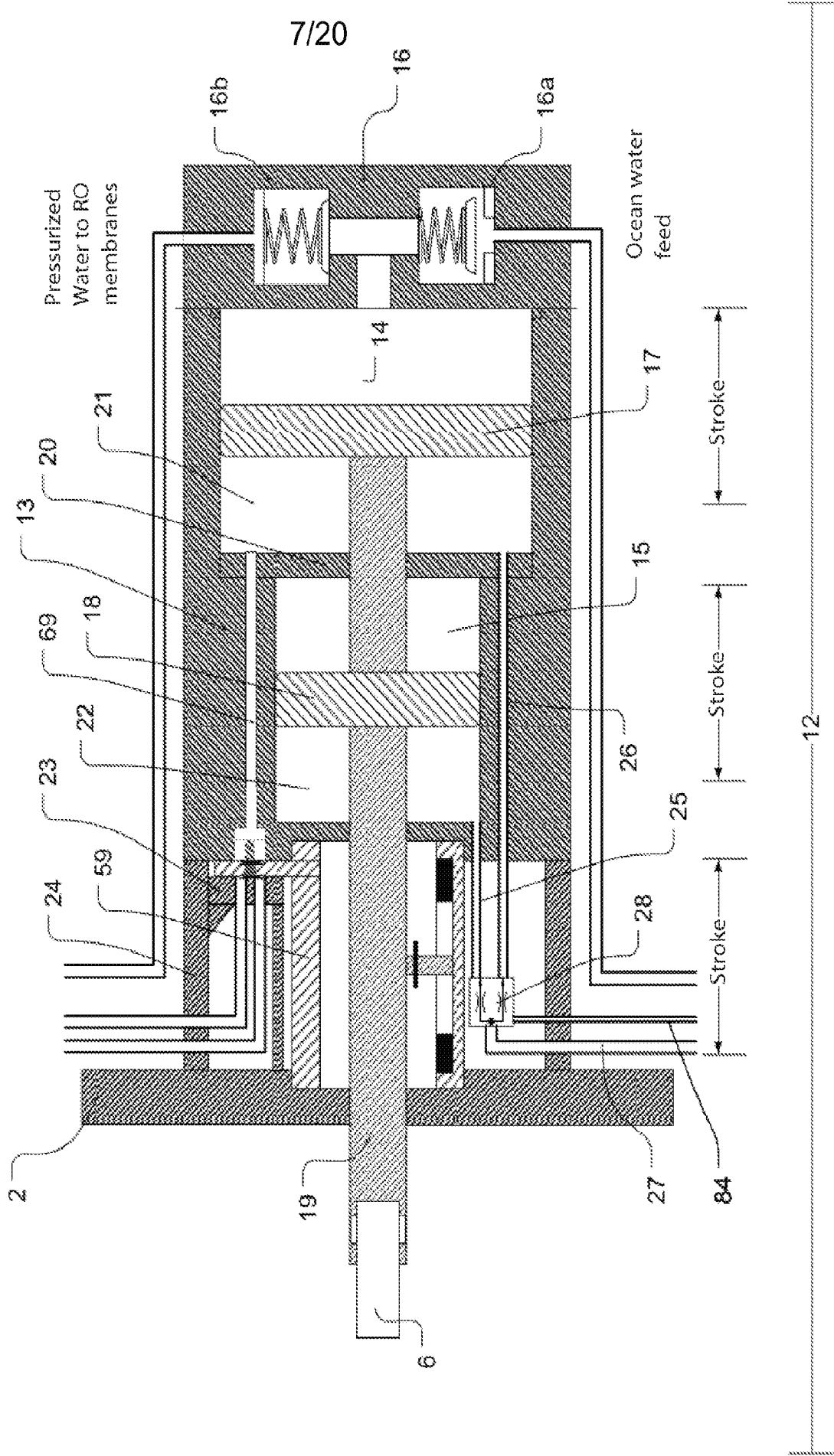


FIGURE 3 (a) - CYLINDER SET SIDE VIEW -- POSITION 1

