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(54) **Title:** PILOT-OPERATED CHECK VALVE FOR HIGH-PRESSURE CONCENTRATED SEAWATER USABLE IN SEA-WATER REVERSE OSMOSIS PUMPING AND ENERGY RECOVERY SYSTEMS

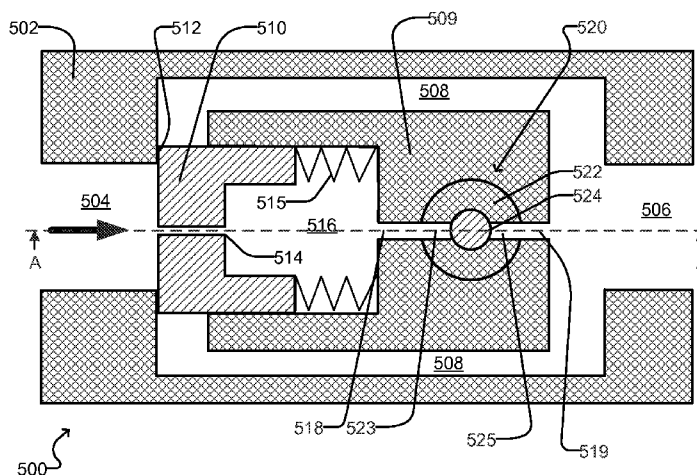


FIG. 4

(57) **Abstract:** A valve comprises a valve body (502) having an inlet (504), an outlet (506) and a main flow path (508) from the inlet (502) to the outlet (506). A valve piston (510) is moveable into and out of engagement with a valve seat (512) to block and unblock the main flow path (508). The valve piston (510) has a front face facing the inlet (502), a back face facing a chamber (516) within the valve body (502), and an orifice (514) providing fluid communication between the front face and the back face of the valve piston (510). When the valve piston (510) is engaged with the valve seat (512) the front face has a smaller area than the back face, such that fluid pressure in the inlet is communicated to the back face to urge the valve piston (510) into engagement with the valve seat (512). A pilot valve (520) is moveable between a closed position and an open position to block and unblock a pilot flow path between the chamber (516) within the valve body (502) and the outlet (506). The pilot flow path has a larger effective cross-sectional area than the orifice, such that when the pilot flow path is unblocked fluid pressure on the back face of the valve piston is reduced.



**PILOT-OPERATED CHECK VALVE FOR HIGH-PRESSURE CONCENTRATED
SEAWATER USABLE IN SEA-WATER REVERSE OSMOSIS PUMPING AND ENERGY
RECOVERY SYSTEMS**

5 FIELD

[0001] This specification relates to pumping systems with energy recovery.

BACKGROUND

[0002] To desalinate seawater by reverse osmosis (RO), the feed water must be pressurized
10 above the osmotic pressure of the feed water. Energy costs, primarily resulting from
electrical consumption by the feed water pumps, are the largest component of the operating
cost of a seawater reverse osmosis (SWRO) plant. However, energy costs can be reduced
by recovering energy from the pressurized brine leaving an RO unit.

[0003] Childs et al. described a piston based pumping and energy recovery system in
15 US Patent Number 6,017,200, entitled Integrated Pumping and/or Energy Recovery System.
This system uses a piston driven by a hydraulic pump to provide pressurized feed water to
an RO membrane module. The front face of the piston drives the feed water to the RO
module. The back face of the piston receives brine from the RO module. The pressure of
the brine acting on the back face of the piston reduces the power required from the hydraulic
20 pump to move the piston.

[0004] In the Childs et al. system, "energy recovery" valves admit brine to the back
face of the piston on a forward stroke. Additional valves allow the brine to leave the piston
on a backward stroke. The energy recovery valves are controlled by a control unit that also
operates the hydraulic pump. The control unit synchronizes the movements of the valves
25 with the movement of the piston. Because the piston reciprocates, it must accelerate and
decelerate and therefore inherently produces an uneven rate of flow and pressure of the feed
water. However, when a set of pistons are used their output may be synchronized to
produce a nearly constant combined output pressure.

[0005] US Patent Application Publication No. US 2013/0082000, entitled Desalination
30 System with Energy Recovery and Related Pumps, Valves and Controller, describes various
improvements to a piston based pumping and energy recovery system. According to one
improvement, the energy recovery valves are designed to begin closing when the velocity of
an associated piston decreases.

SUMMARY

[0006] The following paragraphs are intended to introduce the reader to the detailed description to follow and not to limit or define any claimed invention.

[0007] This specification describes an energy recovery valve for a pump that lets high pressure fluid into and out of the pump. The energy recovery valve has a valve piston with an orifice therethrough to communicate fluid pressure at the inlet to a back face of the valve piston to hold the valve piston against a valve seat. The valve piston is operated by a pilot valve that opens and closes a pilot path between the back face of the valve piston and the outlet. The pilot valve may be operated by compressed air or another suitable pilot fluid. As described below, some embodiments of the present disclosure advantageously allow any air behind the valve piston to leave the valve by providing a flow path through to the outlet. Further, some embodiments of the present disclosure provide a contained leak path within the pilot valve such that any leakage of working fluid or pilot fluid is transmitted to a head of the pilot valve to facilitate external detection.

[0008] Some embodiments of the present disclosure provide a valve comprising a valve body having an inlet chamber and an outlet chamber, a central block between the inlet chamber and the outlet chamber, and a main flow path from the inlet chamber to the outlet chamber. A valve piston is moveable into and out of engagement with a valve seat to block and unblock the main flow path. The valve piston has a front face facing the inlet chamber, a back face facing a chamber within the central block of the valve body, and an orifice providing fluid communication between the front face and the back face of the valve piston. When the valve piston is engaged with the valve seat the front face has a smaller area than the back face, such that fluid pressure in the inlet chamber is communicated to the back face to urge the valve piston into engagement with the valve seat. A pilot valve is moveable between a closed position and an open position to block and unblock a pilot flow path between the chamber within the central block and the outlet. The pilot flow path has a larger effective cross-sectional area than the orifice, such that when the pilot flow path is unblocked fluid pressure on the back face of the valve piston is reduced.

[0009] Some embodiments of the present disclosure provide ...

[0010] Some embodiments of the present disclosure provide a process for operating a valve comprising a valve body having an inlet chamber and an outlet chamber, a central

block between the inlet chamber and the outlet chamber, with a main flow path from the inlet chamber to the outlet chamber, and a valve piston moveable into and out of engagement with a valve seat to block and unblock the main flow path. The valve piston has a front face facing the inlet chamber, a back face facing a chamber within the central block of the valve body wherein when the valve piston is engaged with the valve seat the front face has a smaller area than the back face. The process comprises providing an orifice between the front face and the back face of the valve piston to communicate fluid pressure in the inlet chamber to the back face, opening a pilot flow path between the chamber within the central block and the outlet, the pilot flow path having a larger effective cross-sectional area than the orifice, to reduce fluid pressure on the back face of the valve piston and allow the fluid pressure in the inlet chamber to move the valve piston out of engagement with the valve seat, and, closing the pilot flow path to allow the fluid pressure in the inlet chamber to move the valve piston into engagement with the valve seat.

[0011] Other aspects and features of the present disclosure will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments in conjunction with the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Figure 1 is a schematic drawing of a fluid pumping and energy recovery system in combination with a reverse osmosis system.

[0013] Figure 1A is a schematic drawing of a fluid pumping and energy recovery system in combination with a reverse osmosis system similar to that of Figure 1 except that there are four energy recovery valves associated with each cylinder in Figure 1A.

[0014] Figure 2 is a cross-sectional, schematic view of an example water cylinder used in the system of Figure 1.

[0015] Figure 3 is a cross-sectional, schematic view of an example water cylinder used in the system of Figure 1 with energy recovery valves connected to be operated by compressed air.

[0016] Figure 4 is a cross-sectional, schematic view of an example energy recovery valve, alternatively called a brine valve, in a closed position.

[0017] Figure 4A is a sectional view along line A-A of Figure 4.

[0018] Figure 5 shows the valve of Figure 4 in an open position.

[0019] Figure 5A is a sectional view along line A-A of Figure 5.

[0020] Figure 6 is a cross-sectional, schematic view of another example energy recovery valve in a closed position.

[0021] Figure 6A is a sectional view along line A-A of Figure 6.

[0022] Figure 7 is a sectional view similar to Figure 6A showing the valve of Figure 6 in an open position.

[0023] Figure 8 is a cross-sectional, schematic view of another example energy recovery valve in a closed position.

DETAILED DESCRIPTION

[0024] Generally, the present disclosure provides energy recovery valves for the cylinders of pumps used to supply high pressure feed water to a reverse osmosis (RO) unit. The RO unit receives high pressure feed water, and outputs product water at a relatively low pressure, as well as concentrate (which may also be referred to as “retentate” or “brine”) at a relatively high pressure. The concentrate leaving the RO unit typically has a pressure slightly lower than the feed water provided to the RO unit, but still has a significant amount of energy. The energy of the concentrate may be used to assist in driving the pumps, as described in US Patent No. 6,017,200 and US Patent Application Publication No. US 2013/0082000, which are hereby incorporated by reference herein.

[0025] This specification provides energy recovery valves that make use of the high pressure working fluid to provide the force for opening and closing the main flow path. Certain embodiments provide energy recovery valves having a relatively long working life and low cost in comparison to certain prior art high pressure valves. Some embodiments may also provide other desired features for sea water desalination, including corrosion resistance, pressure control during opening, low pressure drop, and fast valve opening. The energy recovery valves have pilot valves that may be operated using compressed air.

[0026] As depicted in Figure 1, a system 10 includes a source of feed water 110, three hydraulic pumps 12, a water cylinder 200 for each hydraulic pump 12, an RO membrane unit 216, and a control unit 100. The system 10 is similar to the systems described in US Patent Number 6,017,200 and US Patent Application Publication No. US 2013/0082000, but will also be described below. The hydraulic pumps 12 are driven by a motor, not shown. Optionally, the three hydraulic pumps 12 may be replaced with a single hydraulic pump and a system of pipes and valves suitable for producing an output associated with each water cylinder 200. The system 10 has three double acting water cylinders 200, which in effect

provide six water cylinders, but other numbers and arrangements of water cylinders, and means of powering them, may also be used.

[0027] Under instruction from the control unit 100, each hydraulic pump 12 controls the movement of a piston rod 14. The piston rod 14 is mechanically coupled to two opposed
5 pistons 224, 226 (not shown in Figure 1) that are housed within a water cylinder 200. As will be further described below, the hydraulic output of each hydraulic pump 12 causes a piston rod 14 to move. Due to the mechanical coupling, the movement of the piston rod 14 causes the two pistons 224, 226 to move in unison with the movement of the piston rod 14. The piston rod 14 and the pistons 224, 226 may be referred to collectively as a reciprocating
10 assembly 300. For brevity, this specification may at times describe the features of a single hydraulic pump 12, reciprocating assembly 300, water cylinder or other repeated elements of the system 10, but the description similarly applies to the other similar elements.

[0028] The source of feed water 110, which may provide sea water, brackish water, produced water or any other feed water requiring separation, is connected to the water
15 cylinder 200 by low pressure feed water lines 254, 256. The system 10 also includes high pressure feed water lines 262, 264 to direct a high pressure feed water from the water cylinder 200 to the RO membrane unit 216.

[0029] The RO membrane unit 216 produces a flow of permeate (alternatively called filtrate), for example desalted potable water, which is directed through a permeate line 217 for the
20 desired uses of the permeate. The RO membrane unit 216 also produces a flow of high pressure brine, alternatively called concentrate or retentate. The high pressure brine is directed from the RO membrane unit 216 by high pressure brine lines 218, 219 back to the water cylinder 200.

