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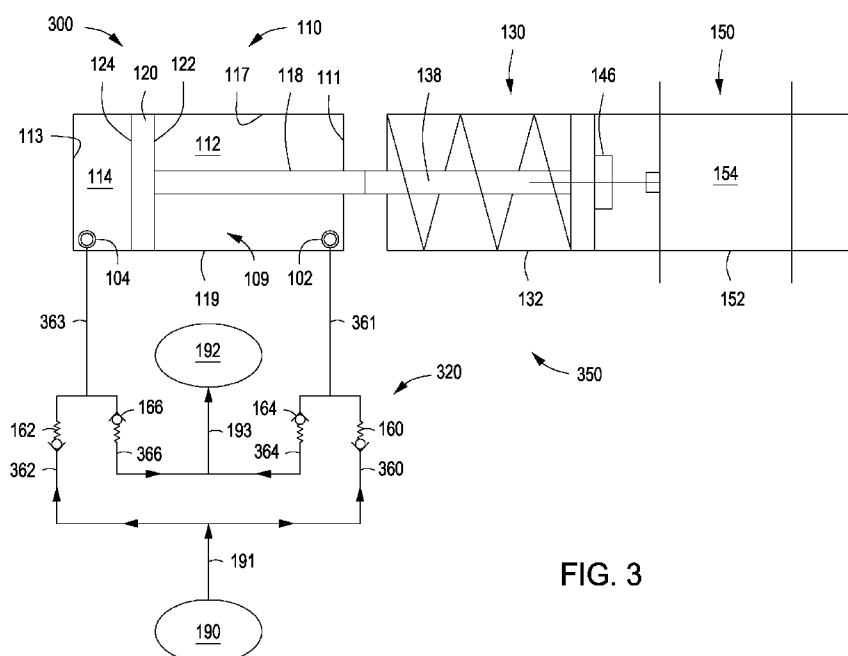


FIG. 3

(57) Abstract: Cylinder pump systems and methods for pumping and measuring fluids are provided. The pump system includes a piston cylinder pump, a linear actuator, and a motor assembly. The piston cylinder pump includes a piston located within a cavity of a cylinder body and dividing the cavity into a first adjustable chamber and a second adjustable chamber and a rod coupled to the piston. The linear actuator includes a shaft coupled to the rod and the linear actuator converts rotational motion to linear motion to linearly move the rod. The motor assembly is coupled to the linear actuator and operable to drive the linear actuator.



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Cylinder Pump Systems and Methods for Pumping and Measuring Fluids

Background

[0001] This section is intended to provide relevant contextual information to facilitate a better understanding of the various aspects of the described embodiments. Accordingly, it should be understood that these statements are to be read in this light and not as admissions of prior art.

[0002] Liquid pumps have been used to transfer or dispense liquids in a variety of industrial fields, such as oil production, chemical processing, pharmaceutical manufacturing, food and cosmetic processing, and other industries. Accuracy and speed are two important properties of a pump that are often in conflict with one another. Typically, the more accurate a pump is at dispensing a precise measured amount of the fluid, the slower the pump is at dispensing the fluid. Alternately, the faster the pump is at dispensing the fluid, the less accurate the pump is at dispensing a precise measured amount of the fluid. Therefore, it will be appreciated that improvements are continually needed in the field of pump systems and methods for pumping and measuring fluids.

Brief Description of the Drawings

[0003] For a detailed description of the embodiments of the invention, reference will now be made to the accompanying drawings in which:

[0004] FIG. 1 depicts a schematic view of a pump system, according to one or more embodiments;

[0005] FIGS. 2A and 2B depict a top view and a side view, respectively, of the pump system shown in FIG. 1 without the control system attached thereto;

[0006] FIG. 2C depicts a cross-sectional view of an exemplary piston cylinder pump, according to one or more embodiments;

[0007] FIG. 3 depicts a schematic view of a pumping assembly containing a pump system fluidly coupled to a conduit system, according to one or more embodiments;

[0008] FIG. 4 depicts a schematic view of another pumping assembly containing a pump system fluidly coupled to a conduit system, according to one or more embodiments;

[0009] FIG. 5 depicts a schematic view of another pumping assembly containing a pump system fluidly coupled to a conduit system, according to one or more embodiments;

[0010] FIG. 6 depicts a schematic view of an exemplary cylinder pump, according to one or more embodiments; and

[0011] FIG. 7 depicts a schematic view of an exemplary ball screw linear actuator coupled to an electric motor by a belt, according to one or more embodiments.