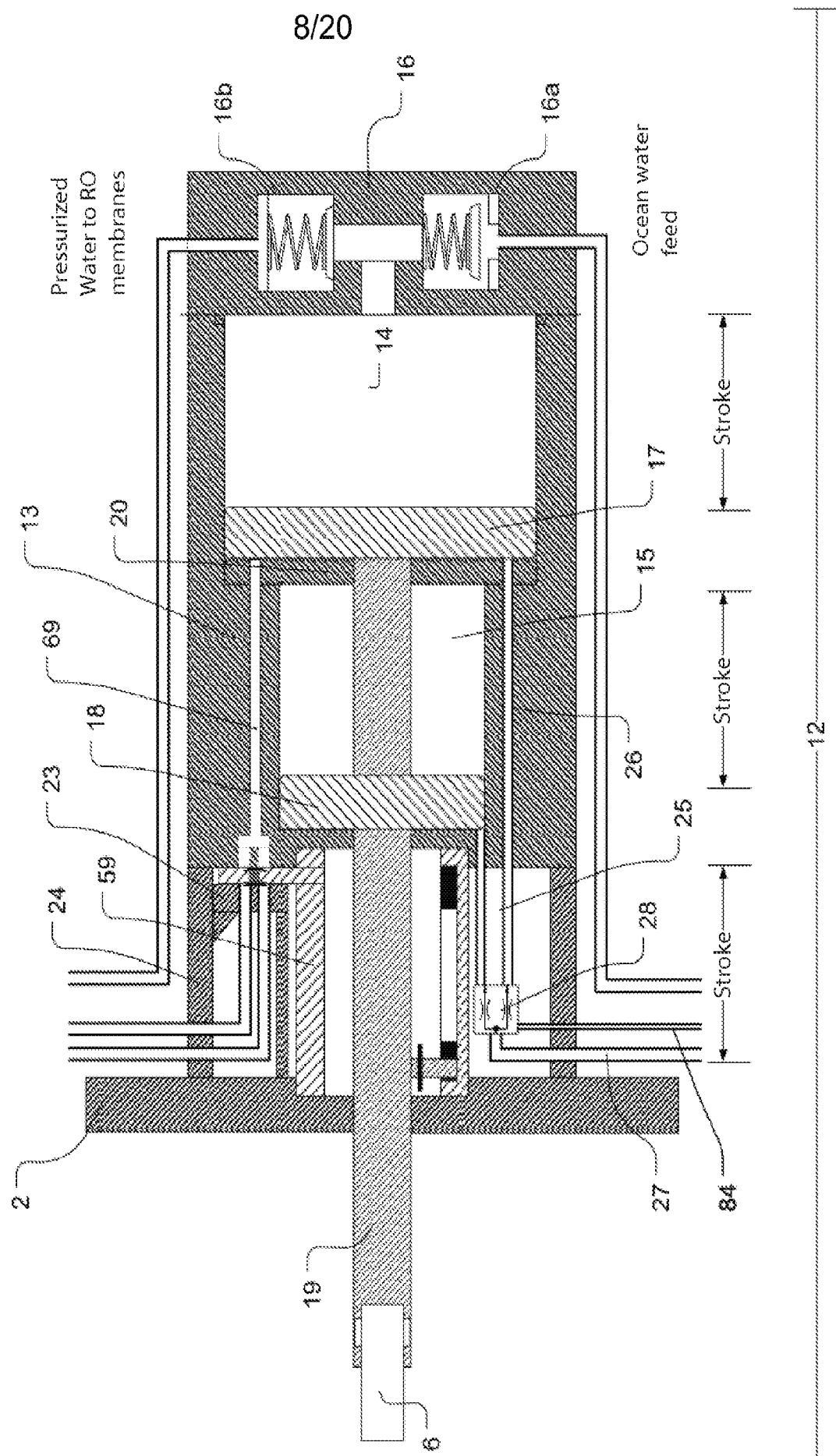
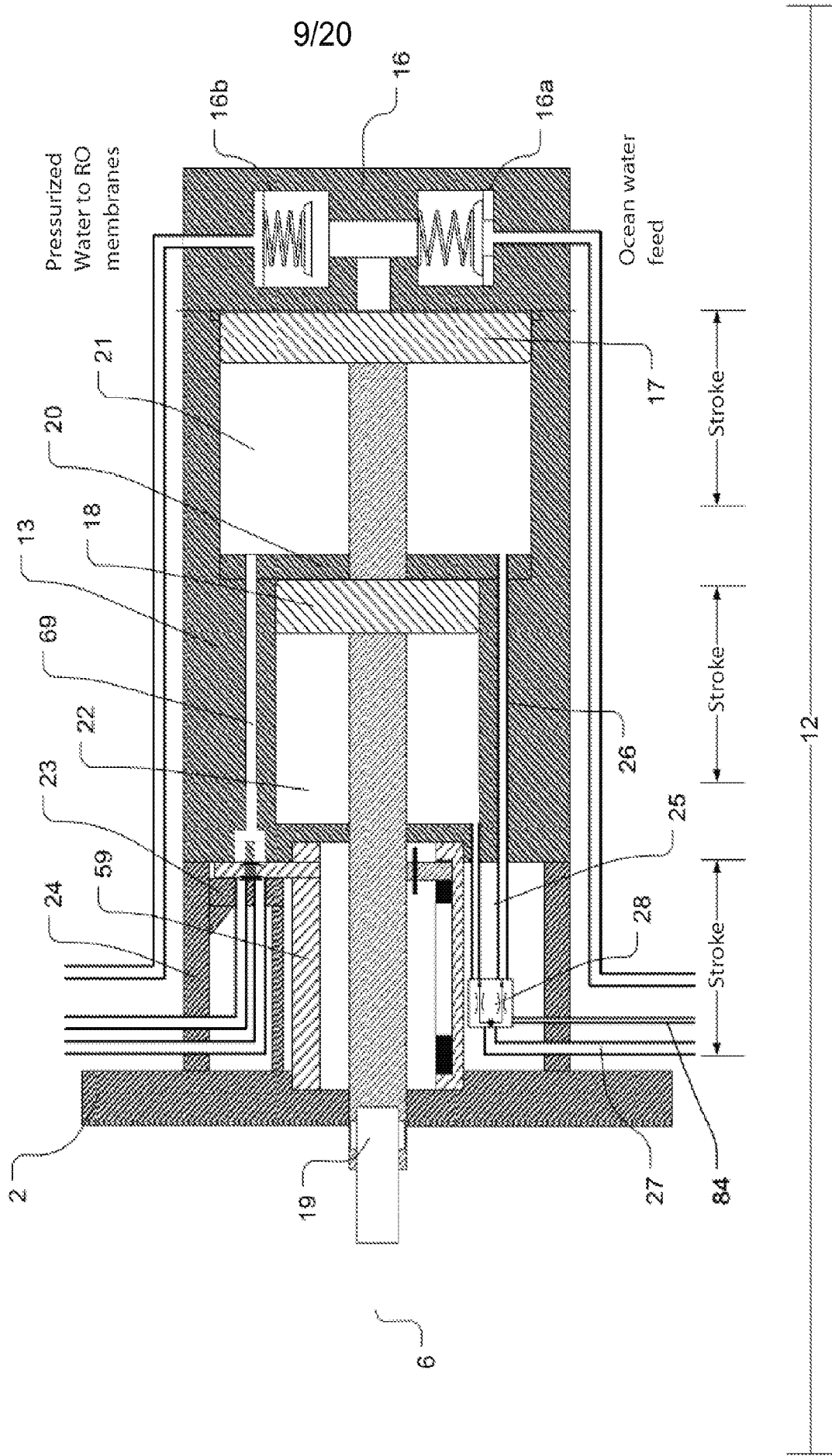
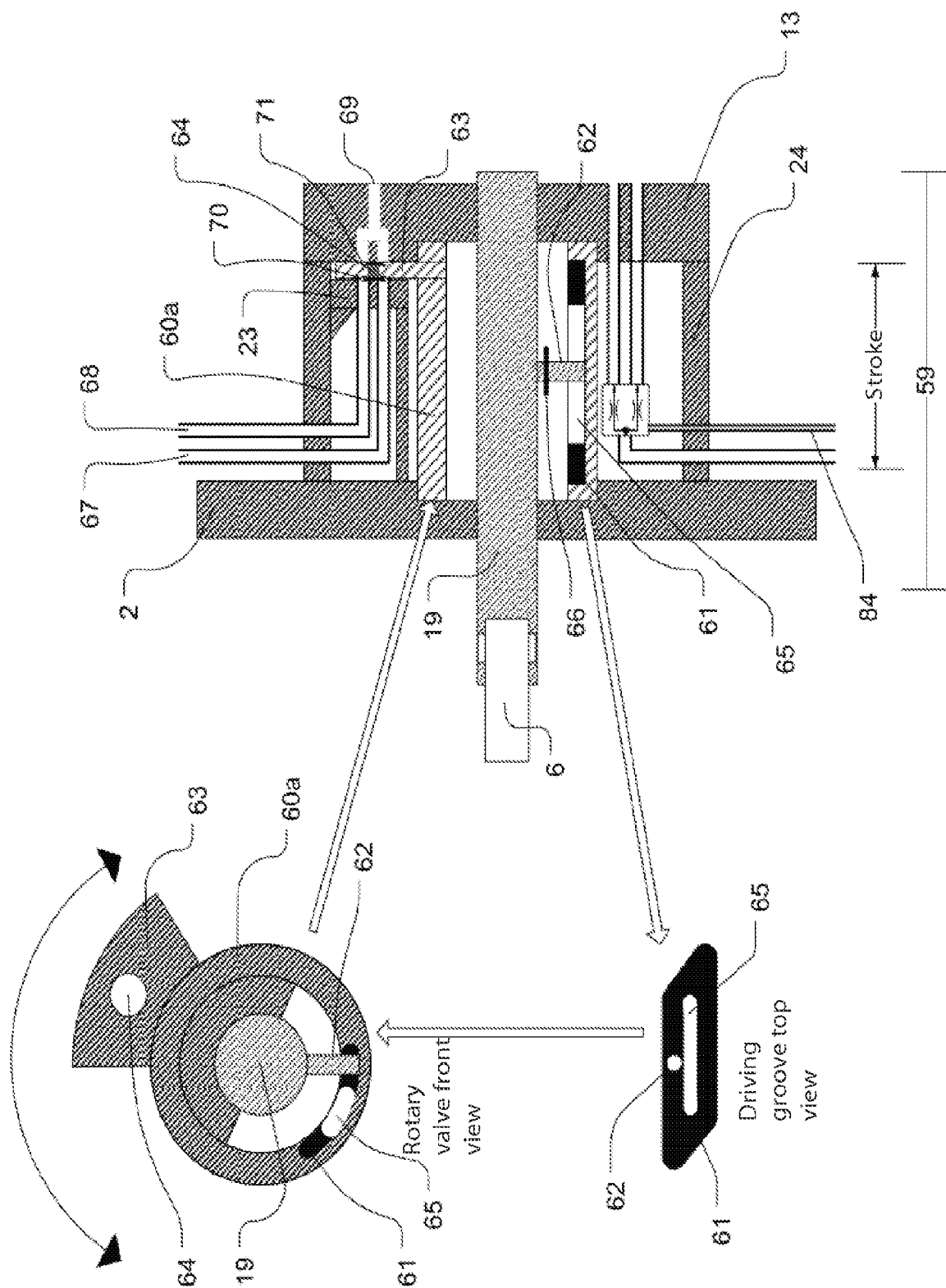