[0030] The water cylinders 200 also include a low pressure brine outlet that is connected to
25 low pressure brine lines, also referred to a discharge lines 250, 252. The low pressure brine may be directed to a waste or recycle stream.

[0031] From a simplified perspective, there are four pressures within this system. The first pressure P1 is the pressure that supplies the feed water from the source 110, through low pressure feed water lines 254, 256, to the water cylinder 200. P1 can be provided by gravity
30 or one of a variety of known pumps. The second pressure P2, which is substantially higher than P1, is the pressure exerted on the feed water from the water cylinder 200 and carried through high pressure feed water lines 262, 264, to the RO membrane unit 216. As described below, P2 is provided by the pistons 224, 226 of the water cylinder 200. The third

pressure P3 is the pressure of the brine as it leaves the RO membrane unit 216 to return to the water cylinder 200 via high pressure brine lines 218, 219. P3 is less than P2 because energy is required to filter the feed water and permeate leaves the system 10. The fourth pressure P4 is the pressure of the brine as it leaves the water cylinder 200 via low pressure
5 brine lines 250, 252. P4 is less than P3.

[0032] For example, P1 may be in the range of about 5 to 100 psig; P2 may be in the range of about 600 to 1000 psig; P3 may be in the range of 500 to 950 psig; and P4 may be in the range of about 1 to 50 psig. The pressures may fluctuate to some extent over time, and the system 10 may include one or more accumulators, pressure release valves or other
10 components of hydraulic systems effective to compensate for recurring or emergency flow or pressure variations.

[0033] Under the control of the control unit 100, the hydraulic pump 12 imparts a desired velocity or displacement profile upon the piston rod 14. The hydraulic pump 12 is driven by a motor and translates the rotational energy of the motor into a flow of hydraulic fluid.
15 Therefore, the hydraulic pump 12, on command from the control unit 100, produces a hydraulic output that can range from a maximal hydraulic output to zero hydraulic output to maximal hydraulic output in the opposite direction. The hydraulic output of pump 12 is translated into the reciprocating displacement of the piston rod 14.

[0034] The piston rod 14 is connected to a hydraulic piston 20 within a hydraulic cylinder 18. Attached at one end of hydraulic cylinder is line 26 and attached at the other end of hydraulic cylinder 18 is line 28. The lines 26 and 28 direct the hydraulic output of the pump 12 to either side of the hydraulic piston 20. Optionally, the piston rod 14 may be connected to one face of the hydraulic piston 20 and another rod (not shown) may be connected to the opposite face of the hydraulic piston 20.
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[0035] Details of example hydraulic pumps are described in US Patent Application Publication No. US 2013/0082000, as well as US Provisional Patent Application No. 61/985,144, filed April 28, 2014 and entitled Energy Recovery Pump with Pressure Balancing Hole and Pressure Transitioning Step, which are hereby incorporated by reference herein.
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[0036] As shown in Figure 2, the water cylinder 200 is generally tubular in shape with two end plates 204, 206 and a lateral wall 208 that extends between the end plates. The water cylinder 200 also includes intermediate plates 203 and 205, which divide the internal bore of the water cylinder 200 into two piston chambers 220 and 222. Within each piston chamber 220 and 222 there is a reciprocating, dual-action piston 224 and 226, each of which defines a
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feed water working chamber 228, 234 and a concentrate working chamber 230, 232. The dual-action pistons 224, 226 are mechanically coupled by a connection rod 278 which extends through an aperture in both of the intermediate plates 203, 205. The connection rod 278 also extends out of the water cylinder, through a bearing and seal assembly 209 within
5 the end plate 206 so that no pressure or fluid leaks across the end plate 206 from the feed water working chamber 234.

[0037] The feed water working chamber 228 is defined by the inner surface of end plate 204, the inner surface of lateral wall 208 and the front face 236, also called the feed water face, of the piston 224. The feed water working chamber 234 is defined by the inner surface of end
10 plate 206, the inner surface of lateral wall 208 and the front face 237, also called the feed water face, of the piston 226. The feed water chambers 228, 234 each have a feed water access port 212, 213 to provide fluid communication across the lateral wall 208 of the feed water working chambers 228, 234, for example to allow the inlet and outlet of feed water.

[0038] The concentrate working chamber 230 is defined by the inner surface of the intermediate plate 203, the inner surface of the lateral wall 208 and the back face 238, also called the concentrate face, of piston 224. The concentrate working chamber 232 is defined by the inner surface of the intermediate plate 205, the inner surface of the lateral wall 208 and the back face 240, also called the concentrate face, of piston 226. The feed water face 236, 237 is positioned opposite to the back face 238, 240 of the pistons. The concentrate
15 working chambers 230, 232 each have a concentrate access port 242, 244 to provide fluid communication across the lateral wall 208 of the concentrate working chambers 230, 232, for example to allow the inlet and outlet of concentrate. In some embodiments, each of the concentrate working chambers 230, 232 has two access ports (not shown in Figure 2), one access port for allowing the concentrate to enter the chamber and the other for allowing the
20 concentrate to leave the chamber.

[0039] The dual-action pistons 224, 226 include one or more seals 280 between the perimeter of the dual-action pistons 224, 226 and the lateral wall 208 to prevent the movement of fluid between the feed water working chambers 228, 234 and the concentrate working chambers 230, 232 so that there is no fluidic communication across the dual-action
25 pistons 224, 226. The one or more seals 280 are sufficiently resilient to withstand the differential pressure across the pistons 224, 226 caused by different hydrostatic pressures within the feed water working chambers 228, 234 and the respective concentrate working chambers 230, 232.

[0040] As described above, the dual-action pistons 224 and 226 are mechanically coupled by a connection rod 278. The connection rod 278 is also mechanically coupled to the piston rod 14 so that both dual-action pistons 224 and 226 move in unison with the piston rod 14. As described above, the piston rod 14, the connection rod 278 and the dual-action pistons 224 and 226 are collectively referred to as the reciprocating assembly 300.

[0041] As described herein below, the movement of the reciprocating assembly 300, including the actual stroke distance of the dual-action pistons 224, 226 within the water cylinder 200 can change. Therefore, the volume of the feed water working chambers 228, 234 and the volume of the concentrate working chambers 230, 232 can also be defined by the cross-sectional area of the dual-action pistons 224, 226 multiplied by the differential position of the dual-action pistons 224, 226 at the beginning and the end of a stroke of the reciprocating assembly 300.

[0042] In the water cylinder 200 shown, the ports 212, 213, 242 and 244 are each respectively connected to valve bodies 258, 260, 400 and 401 that are in turn each connected to a low pressure and a high pressure valve. Optionally, the water cylinder 200 may have twice as many ports, with each port connected to a single low pressure or high pressure valve. For example, Figure 1A shows a system wherein valve bodies 400 and 401 are each replaced with a high pressure valve body 400A, 401A and a low pressure valve body 400B, 401B, each having their own concentrate access port. Alternatively, depending on the arrangement and orientation of water cylinders in a water treatment system, more than two energy recovery valves could be contained in a single housing. For example, in some embodiments four energy recovery valves for a single water cylinder could be contained in the same housing. In other embodiments twelve energy recovery valves for three water cylinders could be contained in the same housing.

[0043] Referring back to Figure 1, the RO membrane unit 216 includes a set of RO modules each having one or more selectively permeable membranes. The feed water, at pressure P2, enters the RO unit 216 and permeate crosses the selectively permeable membranes to enter into a permeate line 217. Effectively, the RO unit 216 removes a volume of permeate from every input volume of feed water. This causes a decrease in the flow of water that enters the high pressure brine lines 218, 219 and ultimately enters the concentrate working chambers 230 and 232. This difference is referred to as the recovery ratio.

[0044] To compensate for the recovery ratio, a ratio sleeve 282 is placed around the connection rod 278, between the back faces 238, 240 of the dual-action pistons 224, 226.

The ratio sleeve 282, also referred to as a ratio rod, is of greater diameter than the connection rod 278 and this decreases the working volume of the concentrate working chamber 230, 232, in comparison to the volume of the feed water working chambers 228, 234. For example, if the recovery ratio of the RO membrane unit 216 is 30%, then the diameter of the ratio sleeve 282 is such that the volume of concentrate pumped out of the concentrate working chamber 230, 232 is 30% smaller than the volume of feed water pumped out of the feed water working chambers 228, 232.

[0045] As shown in Figure 2, the ratio sleeve 282 is part of the reciprocating assembly 300 and the ratio sleeve 282 moves through both the intermediate plates 203, 205. To prevent the communication of fluid or pressure between the concentrate working chambers 230, 232, a ratio sleeve seal assembly 284 is positioned on the inner surface of the lateral wall 208 at the apertures to provide one or more seals 286 against the outer surface of the ratio sleeve 282.

[0046] Each piston 224, 226 also has a hole 225 extending between its faces: between feed water face 237 and back face 240 for piston 226 and between feed water face 236 and back face 238 for piston 224. These holes 225 allow water to move through the pistons 224, 226, in particular when all valves associated with concentrate access ports 242, 244 are closed. Because of the differential area of the pistons 224, 226 (or because the ratio sleeve 282 is present and larger than connection rod 278), moving the reciprocating assembly 300 to the right in Figure 2 causes a decrease in the total volume of right side feed water working chamber 228 and concentrate working chamber 230. The hole 225 allows some liquid to flow from feed water working chamber 228 to concentrate working chamber 230. However, the decrease in total volume causes the pressure in both the feed water working chamber 228 and the concentrate working chamber 230 to rise. Conversely, the pressures in the left side feed water working chamber 234 and concentrate working chamber 232 decreases. When the reciprocating assembly 300 moves to the left, the pressure in left side chambers 232, 234 increases while the pressure in right side chambers 228, 230 decreases.

[0047] Optionally, the holes 225 could be replaced by another type of opening that provides a fluid passageway between feed water face 237 and back face 240 for piston 226 or between feed water face 236 and back face 238 for piston 224. For example, the holes 225 could be replaced by a notch in the side of a piston 226, 224. A hole 225 or other opening can pass through either the main body of a piston 226, 224 or through a seal 280 of the piston 226, 224. Alternatively, the opening can be provided in the lateral wall 208 of the

water cylinder 300. Such an opening only needs to provide a fluid passageway while a piston 226, 224 is at its fully extended or retracted position (but preferably at both of these positions), plus the length of a bump. The length of a bump is optionally about 2 to 5% of the stroke of a piston 226, 224. An opening in the lateral wall 208 does not need to be provided at intermediate positions. This would reduce salt leakage through the opening but the lateral wall 208 might then need to be strengthened to allow the water cylinder 300 to withstand its operating pressures. In another alternative, the opening might be provided by way of a loose tolerance between one or more of the seal 280, the rest of a piston 226, 224, and the lateral wall 208. However, an opening preferably has an area of at least 0.02%, or at least 0.04%, of a feed water face 236, 237 and it would be difficult to provide a selected size of opening and have a smoothly operating piston 226, 224 with an opening of that size provided by loose tolerances alone.

[0048] Further, feed water access ports 212, 213 are each connected to a feed water valve assembly 258, 260 which provide feed water inlet and outlet one way check valves. The one way valves allow water to enter or leave the feed water working chambers 228, 234, but only when the pressure inside each of the feed water working chambers 228 and 234 is near to the pressure on the opposite side of the check valve within a feed water valve assembly 258, 260 that is capable of opening. Accordingly, when moving the reciprocating assembly 300 causes the pressure inside either of the feed water working chambers 228, 234 to increase, it increases only to about, or slightly above, the high feed water pressure P2. When the movement causes the pressure inside of either of feed water working chambers 228, 234 to decrease, it decreases to about, or slightly below, the low feed water pressure P1. The size of the holes 225 and the timing and size of the movement can be adjusted to cause similar or different pressure variations in the concentrate working chambers 230, 232. In particular, the pressure in concentrate working chambers 230, 232 is preferably increased to near, but not above, the high brine pressure P3. Although it is a lesser concern, the pressure in concentrate working chambers 230, 232 is preferably decreased to near, but not below, the low brine pressure P4.