Detailed Description

[0012] FIG. 1 depicts a schematic view of a pump system 100, according to one or more embodiments. The pump system 100 pumps or otherwise transfers one or more fluids, and accurately meters or otherwise measures the fluids that are transferred. The pump system 100 includes a piston cylinder pump 110, a linear actuator 130, a motor assembly 150, and a control system 170. The linear actuator 130 is operably coupled to and between the piston cylinder pump 110 and the motor assembly 150. FIGS. 2A and 2B depict a top view and a side view, respectively, of the pump system 100 without the control system 170 attached thereto.

[0013] FIG. 2C depicts a cross-sectional view of the piston cylinder pump 110, according to one or more embodiments. The piston cylinder pump 110 includes a cylinder body 119 containing a piston 120 located within a cavity 109 of the cylinder body 119. The piston 120 can linearly move between a first inner surface 111 and a second inner surface 113 of the cylinder body 119 within the cavity 109. The piston 120 includes a first side 122 opposite a second side 124. A rod 118 is coupled to the first side 122 of the piston 120, as depicted in FIG. 2C. The rod 118 is used to provide the linear movement between the first and second inner surfaces 111, 113 within the cylinder body 119.

[0014] The piston cylinder pump 110 can also include a first adjustable chamber 112 and a second adjustable chamber 114 separated from one another by the piston 120 and located within the cavity 109. The first adjustable chamber 112 can be defined by or otherwise located between the first side 122 of the piston 120, the first inner surface 111 of the cylinder body 119, and a cylindrical inner surface 117 of the cylinder body 119. The second adjustable chamber 114 can be defined by or otherwise located between the second side 124 of the piston 120, the second inner surface 113 of the cylinder body 119, and the cylindrical inner surface 117 of the cylinder body 119.

[0015] Each adjustable chamber 112, 114 has a variable volume relative to the location of the piston 120. For example, the available surface area of the cylindrical inner surface 117 in each of the adjustable chambers 112, 114 varies relative to the location of the piston 120 when linearly moving within the cylinder body 119. The surface area for each of the first and

second inner surfaces 111, 113 of the cylinder body 119 and each of the first and second sides 122, 124 of the piston 120 is constant during the linear movement of the piston 120.

[0016] The piston cylinder pump 110 can further include two, three, four, or more ports 102, 104, 106, 108 defined in the cylinder body 119 and in fluid communication with one or the other adjustable chambers 112, 114. For example, the piston cylinder pump 110 includes two ports, as depicted in FIG. 3, such as a first port 102 defined in and/or otherwise passing through the cylinder body 119 and in fluid communication with the first adjustable chamber 112 and a second port 104 defined in and/or otherwise passing through the cylinder body 119 and in fluid communication with the second adjustable chamber 114. In other embodiments, such as depicted in FIGS. 1 and 2A-2C, the piston cylinder pump 110 includes four ports, such as a third port 106 defined in and/or otherwise passing through the cylinder body 119 and in fluid communication with the first adjustable chamber 112 and a fourth port 108 defined in and/or otherwise passing through the cylinder body 119 and in fluid communication with the second adjustable chamber 114.