FIGURE 3 (b) - CYLINDER SET SIDE VIEW – POSITION 2



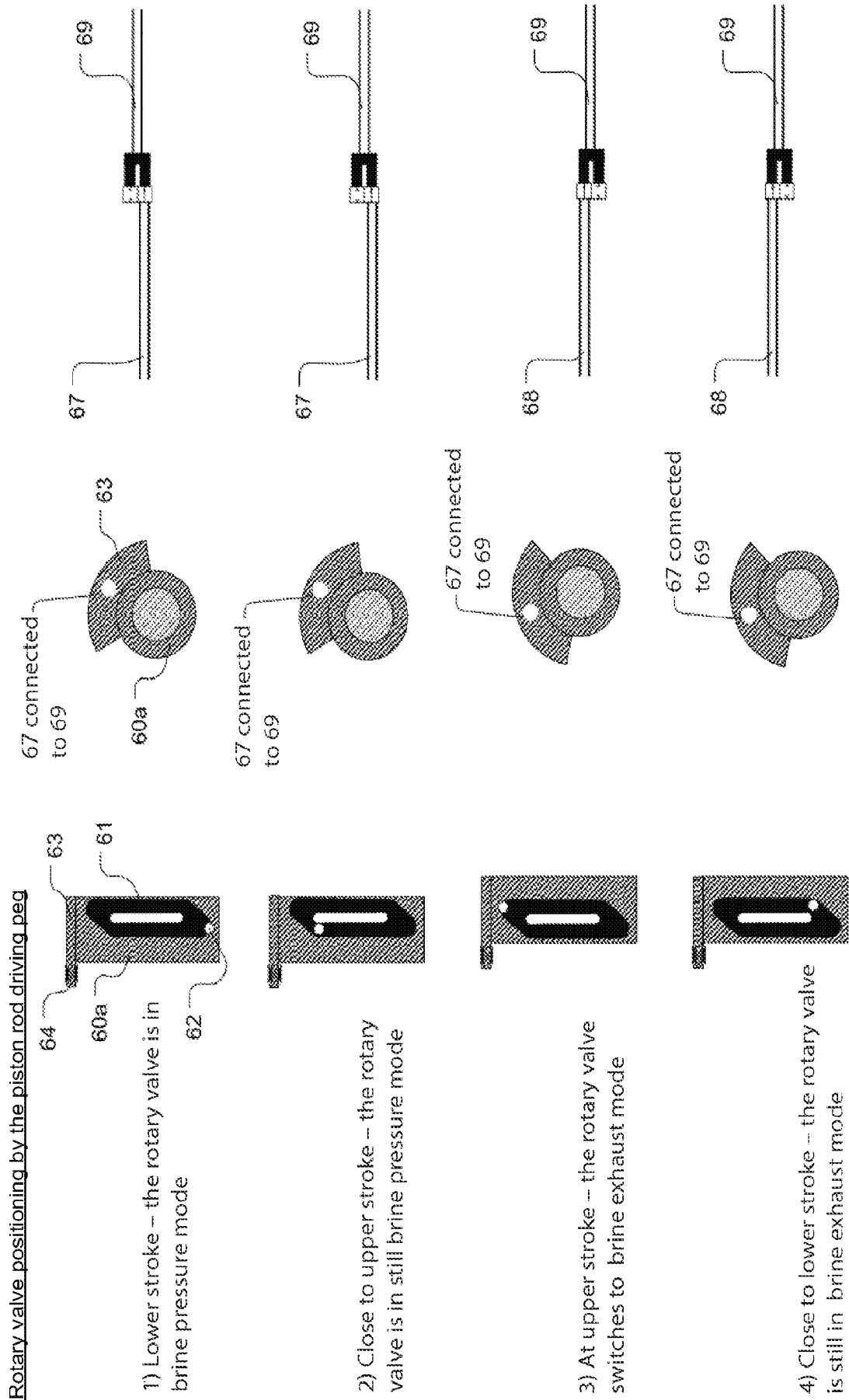
10/20

FIGURE 4 – ROTARY VALVE SIDE VIEW



11/20

FIGURE 5 (a) – ROTARY VALVE POSITIONING