[0049] The water cylinder 200 and other parts of the system 10 may use the materials and other details of construction described in US Patent Application Publication No. US 2013/0082000, Desalination System with Energy Recovery and Related Pumps, Valves and Controller. US Patent Application Publication No. US 2013/0082000 is incorporated by reference.

[0050] As shown in Figure 2, the piston chambers 220, 222 include a feed water valve assembly 258, 260 which regulate the flow of feed water through the feed water access ports 212, 213 to the feed water working chambers 228, 234. For example, when feed water is desired to be supplied to feed water working chamber 228, feed water valve assembly 258 is open to line 254 so that feed water can flow from the source 110, through line 254, and into the feed water working chamber 228 via feed water access port 212. If the feed water valve assembly 258 is closed to line 254, no feed water will flow into the feed water working chamber 228. To supply feed water to the feed water working chamber 234, feed water valve assembly 260 can open to line 256 so that feed water flows from the source 110, through line 256 to the working chamber 234, via feed water access port 213. If feed water valve assembly 260 is closed to line 256 then no feed water will flow into the feed water working chamber 234.

[0051] For feed water to exit the feed water working chambers 228, 234 the feed water valve assembly 258, 260 are closed to lines 254, 256 and open to lines 262, 264. Details of example feed water assemblies are described in US Patent Application Publication No. US 2013/0082000.

[0052] The water cylinder 200 also includes two concentrate (or brine) valve bodies 400, 401, alternatively called energy recovery (ER) valves. The concentrate valve bodies 400, 401 are positioned between lines 218, 219, and the concentrate access ports 242, 244 and the respective concentrate working chambers 230, 232 and lines 250, 252 (see Figure 1). In some embodiments, a separate valve body may be provided for each of lines 218, 219, 250, 252, such as for example valve bodies 400A, 401A, 400B, 401B. In some embodiments, the specific features and functions of the concentrate valve bodies 400 and 401 are the same, with the exception of the specific connections between the concentrate working chamber and the high pressure concentrate lines. Also, as noted above, in some embodiments more than two energy recovery valves could be contained in a single housing.

[0053] Figure 3 shows example concentrate valve bodies 400A, 400B, 401A, and 401B connected between high pressure brine lines 218, 219 and discharge lines 250, 252 and a water cylinder 200. As discussed above, the water cylinder 200 has two piston chambers, each divided into a feed water chamber 220F, 222F and a concentrate chamber 220C, 222C. Each of the concentrate valve bodies 400A, 400B, 401A, 401B includes a poppet-type valve, as described further below with reference to Figures 4-7. In some embodiments, the high pressure valve bodies 400A, 401A and low pressure valve bodies

400B, 401B may be differently configured. In other embodiments, all of the valve bodies 400A/B, 401A/B may be substantially identical. As described further below, each of the valve bodies 400A/B, 401A/B comprises an energy recovery valve having a pilot valve that is connected to a supply of compressed air 410, or some other suitable pilot fluid. For example, in some embodiments the pilot valve may be operated using the working fluid as the pilot fluid, as described for example in International Patent Application No. PCT/US2014/059201 filed October 3, 2014, which is hereby incorporated by reference herein. The pilot fluid is selectively applied to actuate pilot valves to open and close the ER valves. In other embodiments, the pilot valves may comprises solenoid valves actuated by one or more electronic controllers.

[0054] The timing of the opening and closing of the ER valves may be substantially the same as disclosed in US Provisional Patent Application No. 61/985,144. In particular, in some embodiments, the ER valves are opened/closed when the water cylinder piston is stationary, and for each concentrate chamber the inlet valve is closed before the outlet valve is opened, then the outlet valve is closed again before the inlet valve is opened again. Also, in some embodiments, once the reciprocating assembly 300 of a water cylinder is stationary at the end of its main motion in one direction, all of the ER valves are closed and a “bump” is provided in the motion profile of the reciprocating assembly 300 to charge and pre-charge the concentrate chambers, then the inlet ER valve for one concentrate chamber and the outlet ER valve for the other concentrate chamber are opened before the reciprocating assembly 300 starts its main motion in the other direction.

[0055] Details of an example energy recovery (ER) valve 500 are shown in Figures 4, 4A, 5 and 5A. The ER valve 500 may be used as any of concentrate valve bodies 400A, 400B, 401A, 401B. Figures 4 and 4A show the ER valve 500 in the closed position, and Figures 5 and 5A show the ER valve 500 in the open position. The ER valve 500 comprises a main valve body 502 having an inlet 504 and an outlet 506. The inlet 504 is connected to a higher-pressure line or port than the outlet 506 (e.g. the inlet 504 may be connected to one of line lines 218, 219 in the case of a high pressure valve or to a port on a concentrate chamber in the case of a low pressure valve, and the outlet 506 may be connected to a port on a concentrate chamber in the case of a high pressure valve or one of discharge lines 250, 252 in the case of a low pressure valve). A main flow path 508 is provided between the inlet 504 and outlet 506. In the illustrated example, the main flow path 508 comprises two portions that are located on either side of a central block 509 of the valve body 502.

[0056] A valve piston 510 is positioned to be moveable into and out of engagement with a valve seat 512 to selectively block and unblock the flow of fluid between the inlet 504 and the outlet 506. A small orifice 514 in the valve piston 510 allows fluid to pass from the front face of the valve piston 510 (which faces the inlet 504) to a back face of the valve piston 510 (which faces a chamber 516 within the central block 509). The surface area of the back face of the valve piston 510 is larger than the surface area of the front face, such that the pressure of fluid provided at the inlet 504 (indicated by the solid arrow in Figures 4, 4A, 5, and 5A) is communicated to the chamber 516 through the orifice 514 and tends to urge the valve piston 510 into the closed position shown in Figures 4 and 4A. One or more biasing members such as for example springs 515 may be provided to assist in moving the valve piston 510 into the closed position. A first port 518 in the central block 509 provides fluid communication between the chamber 516 behind the valve piston 510 and a pilot valve 520. A second port 519 in the central block 509 provides fluid communication between the pilot valve 520 and the outlet 506.

[0057] In the illustrated example, the pilot valve 520 is a spool-type valve comprising a spool body 522 having a passage therein within which a spool 524 is slidably received. The pilot valve 520 could be a different type of valve in other embodiments, such as, for example, a pneumatic ball valve, a solenoid valve, or other type of valve. The spool 524 is moveable to open and close a pilot flow path between the first and second ports 518 and 519 in the central body 509, such that when the pilot valve 520 is in a closed position as shown in Figures 4 and 4A there is no fluid communication between the chamber 516 and the outlet 506, and when the pilot valve 520 is in an open position as shown in Figures 5 and 5A there is fluid communication between the chamber 516 and the outlet 506. In the illustrated example, the spool body 522 has a first passage 523 in fluid communication with the first port 518 in the central block 509, and a second passage 525 in fluid communication with the second port 519 in the central block 509. The spool 524 has a passage 527 therein which selectively provides fluid communication between the first and second passages 523, 525 in the spool body 522.

[0058] The pilot valve 520 is actuated by applying a force from one end (e.g., the bottom end from the perspective shown in Figures 4A and 5A, as shown by the dashed arrow in Figure 4A) to close the valve and applying a force from the other end (e.g., the top end from the perspective shown in Figures 4A and 5A, as shown by the dashed arrow in Figure 5A) to close the valve. In some embodiments, the pilot valve 520 is actuated by

compressed air. A compressed air fitting (not shown in Figures 4, 4A, 5, and 5A) may be provided at either end of the pilot valve 520, such that when compressed air (or another pilot fluid) is applied to one end of the pilot valve 520, the spool 524 moves into the closed position, and when compressed air is applied to the other end of the pilot valve 520, the spool 524 moves into the open position. Alternatively, a biasing member such as for example a spring (not shown) may be used to urge the spool 524 into either the closed position or the open position, and compressed air may be provided at only one end of the pilot valve 520 and used to counteract the force of the biasing member and move the spool 524 to the open or closed position. In other embodiments, the pilot valve 520 may be actuated by electromagnetic forces. For example, the pilot valve 520 may comprise a solenoid valve in some embodiments, with the dashed arrows in Figures 4A and 5A representing electromagnetic forces.

[0059] The first and second ports 518 and 519 and the pilot flow path therebetween collectively have a larger effective cross-sectional area than the orifice 514 in the valve piston 510. In some embodiments, the orifice 514 has a generally circular cross-section with a diameter of $\frac{1}{4}$ inch or less. When the pilot valve 520 is in the open position shown in Figures 5 and 5A, the pressure in chamber 516 drops such that the forces acting on the back face of the valve piston 510 are no longer sufficient to overcome the force of the fluid pressure on the front face of the valve piston 510, and the valve piston 510 moves into the open position thereby opening the main flow path 508 between the inlet 504 and the outlet 506. When the valve 500 is in the open position, there is also a flow path from the inlet 504 all the way through the orifice 514, chamber 516, first port 518, passages 523, 527, 525 and second port 519 to the outlet 506, such that any air or other gas trapped behind the valve piston 510 can escape the valve 500.

[0060] Details of another example energy recovery (ER) valve 600 are shown in Figures 6, 6A, and 7. The ER valve 600 may be used as any of concentrate valve bodies 400A, 400B, 401A, 401B. Figures 6 and 6A show the ER valve 600 in the closed position, and Figure 7 shows the ER valve 600 in the open position. The ER valve 600 comprises a main valve body 602 having an inlet 604 and an outlet 606. The inlet 604 is connected to a higher-pressure line or port than the outlet 606 (e.g. the inlet 604 may be connected to one of bine lines 218, 219 in the case of a high pressure valve or to a port on a concentrate chamber in the case of a low pressure valve, and the outlet 606 may be connected to a port on a concentrate chamber in the case of a high pressure valve or one of discharge lines 250,

252 in the case of a low pressure valve). A main flow path 608 is provided between the inlet 604 and outlet 606. In the illustrated example, the main flow path 608 comprises two portions that are located on either side of a central block 609 of the valve body 602.

[0061] A valve piston 610 is positioned to be moveable into and out of engagement with a valve seat 612 to selectively block and unblock the flow of fluid between the inlet 604 and the outlet 606. A small orifice 614 in the valve piston 610 allows fluid to pass from the front face of the valve piston 610 (which faces the inlet 604) to a back face of the valve piston 610 (which faces a chamber 616 within the central block 609). The surface area of the back face of the valve piston 610 is larger than the surface area of the front face, such that the pressure of fluid provided at the inlet 604 is communicated to the chamber 616 through the orifice 614 and tends to urge the valve piston 610 into the closed position shown in Figures 6 and 6A. One or more biasing members such as for example a spring 615 may be provided to assist in moving the valve piston 610 into the closed position. A first port 618 in the central block 609 provides fluid communication between the chamber 616 behind the valve piston 610 and a pilot valve 620. A second port 619 in the central block 609 provides fluid communication between the pilot valve 620 and the outlet 606. In the illustrated example, the first port 618 and second port 619 are not aligned due to the configuration of the pilot valve 620, as discussed below.