[0017] One or more components and/or surfaces of the piston cylinder pump 110 can be made of and/or include one or more materials that are substantially or completely non-reactive with the fluids that may pass therethrough. For example, each of the cylinder body 119, the piston 120, and the rod 118 can independently contain, be made of, and/or include, but is not limited to, one or more materials, such as steel, stainless steel, iron, nickel, chromium, alloys thereof, or any mixture thereof. For example, the cylinder body 119, the piston 120, and the rod 118 can independently contain or include 316 stainless steel. The piston cylinder pump 110 can include one or more sealing devices, such as one or more seals, one or more gaskets, one or more O-rings, packing, or any combination thereof therein (not shown). For example, the piston 120 can include one or more seals or O-rings encircling the circumference of the piston 120 and forming a fluid seal (e.g., liquid, gas, or mixtures thereof) against and between the cylindrical inner surface 117 of the cylinder body 119. The rod 118 can include one or more seals or O-rings encircling the circumference of the rod 118 and forming a fluid seal (e.g., liquid, gas, or mixtures thereof) against and between the first inner surface 111 and/or the second inner surface 113. The sealing devices can be or include, but are not limited to, one or more materials, such as natural rubber, synthetic rubber, elastomer, fluoropolymer, hexafluoropropylene, vinylidene fluoride, tetrafluoroethylene, perfluoromethylvinylether, polytetrafluoroethylene, co-polymers thereof, or any combination thereof. Exemplary commercial sealing devices can be or include, but are not limited to,

VITON[®], BUNA-N[®], VANOS[®], and/or TEFLON[®] polymers, rubbers, materials, O-rings, seals, or any combination thereof.

[0018] The piston 120 is linearly moveable in a two-stroke cycle away from the linear actuator 130 during an initial or first stroke at a first stroke speed and toward the linear actuator 130 during a return or second stroke at a second stroke speed. Each of the first and the second stroke speeds is individually controlled to be faster, slower, or equal to one another. For example, the second stroke speed can be controlled to be faster or otherwise greater than the first stroke speed. In one or more examples, the first adjustable chamber 112 contains a first minimum volume at a start of the first stroke and a first maximum volume at an end of the first stroke and the second adjustable chamber 114 contains a second minimum volume at a start of the second stroke and a second maximum volume at an end of the second stroke. Since the rod 118 extends through the first adjustable chamber 112 and the second adjustable chamber 114 is free of the rod 118, the first minimum volume is less than the second minimum volume and the first maximum volume is less than the second maximum volume. The length of the rod 118 within the first adjustable chamber 112 increases and decreases with the linear movement of the piston 120 between the inner surfaces 111, 113. For a given linear speed of the piston 120, the displacement is greater when moving toward the inner surface 113 than when moving toward the inner surface 111. As such, the second stroke speed can be adjusted to be faster or greater than the first stroke speed so that the first port 102 and the second port 104 discharge fluid at the same flowrate or substantially the same flowrate. The first port 102 and the second port 104 also uptake fluid at the same flowrate or substantially the same flowrate.

[0019] The motor assembly 150 is coupled to the linear actuator 130 and operable to drive the linear actuator 130 with rotational motion. The motor assembly 150 is coupled to the linear actuator 130 by direct drive or indirect drive, including, but not limited to, one or more shafts, one or more connectors, one or more gears, one or more pulleys, one or more belts, one or more chains, or any combination thereof. In one or more embodiments, the motor assembly 150 is an electric motor assembly and can be or include a servomotor or another type of electric motor. Alternatively, the motor assembly 150 is a hydraulic motor or a pneumatic motor with a respective controller. For example, the motor assembly 150 can be a hydraulic motor and a hydraulic controller and used to operate or drive the linear actuator 130. The linear actuator 130 can be or include, but is not limited to, a screw actuator, a hydraulic actuator, a pneumatic actuator, or any combination thereof. In one or more

examples, the linear actuator 130, such as a screw actuator, converts rotational motion to linear motion. An exemplary screw actuator is or contains a ball screw linear actuator.

[0020] The linear actuator 130 includes a support structure, a frame, or a body 132 and the motor assembly 150 includes a support structure, a frame, or a body 152, as depicted in FIGS. 1 and 2A-2B. In one or more embodiments, the linear actuator 130 also includes a shaft and/or drive screw 138 operably coupled to the rod 118 of the piston cylinder pump 110, and the motor assembly 150 includes a motor 154 (e.g., electric motor) operably coupled to the shaft and/or drive screw 138 of the linear actuator 130, as depicted in FIGS. 3-5. The linear actuator 130 can also include bearings 146 (e.g., thrust bearings) at least partially located around the shaft and/or drive screw 138, as depicted in FIGS. 3-5. The motor assembly 150 is coupled to the linear actuator 130 and operable to drive the linear actuator 130, and the linear actuator 130 is coupled to the rod 118 and operable to drive the piston 120.