12/20

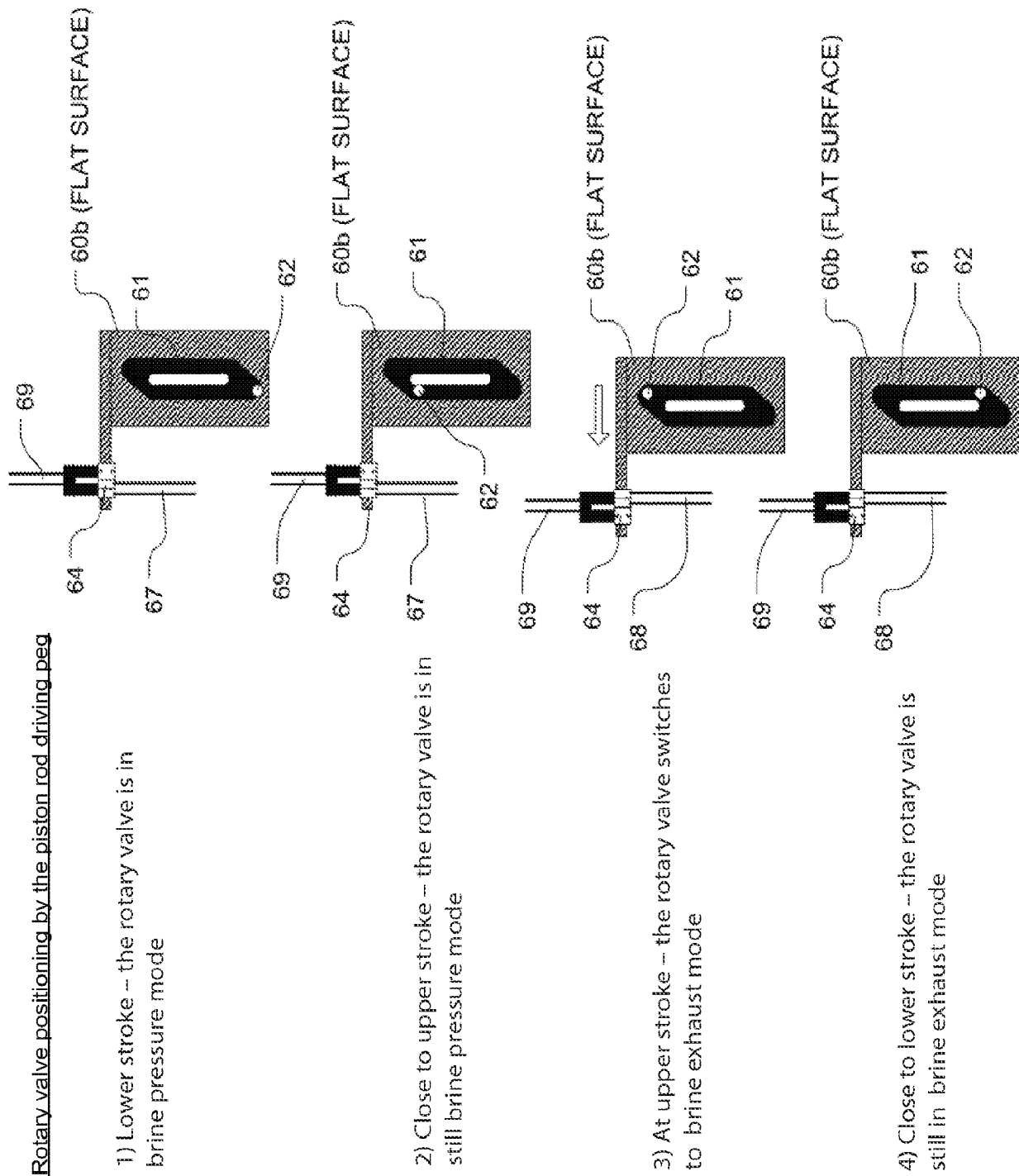
FIGURE 5 (b) – ALTERNATIVE EMBODIMENT OF THE TIMING VALVE

FIGURE 6 – HYDRAULIC CONTROL UNIT AND BRINE RECIRCULATION VALVE