[0062] The pilot valve 620 is a spool-type valve comprising a spool body 622 having a passage therein within which a spool 624 is slidably received. In some embodiments, the spool body 622 and the spool 624 are constructed from polyether ether ketone (PEEK) plastic for corrosion resistance, and a plurality of seals are provided between the spool body 622 and the central block 609, and between the spool body 622 and the spool 624, as discussed further below. The spool 624 is moveable to open and close a pilot flow path between the first and second ports 618 and 619 in the central body 609, such that when the pilot valve 620 is in a closed position as shown in Figures 6 and 6A there is no fluid communication between the chamber 616 and the outlet 606, and when the pilot valve 620 is in an open position as shown in Figure 7 there is fluid communication between the chamber 616 and the outlet 606. In the illustrated example, the spool body 622 has a first passage 623 in fluid communication with the first port 618 in the central block 609, and a second passage 625 in fluid communication with the second port 619 in the central block 609. Each of the first and second passages 623 and 625 may comprise a plurality of holes through the spool body 622 spaced around the circumference of the spool body 622 at generally the

same longitudinal position along the spool body 622. The spool 624 has a passage 627 therein which selectively provides fluid communication between the first and second passages 623, 625 in the spool body 622. The passage 627 of the spool 624 may be an annular indentation around the periphery of the spool 624.

5 **[0063]** A pair of working fluid seals 644 (e.g., o-rings) are provided above and below (from the perspective shown in Figures 6A and 7) the passage 627 to contain working fluid therebetween. A pair of pilot fluid seals 646 (e.g. o-rings) are provided near opposed ends of the spool 624. The seals 644, 646 may, for example, be constructed from Teflon™ or the like. The working fluid seal 644 that slides across passages 625 may, for example, comprise
10 a biased cut Teflon seal.

[0064] The spool 624 has a contained leak path 640 and leak passages 642 defined therein. Each leak passage 642 is located between one of the working fluid seals 644 and one of the air seals 646 such that any working fluid or air that leaks past their respective seals 644, 646 passes through a leak passage 642 and into the leak path 640 to be directed to the head of
15 the pilot valve 620. This configuration ensures that the working fluid (e.g., brine) doesn't leak into the pilot fluid (e.g., air) supply and air doesn't leak into the working fluid. Any leakage of working fluid or pilot fluid may thus be detected externally, indicating a need to replace the seals of the pilot valve 620.

[0065] Compressed air fittings 650 are provided at either end of the pilot valve 620, such that when compressed air is applied to one end of the pilot valve 620 (e.g., the bottom end from the perspective shown in Figures 6A and 7, as shown by the dashed arrow in Figure 6A), the spool 624 moves into the closed position, and when compressed air is applied to the other end of the pilot valve 620 (e.g., the top end from the perspective shown in Figures 6A and 7, as shown by the dashed arrow in Figure 7), the spool 624 moves into
25 the open position. Alternatively, a biasing member such as for example a spring (not shown) may be used to urge the spool 624 into either the closed position or the open position, and compressed air may be provided at only one end of the pilot valve 620 and used to counteract the force of the biasing member and move the spool 624 to the open or closed position.

30 **[0066]** The first and second ports 618 and 619 and the pilot flow path therebetween collectively have a larger effective cross-sectional area than the orifice 614 in the valve piston 610. In some embodiments, the orifice 614 has a generally circular cross-section with a diameter of ¼ inch or less. When the pilot valve 620 is in the open position shown in

Figure 7, the pressure in chamber 616 drops such that the forces acting on the back face of the valve piston 610 are no longer sufficient to overcome the force of the fluid pressure on the front face of the valve piston 610, and the valve piston 610 moves into the open position thereby opening the main flow path 608 between the inlet 604 and the outlet 606. When the valve 600 is in the open position, there is also a flow path from the inlet 604 all the way through the orifice 614, chamber 616, first port 618, passages 623, 627, 625 and second port 619 to the outlet 606, such that any air or other gas trapped behind the valve piston 610 can escape the valve 600.

[0067] In the examples described above, the pilot valve is positioned within the body of the main valve, but this is not required in all embodiments. For example, details of another example energy recovery (ER) valve 800 are shown in Figure 8. The ER valve 800 may be used as any of concentrate valve bodies 400A, 400B, 401A, 401B. Figure 8 shows the ER valve 800 in the closed position. The ER valve 800 comprises a main valve body 802 having an inlet 804 and an outlet 806. The inlet 804 is connected to a higher-pressure line or port than the outlet 806 (e.g. the inlet 804 may be connected to one of bine lines 218, 219 in the case of a high pressure valve or to a port on a concentrate chamber in the case of a low pressure valve, and the outlet 806 may be connected to a port on a concentrate chamber in the case of a high pressure valve or one of discharge lines 250, 252 in the case of a low pressure valve). A main flow path 808 is provided between the inlet 804 and outlet 806.

[0068] A valve piston 810 is positioned to be moveable into and out of engagement with a valve seat 812 to selectively block and unblock the flow of fluid between the inlet 804 and the outlet 806. A small orifice 814 in the valve piston 810 allows fluid to pass from the front face of the valve piston 810 (which faces the inlet 804) to a back face of the valve piston 810 (which faces a chamber 816 within the valve body 802). The surface area of the back face of the valve piston 810 is larger than the surface area of the front face, such that the pressure of fluid provided at the inlet 804 is communicated to the chamber 816 through the orifice 814 and tends to urge the valve piston 810 into the closed position shown in Figure 8. One or more biasing members such as for example springs 815 may be provided to assist in moving the valve piston 810 into the closed position. A first port 818 in the valve body 802 provides fluid communication between the chamber 816 behind the valve piston 810 and a pilot valve 820. A pilot flow path return conduit 819 provides fluid communication between the pilot valve 820 and the outlet 806.

[0069] In the illustrated example, the pilot valve 820 is a spool-type valve comprising a spool body 822 having a passage therein within which a spool 824 is slidably received. The pilot valve 820 could be a different type of valve in other embodiments, such as, for example, a pneumatic ball valve, a solenoid valve, or other type of valve. The spool 824 is moveable to open and close a pilot flow path between the chamber 816 and the outlet 806, such that when the pilot valve 820 is in a closed position as shown in Figure 8 there is no fluid communication between the chamber 816 and the outlet 806, and when the pilot valve 820 is in an open position (not shown) there is fluid communication between the chamber 816 and the outlet 806. In the illustrated example, the spool body 822 has a first passage 823 in fluid communication with the first port 818 in the valve body 802, and a second passage 825 in fluid communication with the pilot flow path return conduit 819. The spool 824 has a passage 827 therein which selectively provides fluid communication between the first and second passages 823, 825 in the spool body 822. A compressed air fitting 850 is provided at one end of the pilot valve 820. A biasing member such as for example a spring 852 is provided at the opposite end of the pilot valve 820 to bias the pilot valve into the closed position shown in Figure 8. When compressed air (or another pilot fluid) is applied to the pilot valve 820, the biasing force of the spring 852 is overcome and the spool 824 moves into the open position. .

[0070] The pilot flow path between the chamber 816 and the outlet 806 (comprising port 818, passages 823, 827, 825 and return conduit 819 in the illustrated example of Figure 8) collectively have a larger effective cross-sectional area than the orifice 814 in the valve piston 810. In some embodiments, the orifice 814 has a generally circular cross-section with a diameter of ¼ inch or less. When the pilot valve 820 is in the open position (not shown), the pressure in chamber 816 drops such that the forces acting on the back face of the valve piston 810 are no longer sufficient to overcome the force of the fluid pressure on the front face of the valve piston 810, and the valve piston 810 moves into the open position thereby opening the main flow path 808 between the inlet 804 and the outlet 806. When the valve 800 is in the open position, there is also a flow path from the inlet 804 all the way through the orifice 814, chamber 816, first port 818, passages 823, 827, 825 and return conduit 819 to the outlet 806, such that any air or other gas trapped behind the valve piston 810 can escape the valve 800.

[0071] This written description uses examples to disclose the invention, including the best mode, to enable any person skilled in the art to practice the invention, including making

and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art.

[0072] The above-described embodiments are intended to be examples only.

- 5 Alterations, modifications and variations can be effected to the particular embodiments by those of skill in the art. The scope of the claims should not be limited by the particular embodiments set forth herein, but should be construed in a manner consistent with the specification as a whole.

WHAT IS CLAIMED IS:

1. A valve comprising:

a valve body having an inlet, an outlet and a main flow path from the inlet to the outlet;

5 a valve piston moveable into and out of engagement with a valve seat to block and unblock the main flow path, the valve piston having a front face facing the inlet, a back face facing a chamber within the valve body, and an orifice providing fluid communication between the front face and the back face of the valve piston, wherein when the valve piston is engaged with the valve seat the front face has a smaller area than the back face, such that fluid pressure in the inlet is communicated to the back face to urge the valve piston into engagement with the valve seat; and

10 a pilot valve moveable between a closed position and an open position to block and unblock a pilot flow path between the chamber within the valve body and the outlet, wherein the pilot flow path has a larger effective cross-sectional area than the orifice, such that when the pilot flow path is unblocked fluid pressure on the back face of the valve piston is reduced.

2. The valve of claim 1 wherein the pilot valve comprises a spool slidably received within a spool body.

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3. The valve of claim 2 wherein pilot valve is positioned within a central block of the valve body, and the main flow path comprises two portions on opposed sides of the central block.

25 4. The valve of claim 3 wherein the central block has a first port providing fluid communication between the chamber and the pilot valve and a second providing fluid communication between the pilot valve and the outlet.

5. The valve of claim 4 wherein the spool body has a first passage in communication with the first port and a second passage in fluid communication with the second port, and wherein the spool has a spool passage moveable to selectively provide fluid communication between the first and second passages of the spool body.

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6. The valve of claim 5 wherein the spool and the spool body are generally cylindrical, and wherein the spool passage comprises an annular indentation around a periphery of the spool.

5 7. The valve of claim 6 comprising a pilot fluid fitting at each of two opposed ends of the pilot valve for providing pilot fluid to move the pilot valve between the closed position and the open position.

8. The valve of claim 7 wherein the spool has a pair of working fluid seals on opposite
10 sides of the spool passage, and a pair of pilot fluid seals near two opposed ends of the spool.

9. The valve of claim 8 wherein the spool has a contained leak path defined in a central portion thereof, and a pair of leak passages in fluid communication with the contained leak path, wherein each of the pair of leak passages is located between one of the working fluid
15 seals and one of the pilot fluid seals.

10. The valve of claim 1 comprising a compressed air fitting at an end of the pilot valve for providing compressed air to move the pilot valve between the closed position and the open position.

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11. The valve of claim 1 comprising one or more springs connected between the valve piston and the valve body to provide a biasing force to urge the valve piston into engagement with the valve seat.

25 12. The valve of claim 1 wherein one of the inlet and outlet is in fluid communication with a working fluid chamber of a cylinder pumping an operating fluid, and the other of the inlet and outlet is in fluid communication with one of a working fluid supply line and a working fluid discharge line.

30 13. The valve of claim 2 wherein the spool body and the spool are constructed from polyether ether ketone.

14. The valve of claim 1 wherein the pilot valve comprises a solenoid valve.

15. A valve comprising:

a valve body having an inlet chamber and an outlet chamber, a central block between the inlet chamber and the outlet chamber, and a main flow path from the inlet chamber to the outlet chamber;

a valve piston moveable into and out of engagement with a valve seat to block and unblock the main flow path, the valve piston having a front face facing the inlet chamber, a back face facing a chamber within the central block of the valve body, and an orifice providing fluid communication between the front face and the back face of the valve piston, wherein when the valve piston is engaged with the valve seat the front face has a smaller area than the back face, such that fluid pressure in the inlet chamber is communicated to the back face to urge the valve piston into engagement with the valve seat;

a pilot valve within the central block of the valve body, the pilot valve moveable between a closed position and an open position to block and unblock a pilot flow path between the chamber within the central block and the outlet, wherein the pilot flow path has a larger effective cross-sectional area than the orifice, such that when the pilot flow path is unblocked fluid pressure on the back face of the valve piston is reduced.