[0021] In one or more examples, the linear actuator 130 includes a ball screw that converts the rotational motion of the motor assembly 150 (e.g., electric motor assembly or servo motor) to linear motion for the piston cylinder pump 110. The ball screw on the linear actuator 130 is equipped with or otherwise includes a position feedback sensor which is used to find volumetric flowrate of the fluid passing through the piston cylinder pump 110. The position feedback sensor can also be positioned on the piston cylinder pump 110 and/or the motor assembly 150. The volumetric flowrate of the fluid is used to accurately meter or otherwise measure the fluids (e.g., liquid additives), such as the fluid passing through the piston cylinder pump 110.

[0022] The control system 170 is operably coupled to at least the motor assembly 150, but can also be operably coupled to the piston cylinder pump 110, the linear actuator 130, and/or one or more sensors (not shown). The control system 170 is operably coupled to the components and/or sensors by one or more cables and/or by wireless communication. The control system 170 can be or include, but is not limited to, one or more controllers, one or more modules, one or more amplifiers, one or more computers, one or more communication devices, or any combination thereof. In one or more configurations, the control system 170 sequentially switches between the first stroke at the first stroke speed of the piston 120 and the second stroke at the second stroke speed of the piston 120. The control system 170 is used to maintain or adjust the stroke speeds so that the second stroke speed is controlled to be faster or otherwise greater than the first stroke speed (or in the alternative, the first stroke speed is slower or otherwise less than the second stroke speed) and the flowrates of the fluid

via the discharge lines and/or ports are equal or substantially equal during the first and second strokes. The control system 170 and/or the motor assembly 150 (e.g., electric motor assembly or servo motor) can include an amplifier to control the servo speed and/or rotation direction.

[0023] In one or more embodiments, the piston cylinder pump 110 includes one, two, three, four, or more fluid lines and one, two, three, four, or more valves (four valves are shown in FIGS. 3-5). Each of the fluid lines can be or include a feed line, a discharge line, or a hybrid feed-discharge line. The feed line transfers fluid into the piston cylinder pump 110, the discharge line transfers fluid from the piston cylinder pump 110, and the hybrid feed-discharge line transfers fluid, at different times, to and from the piston cylinder pump 110. In one or more configurations, as depicted in FIGS. 3-5, two or more feed lines 360, 362 are fluidly coupled to one or more fluid sources 190 via one or more lines 191. Also, two or more discharge lines 364, 366 are fluidly coupled to one or more fluid containers 192 via one or more lines 193. The fluid source 190 can be or include, but is not limited to, one or more containers or vessels, one or more lines or conduits, or other sources of one or more fluids that are flowed or otherwise transferred into the piston cylinder pump 110. The fluid container 192 can be or include, but is not limited to, one or more containers or vessels, one or more reaction chambers, one or more mixers, one or more lines or conduits, or other destinations for one or more fluids that are flowed or otherwise transferred from the piston cylinder pump 110. The fluids can be combined, mixed, and/or stored in the fluid container 192.

[0024] FIG. 3 depicts a schematic view of a pumping assembly 350 containing a pump system 300 fluidly coupled to a conduit system 320, according to one or more embodiments. The pump system 300 also contains the piston cylinder pump 110 operably coupled to the linear actuator 130 that is operably coupled to the motor assembly 150. The pump system 300 contains the piston cylinder pump 110 coupled to and in fluid communication with the conduit system 320. The conduit system 320 and/or the pump system 300 can each include one, two, three, four, or more valves. As shown in FIG. 3, the pumping assembly 350 contains the four valves 160, 162, 164, 168 located in the conduit system 320.