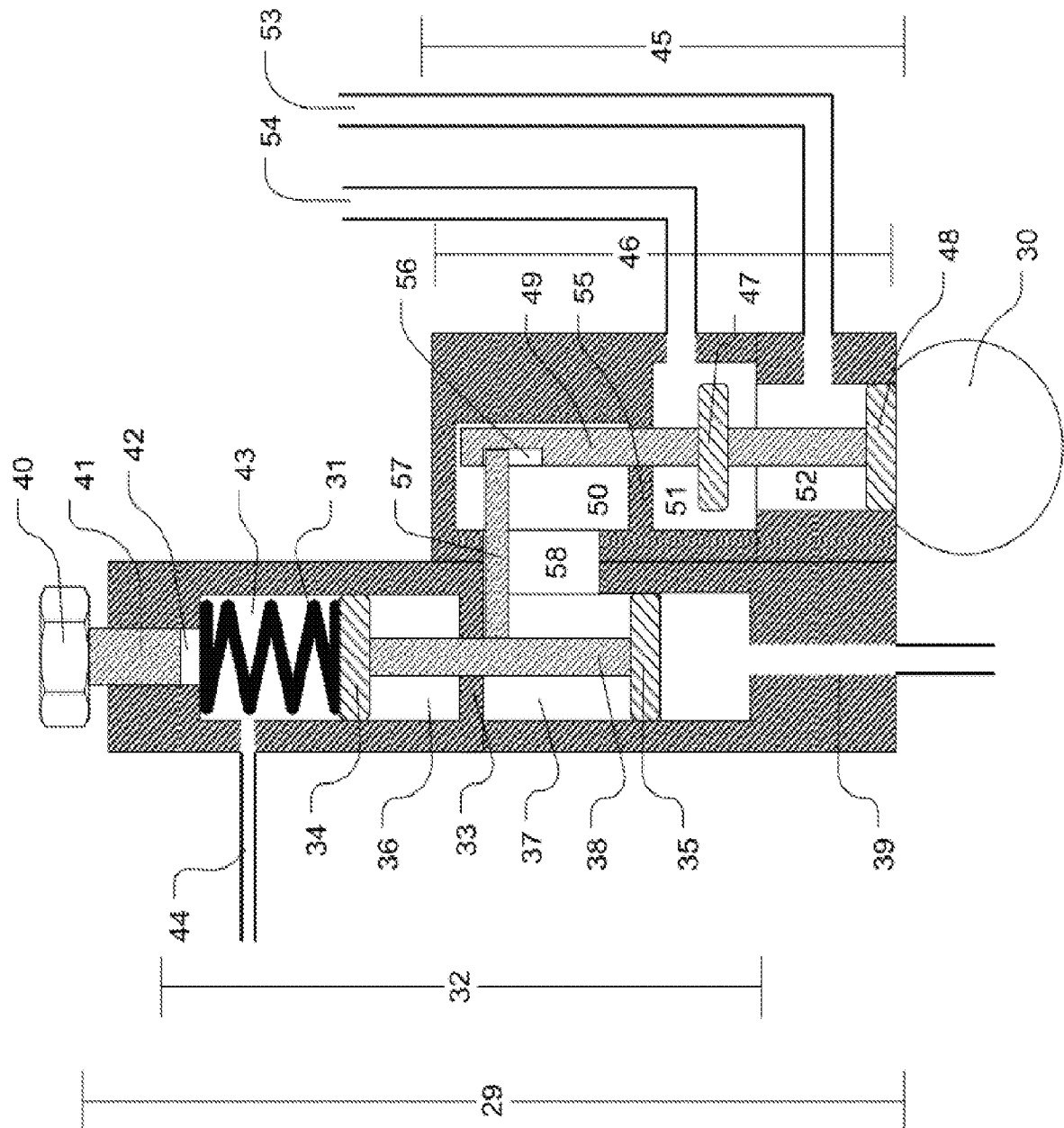


FIGURE 6 (a) – HYDRAULIC CONTROL UNIT AND BRINE RECIRCULATION VALVE – POSITION 1

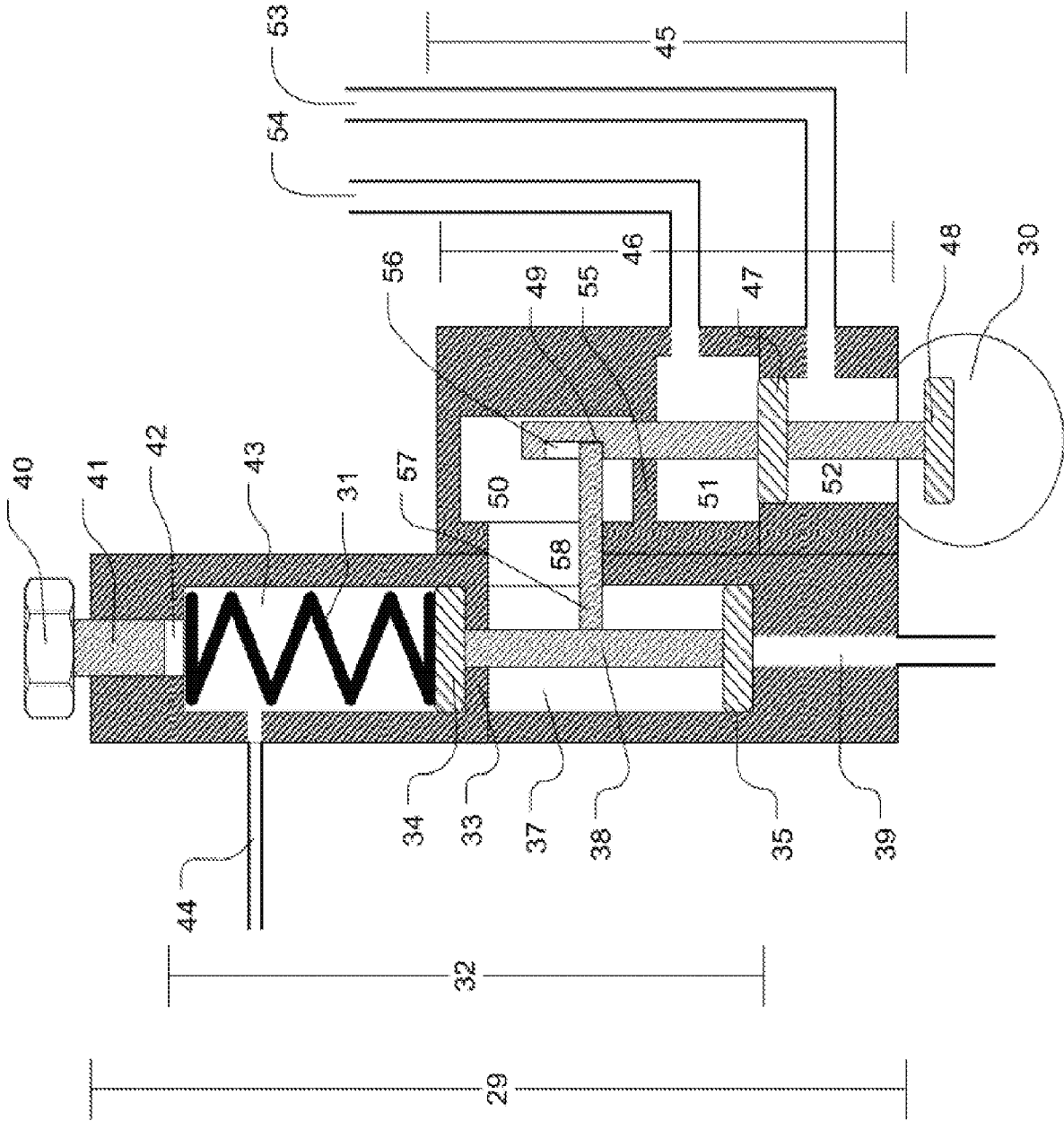