16. A process for operating a valve comprising a valve body having an inlet and an outlet, with a main flow path from the inlet chamber to the outlet chamber, and a valve piston moveable into and out of engagement with a valve seat to block and unblock the main flow path, the valve piston having a front face facing the inlet chamber, a back face facing a chamber within the valve body wherein when the valve piston is engaged with the valve seat the front face has a smaller area than the back face, the process comprising:

providing an orifice between the front face and the back face of the valve piston to communicate fluid pressure in the inlet chamber to the back face;

opening a pilot flow path between the chamber within the valve body and the outlet, the pilot flow path having a larger effective cross-sectional area than the orifice, to reduce fluid pressure on the back face of the valve piston and allow the fluid pressure in the inlet to move the valve piston out of engagement with the valve seat; and,

closing the pilot flow path to allow the fluid pressure in the inlet to move the valve piston into engagement with the valve seat.

17. The process of claim 16 wherein the valve comprises a pilot valve within a central block of the valve body, and wherein opening and closing the pilot flow path comprises actuating the pilot valve.

5 18. The process of claim 17 wherein the pilot valve comprises a spool slidably movable within a spool body, and wherein opening the pilot flow path comprises moving the spool in a first direction and closing the pilot flow path comprises moving the spool in a second direction opposite to the first direction.

10 19. The process of claim 18 wherein moving the spool in the first direction comprises applying compressed air to one end of the pilot valve and moving the spool in the second direction comprises applying compressed air to an opposite end of the pilot valve.

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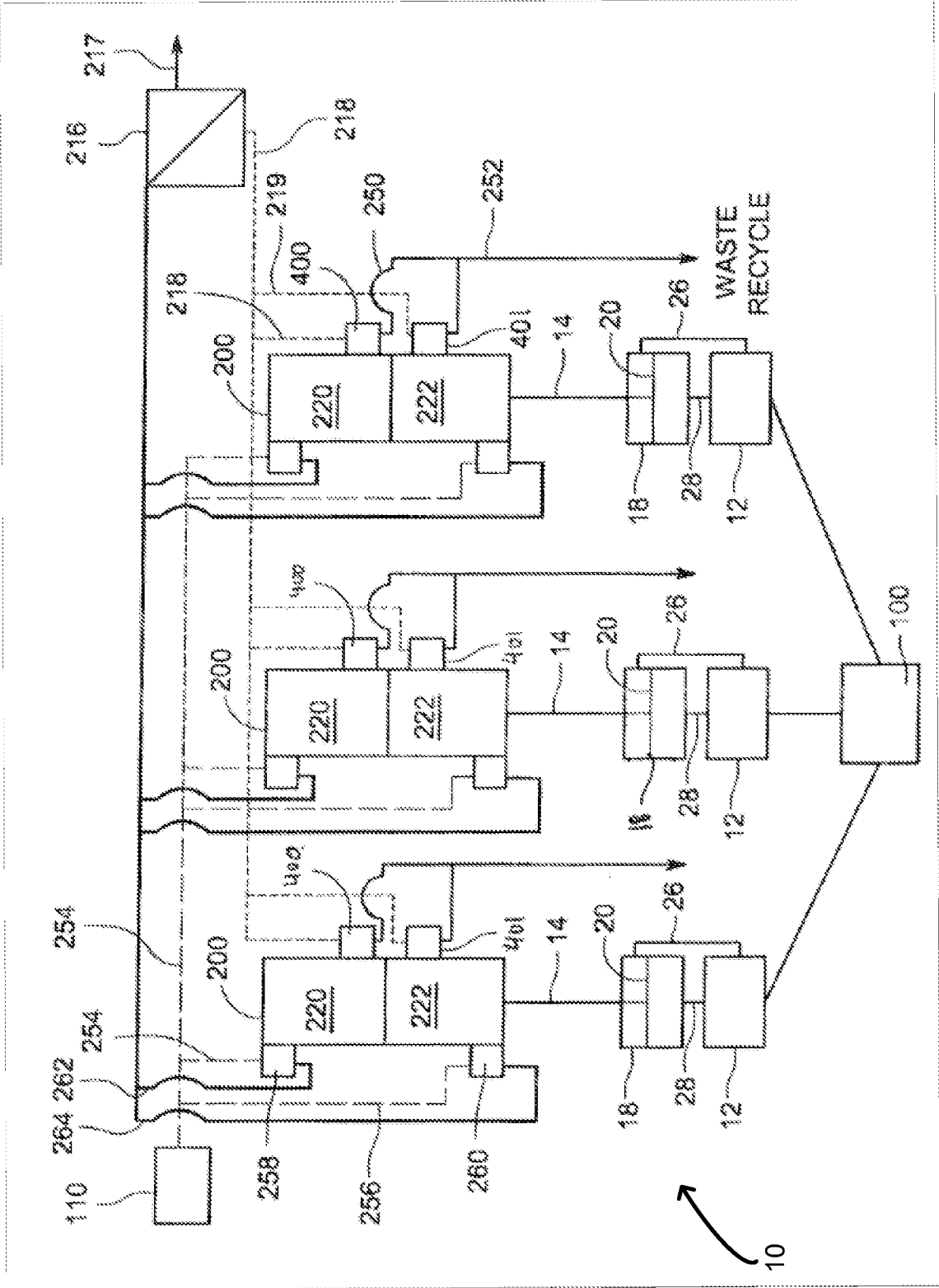


FIG. 1

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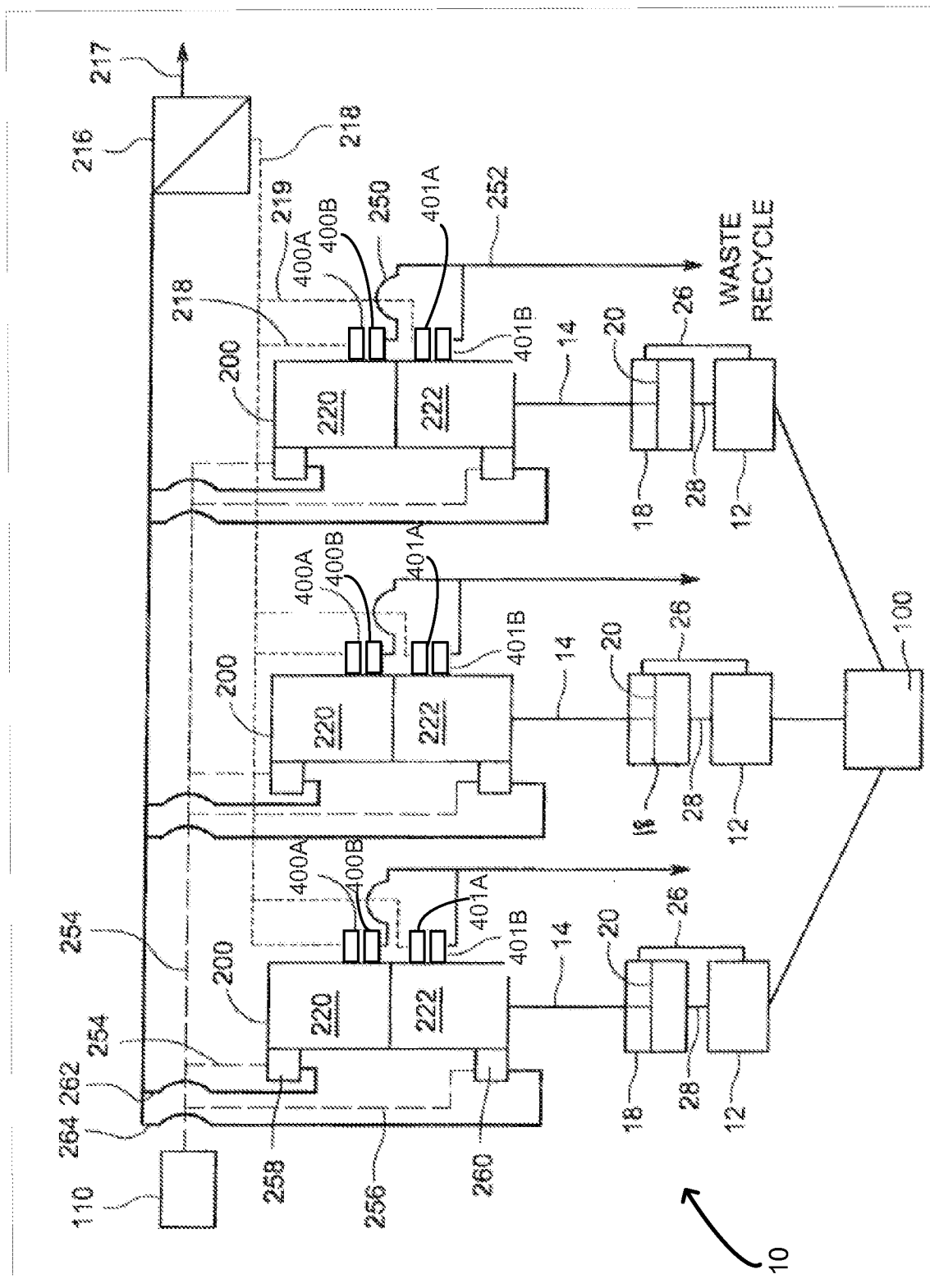