[0025] In one or more configurations, the valve 160 is fluidly coupled to and between the first adjustable chamber 112 and the feed line 360, and the valve 164 is fluidly coupled to and between the first adjustable chamber 112 and the discharge line 364. The valve 162 is fluidly coupled to and between the second adjustable chamber 114 and the feed line 362, and the valve 166 is fluidly coupled to and between the second adjustable chamber 114 and the

discharge line 366. For example, the port 102 is in fluid communication with the feed line 360 and the discharge line 364 via line 361. The port 104 is in fluid communication with the feed line 362 and the second discharge line 366 via line 363. A first pair of valves 160, 164 controls the fluid communication between the port 102 and the feed line 360 and the discharge line 364, respectively. A second pair of valves 162, 166 controls the fluid communication between the port 104 and the feed line 362 and the discharge line 366, respectively. The first pair of valves 160, 164 includes the valve 160 located between the port 102 and the feed line 360 and the valve 164 located between the port 102 and the discharge line 364. The second pair of valves 162, 166 includes the valve 162 located between the port 104 and the feed line 362 and the valve 166 located between the port 104 and the discharge line 366.

[0026] In one or more embodiments of the pumping assembly 350, the piston 120 is linearly moved away from the linear actuator 130 to increase the useable volume in the first adjustable chamber 112 and to decrease the useable volume in the second adjustable chamber 114. The first adjustable chamber 112 contains a first minimum volume at a start of the first stroke and a first maximum volume at an end of the first stroke. During the first stroke, the fluid in the fluid source 190 is transferred via line 191, through the feed line 360, the valve 160, the line 361, and the port 102, and into the first adjustable chamber 112. Also, during the first stroke, the fluid in the second adjustable chamber 114 is transferred through the port 104, the line 363, the valve 166, and the discharge line 366 to the fluid container 192 via line 193. The second adjustable chamber 114 contains a second minimum volume at a start of the second stroke and a second maximum volume at an end of the second stroke. During the second stroke, the fluid in the fluid source 190 is transferred via line 191, through the feed line 362, the valve 162, the line 363, and the port 104, and into the second adjustable chamber 114. Also, during the second stroke, the fluid in the first adjustable chamber 112 is transferred through the port 102, the line 361, the valve 164, and the discharge line 364 to the fluid container 192 via line 193.

[0027] FIG. 4 depicts a schematic view of a pumping assembly 450 containing a pump system 400 fluidly coupled to a conduit system 420, according to one or more embodiments. The pump system 400 contains the piston cylinder pump 110 operably coupled to the linear actuator 130 that is operably coupled to the motor assembly 150. The pump system 400 also contains the piston cylinder pump 110 coupled to and in fluid communication with the conduit system 420. The conduit system 420 and/or the pump system 400 can each

independently include one, two, three, four, or more valves. As shown in FIG. 4, the pumping assembly 450 contains the four valves 160, 162, 164, 168 located in the conduit system 420. For example, the valve 160 is fluidly coupled to and between the port 106 and the feed line 360, the valve 162 is fluidly coupled to and between the port 108 and the feed line 362, the valve 164 is fluidly coupled to and between the port 102 and the discharge line 364, and the valve 166 is fluidly coupled to and between the port 104 and the discharge line 366.

[0028] In one or more embodiments of the pumping assembly 450, the piston 120 is linearly moved away from the linear actuator 130 to increase the useable volume in the first adjustable chamber 112 and to decrease the useable volume in the second adjustable chamber 114. The first adjustable chamber 112 contains a first minimum volume at a start of the first stroke and a first maximum volume at an end of the first stroke. During the first stroke, the fluid in the fluid source 190 is transferred via line 191, through the feed line 360, the valve 160, and the port 106, and into the first adjustable chamber 112. Also, during the first stroke, the fluid in the second adjustable chamber 114 is transferred through the port 104, the valve 166, and the discharge line 366 to the fluid container 192 via line 193. The second adjustable chamber 114 contains a second minimum volume at a start of the second stroke and a second maximum volume at an end of the second stroke. During the second stroke, the fluid in the fluid source 190 is transferred via line 191, through the feed line 362, the valve 162, and the port 108, and into the second adjustable chamber 114. Also, during the second stroke, the fluid in the first adjustable chamber 112 is transferred through the port 102, the valve 164, and the discharge line 364 to the fluid container 192 via line 193.