FIGURE 6 (b) -- HYDRAULIC CONTROL UNIT AND BRINE RECIRCULATION VALVE -- POSITION 2

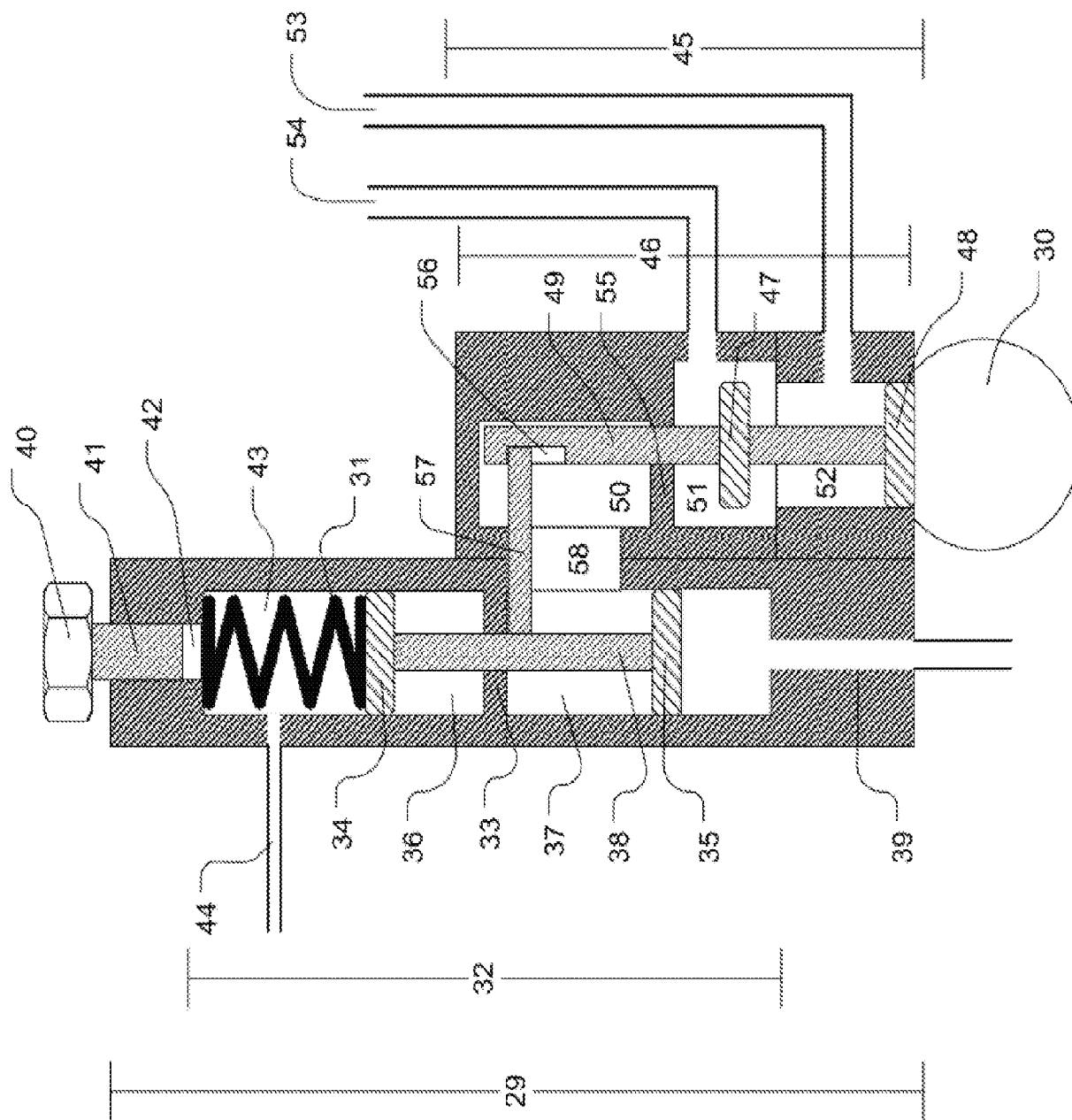


FIGURE 7 – VARIABLE BRINE RECOVERY VALVE