FIG. 1A

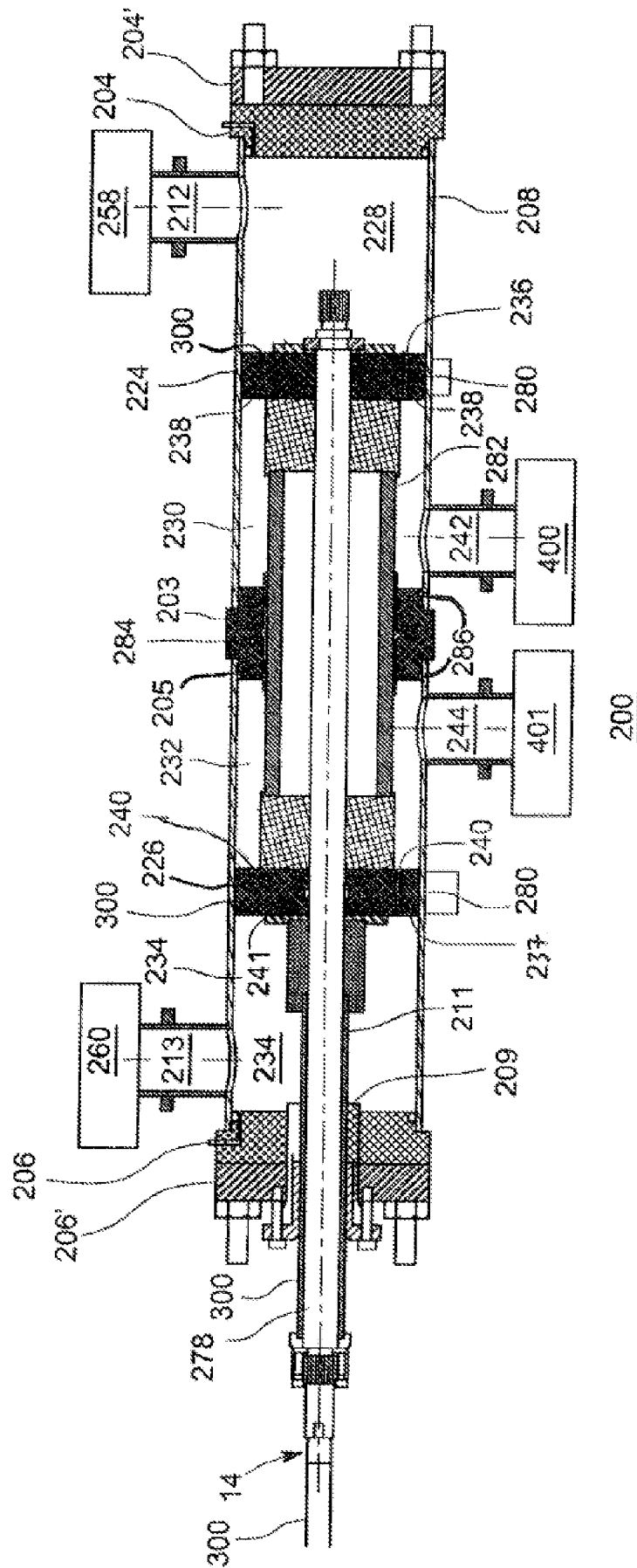


FIG. 2

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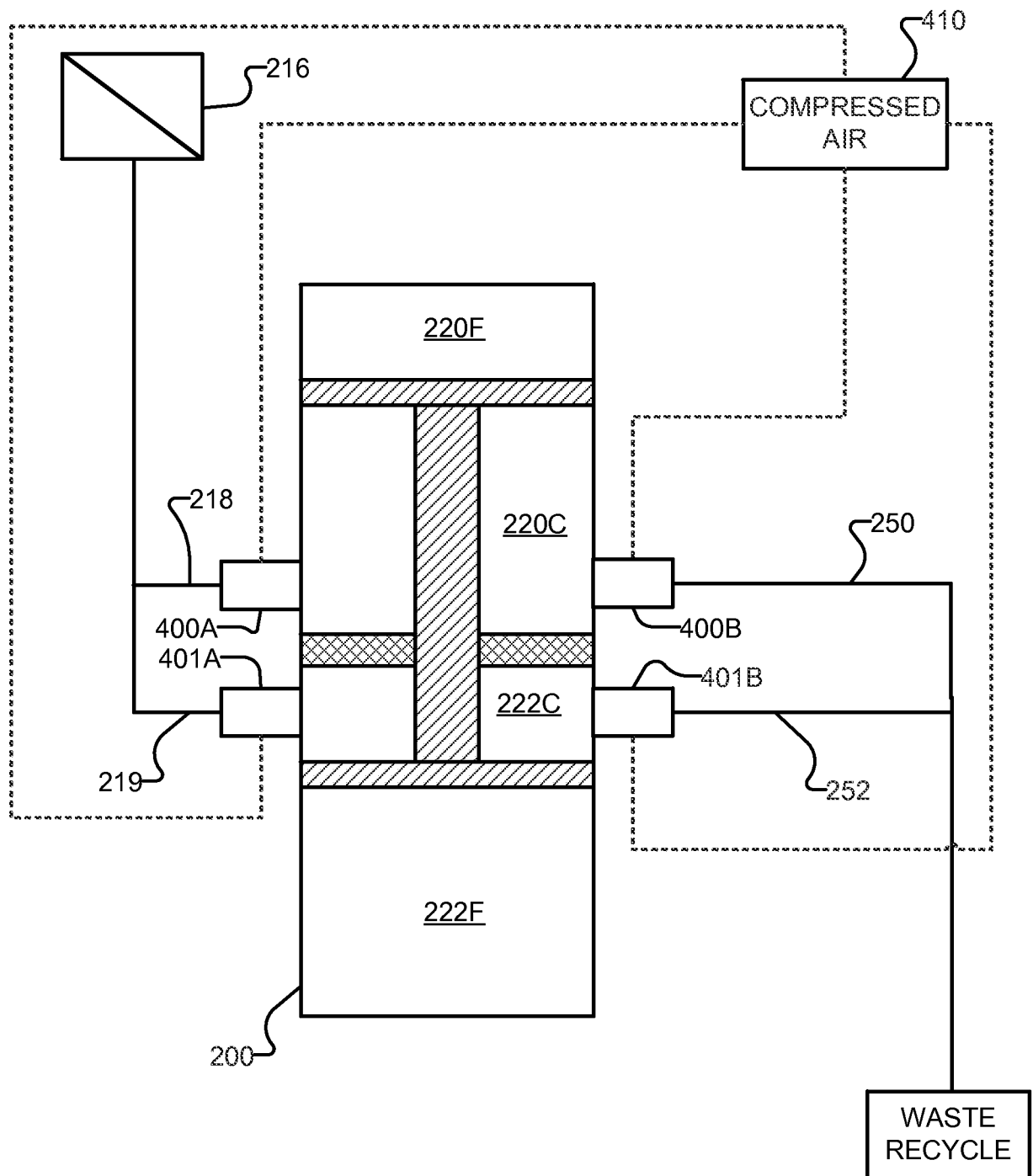


FIG. 3

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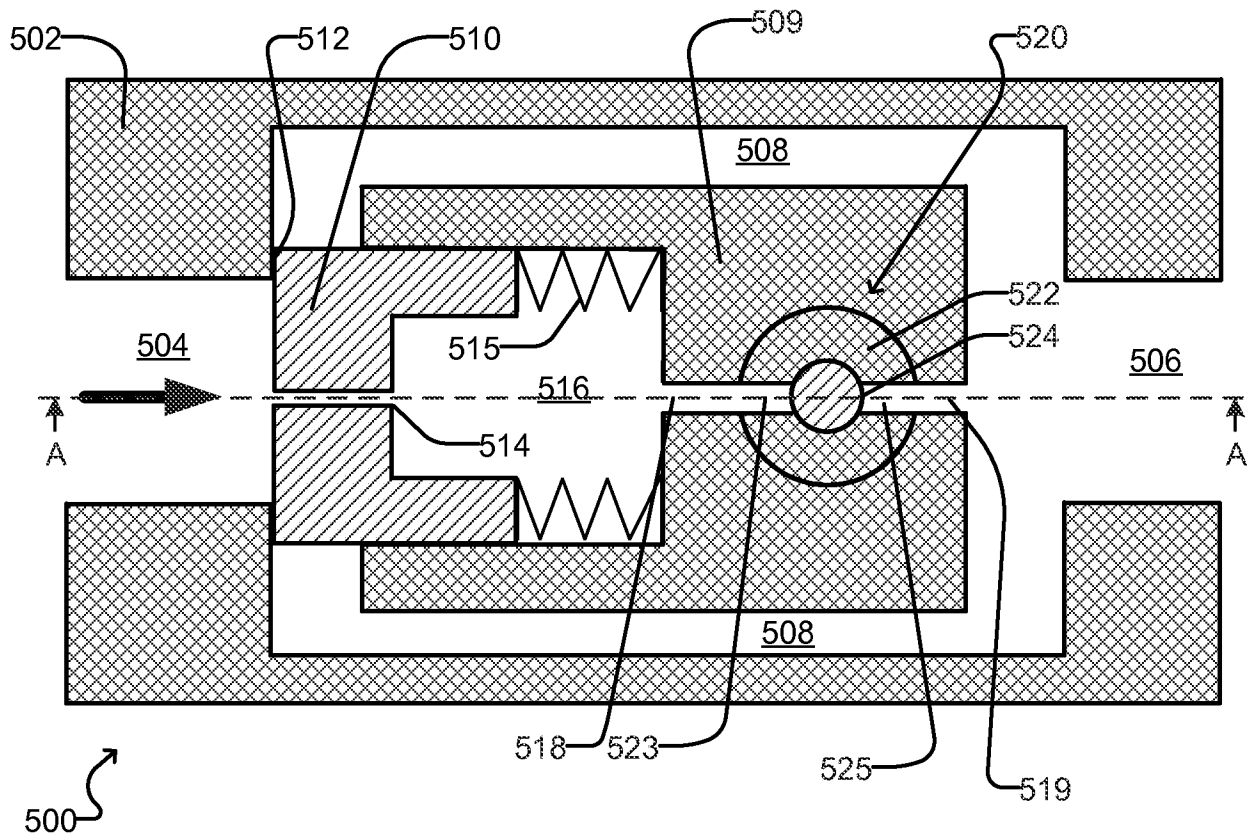