[0029] FIG. 5 depicts a schematic view of a pumping assembly 550 containing a pump system 500 fluidly coupled to a conduit system 520, according to one or more embodiments. The pump system 500 contains the piston cylinder pump 110 operably coupled to the linear actuator 130 that is operably coupled to the motor assembly 150. The pump system 500 also contains the piston cylinder pump 110 coupled to and in fluid communication with the conduit system 520. The piston cylinder pump 110 of the pump system 500 can include one, two, three, four, or more valve housings 115 that can each include one or more valves 160, 162, 164, 166. As shown in FIG. 5, the piston cylinder pump 110 of the pump system 500 contains the four valve housings 115 and the four valves 160, 162, 164, 168, such that each of the valves 160, 162, 164, 168 is located in a respective valve housing 115. For example, the valve 160 within the valve housing 115 is fluidly coupled to and between the port 106 and the feed line 360, the valve 162 within the valve housing 115 is fluidly coupled to and between

the port 108 and the feed line 362, the valve 164 within the valve housing 115 is fluidly coupled to and between the port 102 and the discharge line 364, and the valve 166 within the valve housing 115 is fluidly coupled to and between the port 104 and the discharge line 366.

[0030] In one or more embodiments of the pumping assembly 550, the piston 120 is linearly moved away from the linear actuator 130 to increase the useable volume in the first adjustable chamber 112 and to decrease the useable volume in the second adjustable chamber 114. The first adjustable chamber 112 includes a first minimum volume at a start of the first stroke and a first maximum volume at an end of the first stroke. During the first stroke, the fluid in the fluid source 190 is transferred via line 191, through the feed line 360, the valve 160 within the valve housing 115, and the port 106, and into the first adjustable chamber 112. Also, during the first stroke, the fluid in the second adjustable chamber 114 is transferred through the port 104, the valve 166 within the valve housing 115, and the discharge line 366 to the fluid container 192 via line 193. The second adjustable chamber 114 contains a second minimum volume at a start of the second stroke and a second maximum volume at an end of the second stroke. During the second stroke, the fluid in the fluid source 190 is transferred via line 191, through the feed line 362, the valve 162 within the valve housing 115, and the port 108, and into the second adjustable chamber 114. Also, during the second stroke, the fluid in the first adjustable chamber 112 is transferred through the port 102, the valve 164 within the valve housing 115, and the discharge line 364 to the fluid container 192 via line 193.

[0031] Each of the valves 160, 162, 164, 168 can be or include, but not limited to, a check valve, a two-way valve, a three-way valve, a stop valve, a pressure valve, or any combination thereof. Each of the valves 160, 162, 164, 168 can independently be controlled and/or operated by, but not limited to, manual control, electronic control, pneumatic control, hydraulic control, or any combination thereof. For example, each of the valves 160, 162, 164, 168 can independently be a check valve.

[0032] Alternatively, one, two, three, four, or more of the valves 160, 162, 164, 168 (e.g., two valves) can independently be three-way valves and are used to control the fluid communication between, to, or from, any of the ports 102, 104, 106, 108, the fluid sources 190, the containers 192, any of the fluid source or discharge lines, other lines, or any combination thereof. For example, although not shown, a first three-way valve controls the fluid communication between the port 102 and the fluid source line 360 and the fluid discharge line 364 (e.g., substituting the valves 160 and 164 in FIG. 3), and a second three-

way valve controls the fluid communication between the port 104 and the fluid source line 362 and the fluid discharge line 366 (e.g., substituting the valves 160 and 164 in FIG. 3).

[0033] The pump systems 100, 300, 400, 500 include one, two, or more position feedback sensors operably coupled to one or more of the components, such as the piston cylinder pump 110, the linear actuator 130, and/or the motor assembly 150 and further operably coupled to the control system 170. For example, the position feedback sensor is operably coupled to the linear actuator 130 and/or the motor assembly 150. The position feedback sensor measures or otherwise determines volumetric flowrate.