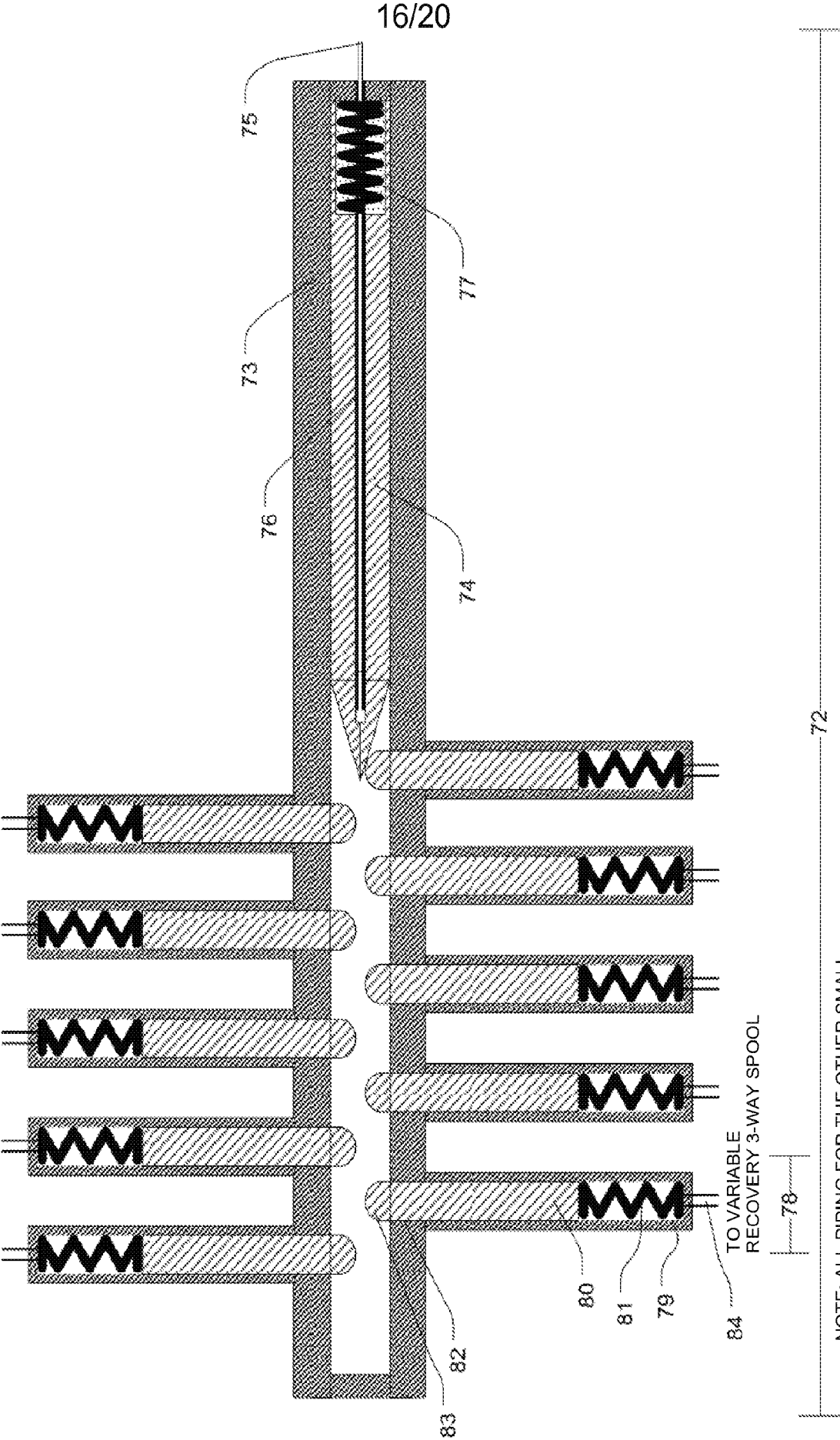


FIGURE 7 (a) – VARIABLE BRINE RECOVERY VALVE – POSITION 1

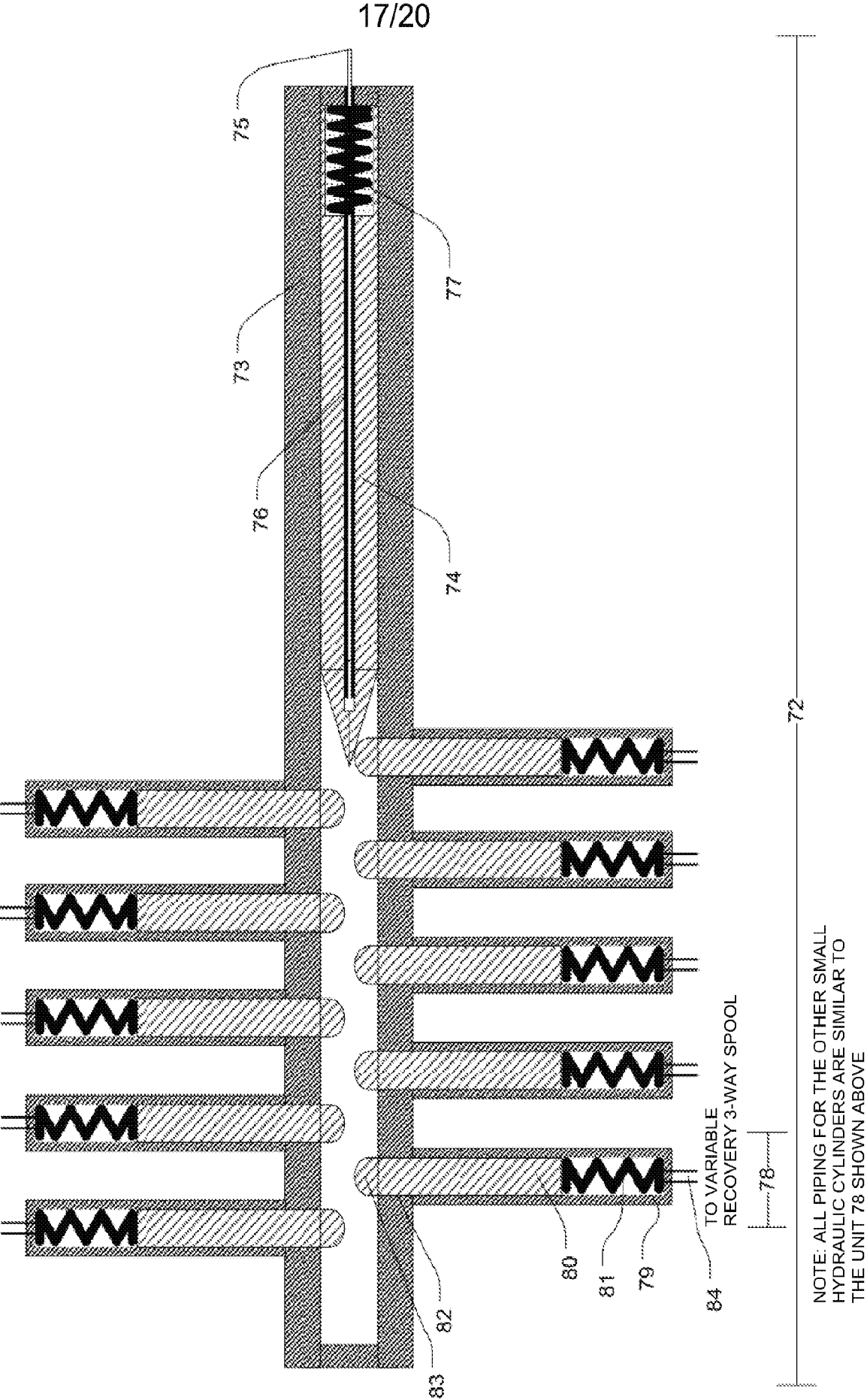
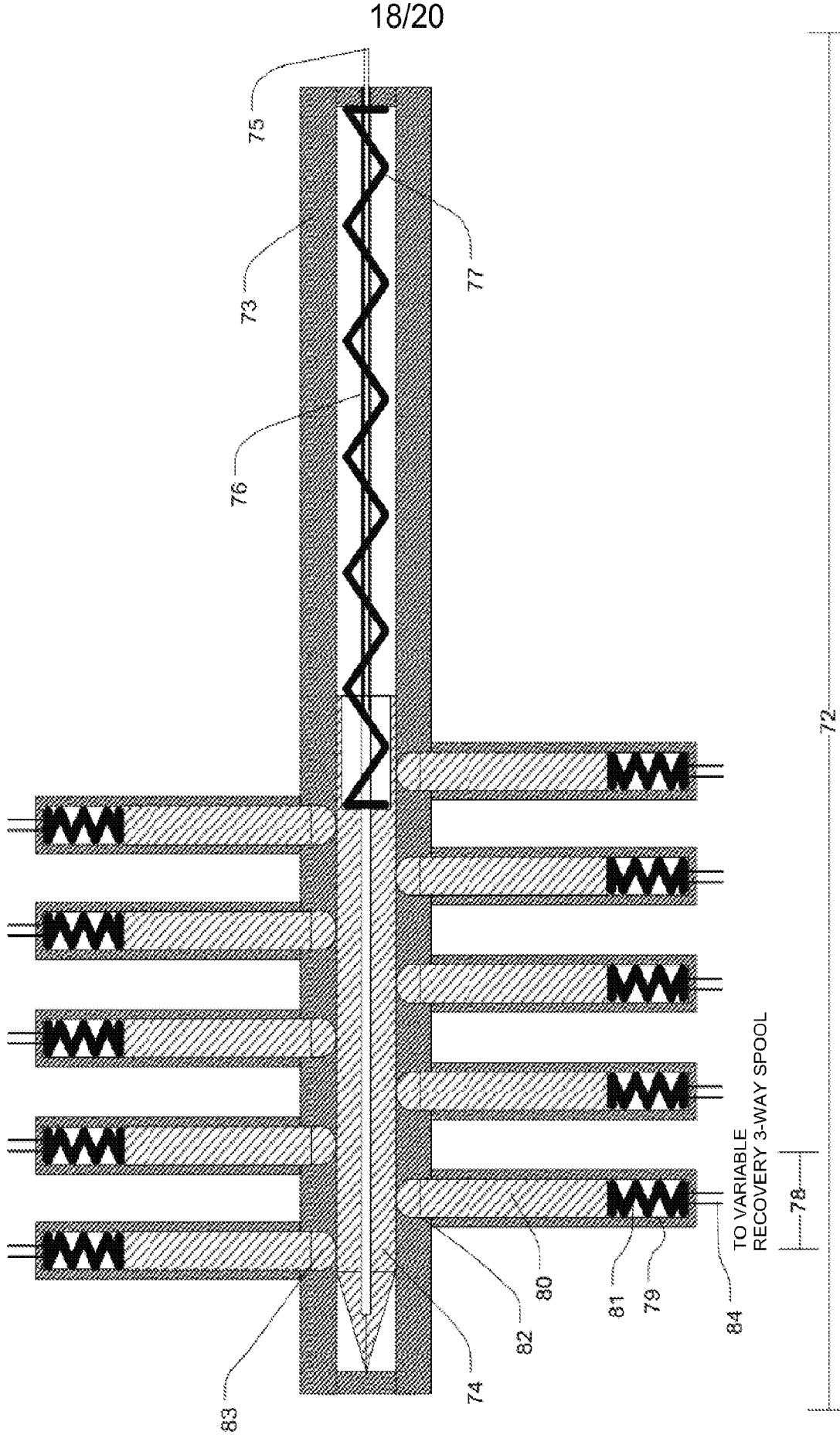