FIG. 4

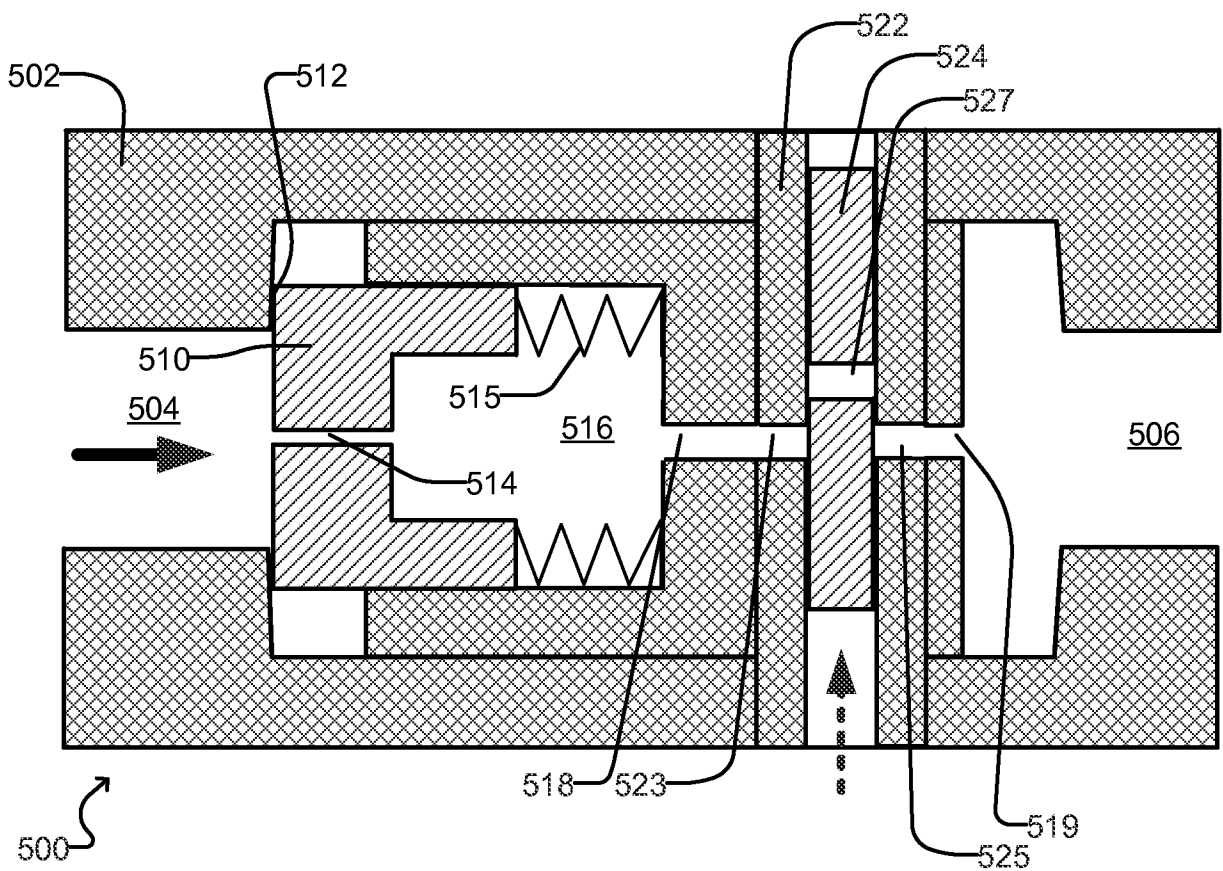
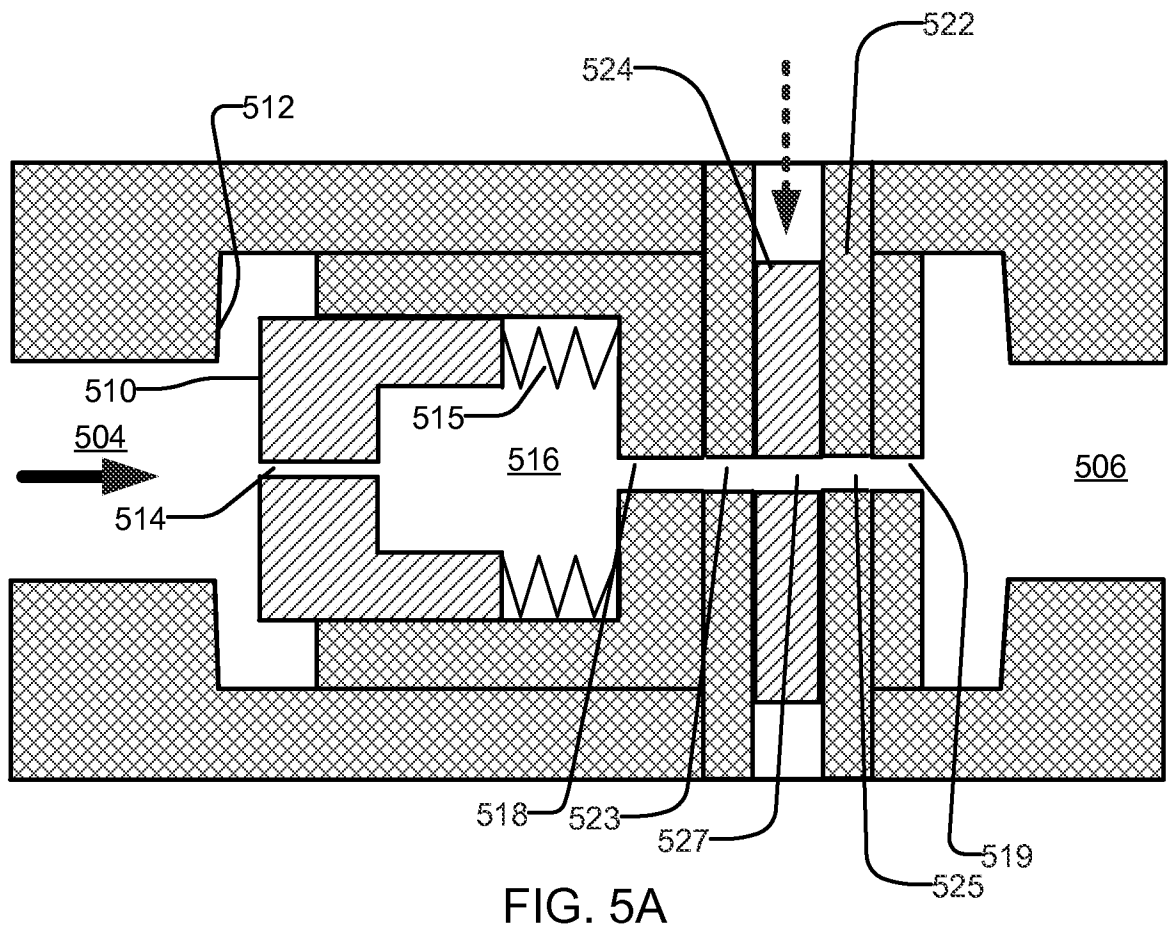
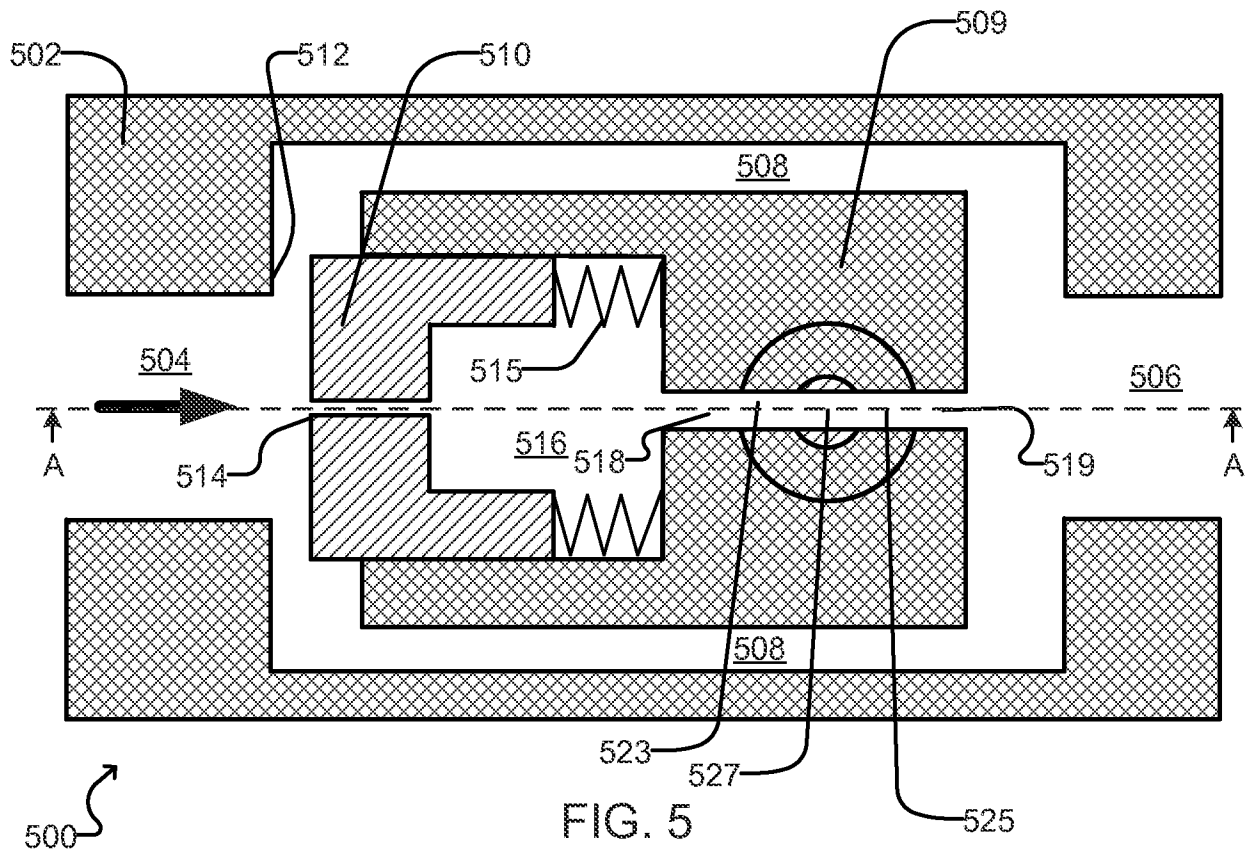