[0034] The pump systems 100, 300, 400, 500, or other pump systems described or discussed herein, can have a flowrate of about 0.1 gallons per minute (gpm), about 0.2 gpm, about 0.5 gpm, about 0.8 gpm, about 1 gpm, or about 2 gpm to about 3 gpm, about 5 gpm, about 8 gpm, about 10 gpm, about 15 gpm, about 20 gpm, about 30 gpm, about 40 gpm, about 50 gpm, about 75 gpm, about 100 gpm, or greater. For example, the pump systems 100, 300, 400, 500, or other pump systems described or discussed herein, can have a flowrate of about 0.1 gpm to about 100 gpm, about 0.1 gpm to about 75 gpm, about 0.1 gpm to about 50 gpm, about 0.1 gpm to about 40 gpm, about 0.2 gpm to about 40 gpm, about 0.5 gpm to about 40 gpm, about 0.1 gpm to about 30 gpm, about 0.2 gpm to about 30 gpm, about 0.5 gpm to about 30 gpm, about 0.1 gpm to about 20 gpm, about 0.2 gpm to about 20 gpm, about 0.5 gpm to about 20 gpm, about 0.1 gpm to about 10 gpm, about 0.2 gpm to about 10 gpm, about 0.5 gpm to about 10 gpm, about 0.1 gpm to about 5 gpm, about 0.2 gpm to about 5 gpm, or about 0.5 gpm to about 5 gpm.

[0035] The piston 120 within the cylinder body 119 for any of the pump systems 100, 300, 400, 500, or other pump systems described or discussed herein, can have a linear speed of about 0.04 inches per second (ips), about 0.08 ips, about 0.1 ips, about 0.5 ips about 0.8 ips, about 1 ips, or about 2 ips to about 3 ips, about 4 ips, about 5 ips, about 7 ips, about 10 ips, about 12 ips, about 15 ips, about 20 ips, about 25 ips, about 35 ips, about 50 ips, or faster. For example, the piston 120 within the cylinder body 119 for any of the pump systems 100, 300, 400, 500, or other pump systems described or discussed herein, can have a linear speed of about 0.04 ips to about 50 ips, about 0.04 ips to about 35 ips, about 0.04 ips to about 20 ips, about 0.04 ips to about 15 ips, about 0.5 ips to about 15 ips, about 1 ips to about 15 ips, about 2 ips to about 15 ips, about 5 ips to about 15 ips, about 10 ips to about 15 ips, about 0.04 ips to about 10 ips, about 0.5 ips to about 10 ips, about 1 ips to about 10 ips, about 2 ips to about

10 ips, about 5 ips to about 10 ips, about 0.04 ips to about 5 ips, about 0.5 ips to about 5 ips, about 1 ips to about 5 ips, or about 2 ips to about 5 ips.

[0036] The linear actuator 130 in any of the pump systems 100, 300, 400, 500, or other pump systems described or discussed herein, can have a rotational speed of about 0.5 rpm, about 1 rpm, about 5 rpm, about 6 rpm, about 8 rpm, about 10 rpm, about 20 rpm, about 50 rpm, or about 100 rpm to about 200 rpm, about 500 rpm, about 800 rpm, about 1,000 rpm, about 1,200 rpm, about 1,500 rpm, about 1,800 rpm, about 2,000 rpm, about 2,200 rpm, about 2,300 rpm, about 2,500 rpm, about 3,000 rpm, about 4,000 rpm, about 5,000 rpm, or greater. For example, the linear actuator 130 in any of the pump systems 100, 300, 400, 500, or other pump systems described or discussed herein, can have a rotational speed of about 0.5 rpm to about 5,000 rpm, about 0.5 rpm to about 3,000 rpm, about 0.5 rpm to about 2,500 rpm, about 1 rpm to about 2,500 rpm, about 6 rpm to about 2,500 rpm, about 10 rpm to about 2,500 rpm, about 50 rpm to about 2,500 rpm, about 100 rpm to about 2,500 rpm, about 200 rpm to about 2,500 rpm, about 500 rpm to about 2,500 rpm, about 700 rpm to about 2,500 rpm, about 6 rpm to about 2,300 rpm, about 1 rpm to about 2,000 rpm, about 6 rpm to about 2,000 rpm, about 10 rpm to about 2,000 rpm, about 50 rpm to about 2,000 rpm, about 100 rpm to about 2,000 rpm, about 200 rpm to about 2,000 rpm, about 500 rpm to about 2,000 rpm, about 700 rpm to about 2,000 rpm, about 1 rpm to about 1,200 rpm, about 6 rpm to about 1,200 rpm, about 10 rpm to about 1,200 rpm, about 50 rpm to about 1,200 rpm, about 100 rpm to about 1,200 rpm, about 200 rpm to about 1,200 rpm, about 500 rpm to about 1,200 rpm, or about 700 rpm to about 1,200 rpm.