FIGURE 7 (b) – VARIABLE BRINE RECOVERY VALVE – POSITION 2



NOTE: ALL PIPING FOR THE OTHER SMALL HYDRAULIC CYLINDERS ARE SIMILAR TO THE UNIT 78 SHOWN ABOVE

FIGURE 8 (a) -- PROCESS OVERVIEW -- BRINE RECIRCULATION OPENED

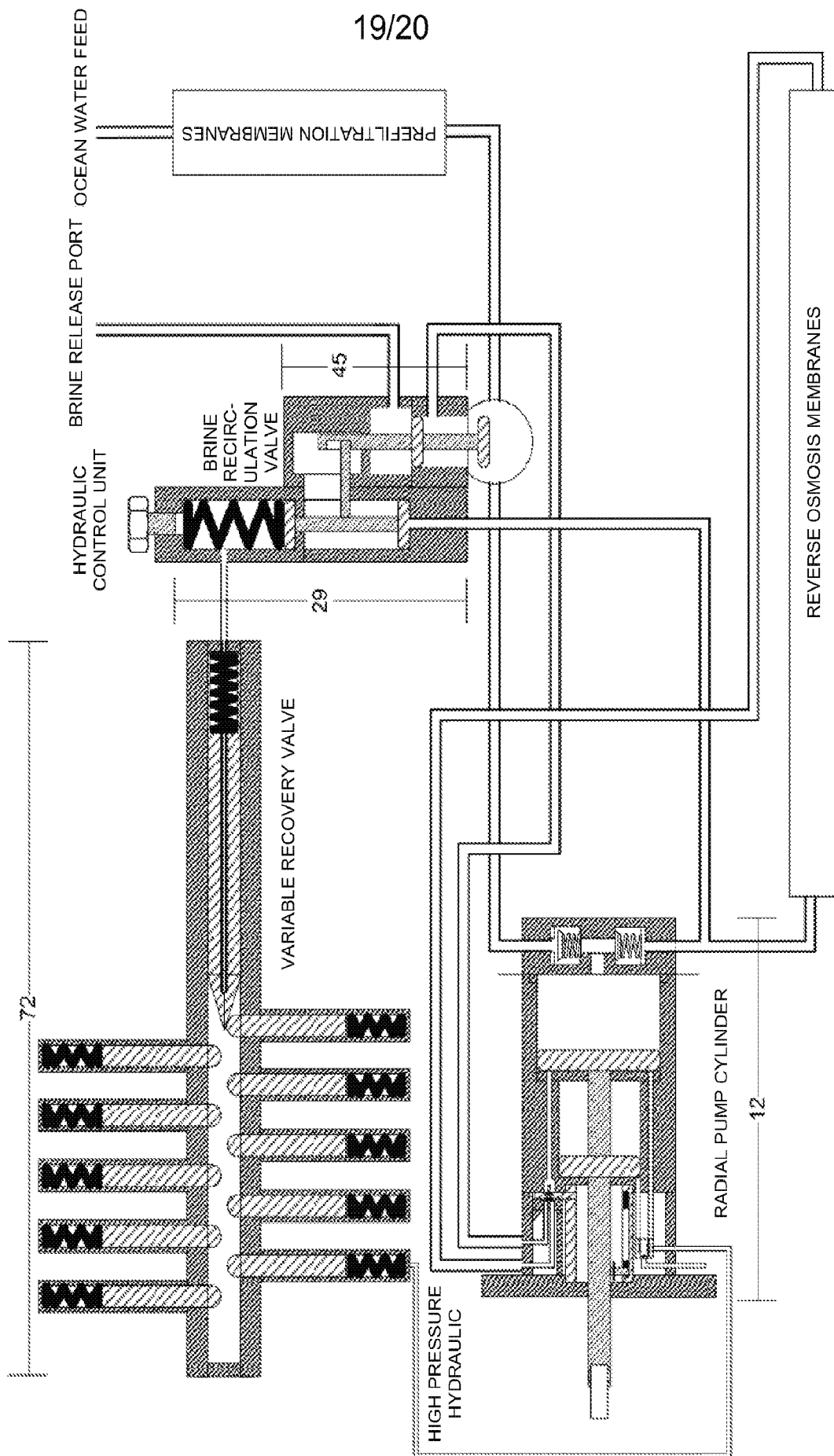


FIGURE 8 (b) – PROCESS OVERVIEW – BRINE RECIRCULATION CLOSED