FIG. 4A

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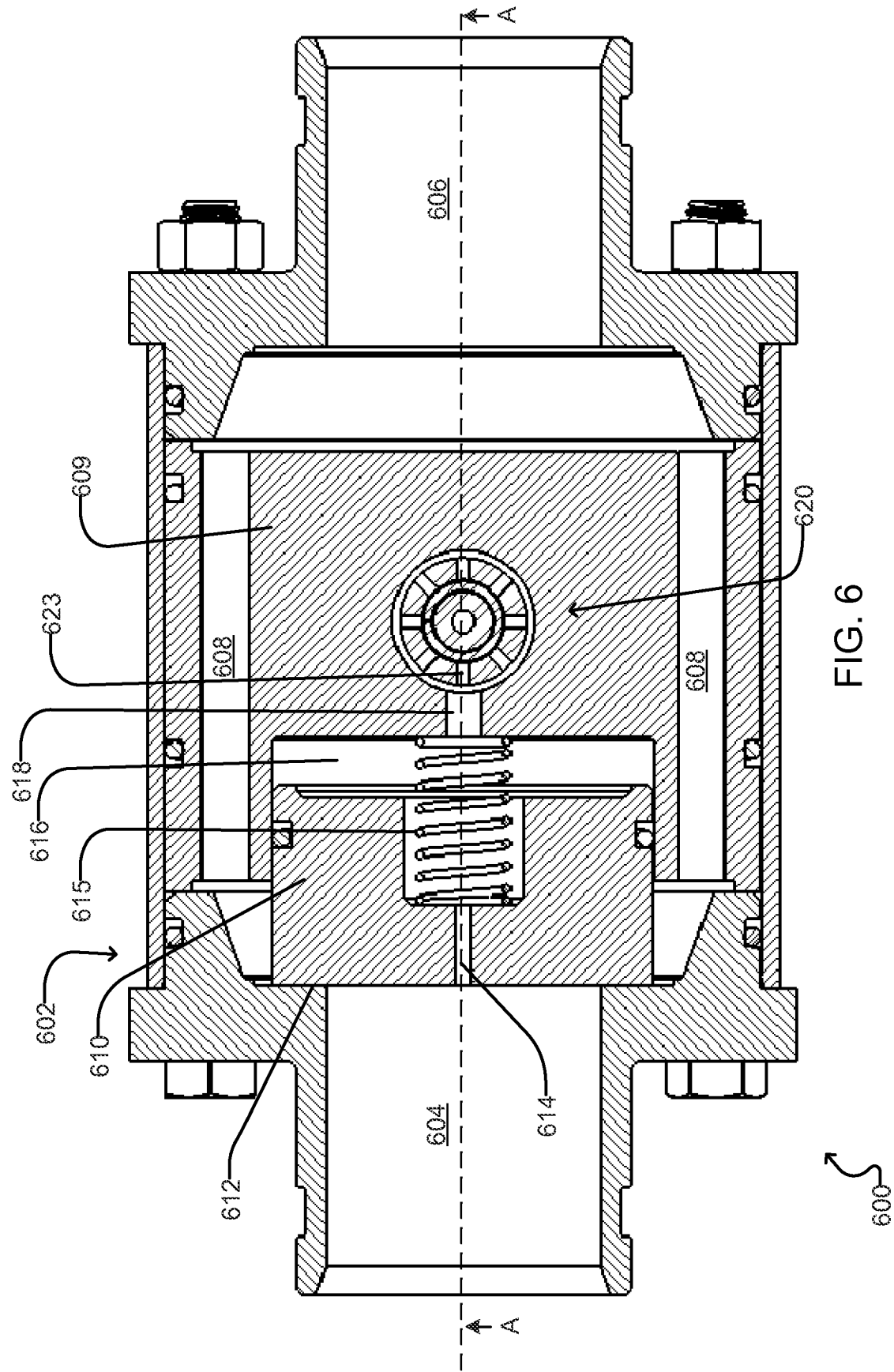
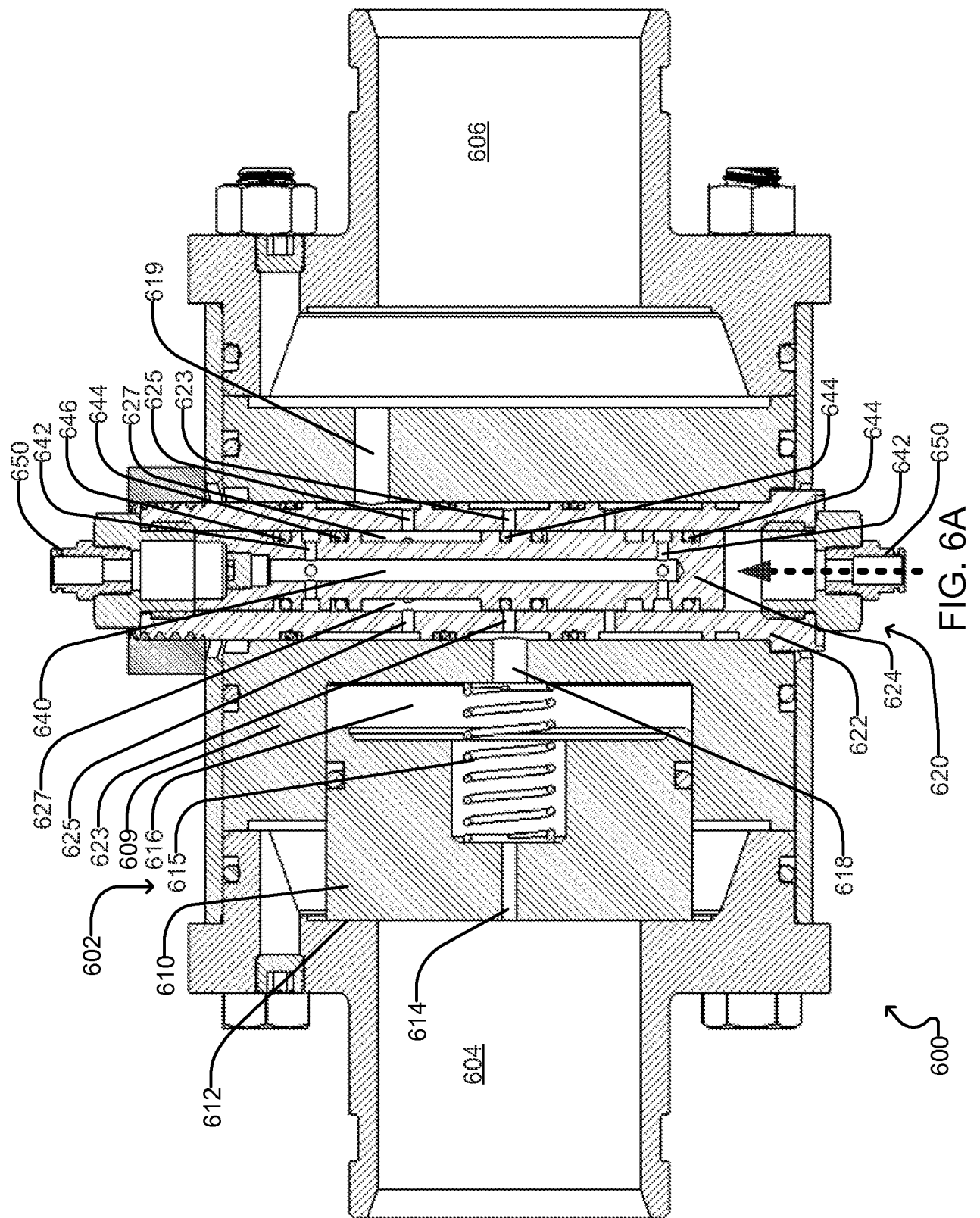
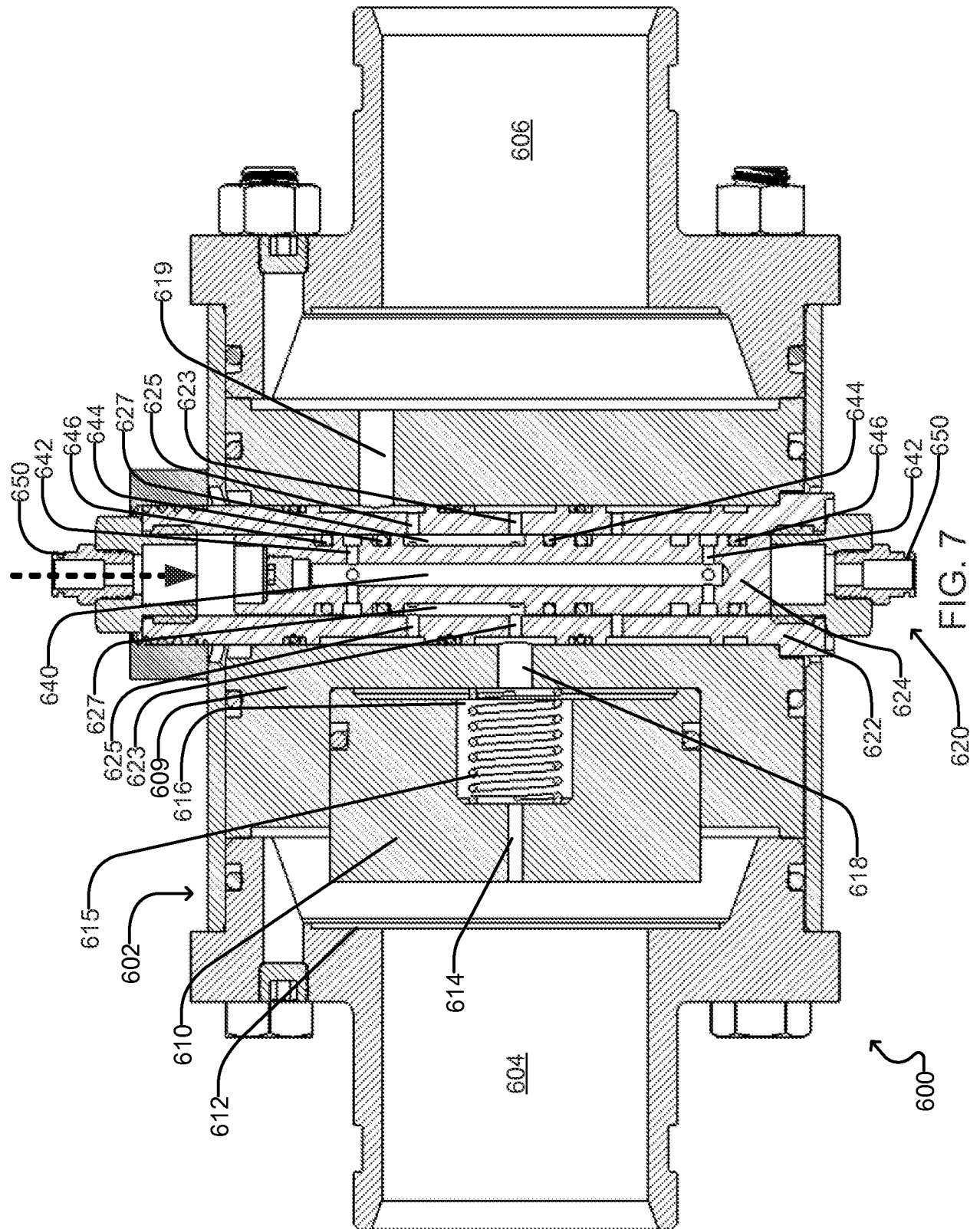


FIG. 6



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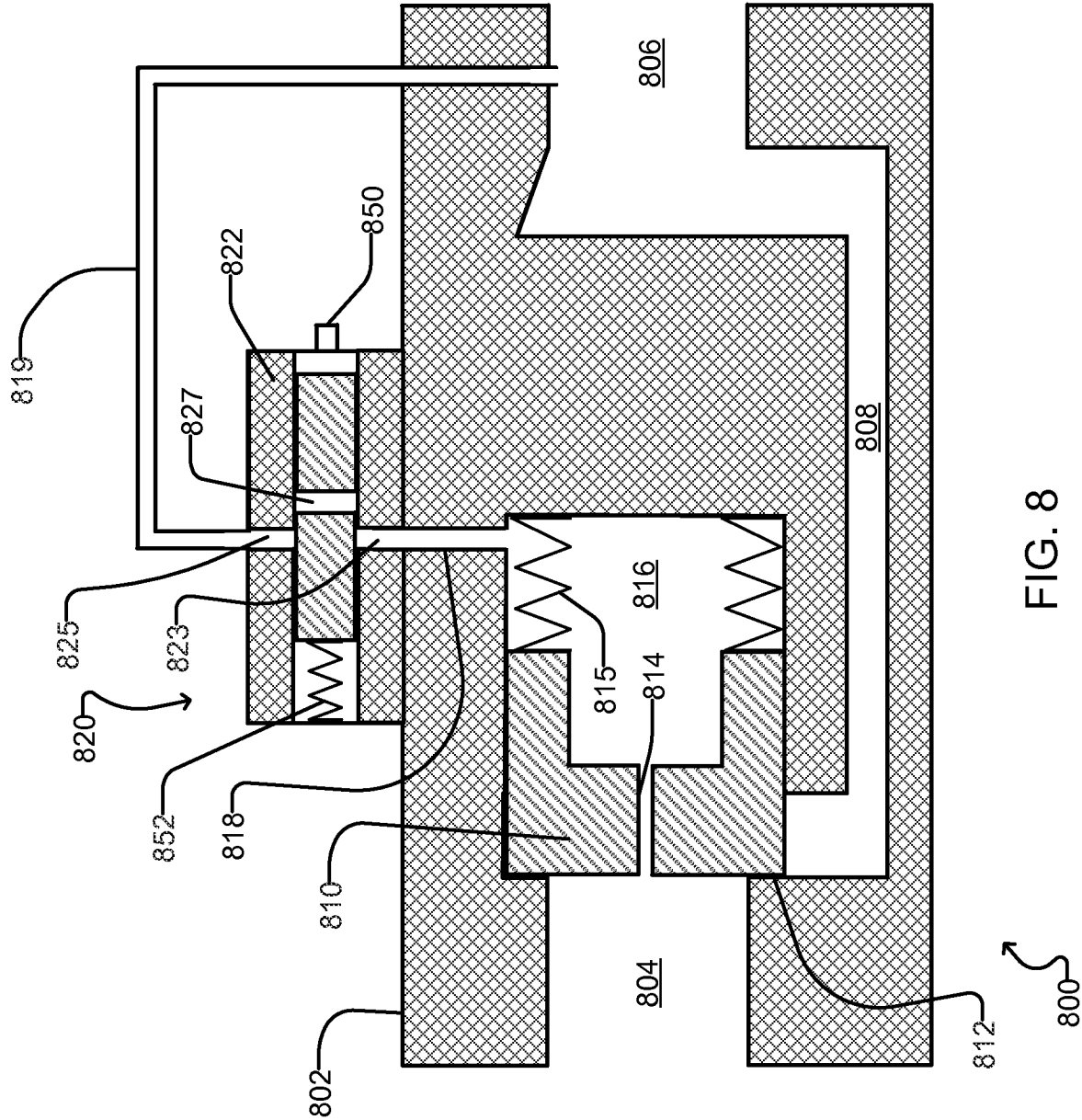


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2014/068157

A. CLASSIFICATION OF SUBJECT MATTER
 INV. F16K31/383 F16K1/12
 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)
 F16K

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	US 3 003 516 A (GRANBERG ALBERT J ET AL) 10 October 1961 (1961-10-10) figure 1	1-19
X	US 1 777 060 A (RUDOLPH WELCKER) 30 September 1930 (1930-09-30) figures 1,2	1-19
X	US 845 063 A (DESPER HENRY A [US]) 26 February 1907 (1907-02-26) figures 1-8	1-19
X	US 3 289 689 A (HIROTO KOBAYASHI ET AL) 6 December 1966 (1966-12-06) figure 1	1-19
X	US 3 540 464 A (RENZI NICHOLAS ALBERT) 17 November 1970 (1970-11-17) figures 1-4	1-19



Further documents are listed in the continuation of Box C.



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

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"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

6 August 2015

Date of mailing of the international search report

21/08/2015

Name and mailing address of the ISA/

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Authorized officer

Bilo, Eric

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2014/068157

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 3003516	A	10-10-1961	NONE	
US 1777060	A	30-09-1930	NONE	
US 845063	A	26-02-1907	NONE	
US 3289689	A	06-12-1966	NONE	
US 3540464	A	17-11-1970	NONE	