[0037] In one or more embodiments, any of the pump systems 100, 300, 400, 500, or other pump systems described or discussed herein, can be used in methods for pumping, transferring, dispensing, measuring, metering, and/or combining, one or more fluids. The fluids can be or include, but are not limited to, one or more liquids, one or more gases, one or more solutions, one or more suspensions, or any mixture thereof. The fluids can be or include, but are not limited to, one or more precursors, one or more components, one or more additives, one or more solvents, or any mixture thereof, that can be combined together to produce a mixture or one or more products.

[0038] The method includes sequentially switching between a first stroke at a first stroke speed and a second stroke at a second stroke speed of the piston 120 located within the cylinder body 119 of the piston cylinder pump 110. The second stroke speed is greater than the first stroke speed. The piston cylinder pump 110 includes the first adjustable chamber 112

and the second adjustable chamber 114 separated from each other by the piston 120. The piston 120 linearly moves in a first direction to adjust from a first minimum volume of the first adjustable chamber 112 at a start of the first stroke to a first maximum volume of the first adjustable chamber 112 at an end of the first stroke. The piston 120 linearly moves in a second direction opposite of the first direction to adjust from a second minimum volume of the second adjustable chamber 114 at a start of the second stroke to a second maximum volume of the second adjustable chamber 114 at an end of the second stroke. The fluid discharges from the first and second adjustable chambers 112, 114 at the same flowrate or substantially the same flowrate.

[0039] FIG. 6 depicts a schematic view of a cylinder pump 610 that can be used as the cylinder pump 110 in any of the pump systems 100, 300, 400, 500, or other pump systems described or discussed herein. The cylinder pump 610 includes a cylinder body 119 containing a piston 120 and ports 102, 104, 106, 108 passing through the cylinder body 119. The piston 120 linearly moves between the first inner surface 111 and the second inner surface 113 of the cylinder body 119. The piston 120 includes the first side 122 opposite the second side 124. The rod 118 is coupled to the first side 122 of the piston 120, as depicted in FIG. 6. The rod 118 provides the linear movement between the first and second inner surfaces 111, 113 within the cylinder body 119. The piston cylinder pump 110 also includes the first adjustable chamber 112 and the second adjustable chamber 114 separated from one another by the piston 120. The ports 102, 106 are in fluid communication with the first adjustable chamber 112 and the ports 104, 108 are in fluid communication with the second adjustable chamber 114.

[0040] FIG. 7 depicts a schematic view of a ball screw linear actuator 730 coupled to an electric motor assembly 750 by a belt 760, according to one or more embodiments. The ball screw linear actuator 730 can be used as the linear actuator 130 and the electric motor assembly 750 can be used as the motor assembly 150 in any of the pump systems 100, 300, 400, 500 or other pump systems described or discussed herein.

[0041] The electric motor assembly 750 includes an electric motor located inside a housing 752 and a pulley 754 coupled to a stator or driveshaft of the electric motor. The belt or timing belt 760 is coupled to and between the pulley 754 and a gear or pulley 748 on the ball screw linear actuator 730. The linear actuator 730 includes a ball or drive screw 740 that converts the rotational motion of the electric motor assembly 750 (e.g., servo motor) to linear motion for the piston cylinder pump (not shown).

[0042] The ball screw linear actuator 730 also includes a support structure, a frame or body 732, a shaft or rod 734, one or more seals 736, a drive screw 740, a drive nut 742, and thrust bearings 746. The gear or pulley 748 of the ball screw linear actuator 730 is operably coupled to the drive nut 742, the drive screw 740, and the shaft or rod 734 that is operably coupled to the rod of the piston cylinder pump (not shown).

[0043] In addition to the embodiments described above, embodiments of the present disclosure further relate to one or more of the following paragraphs:

[0044] 1. A pump system, comprising a piston cylinder pump comprising: a piston located within a cavity of a cylinder body and dividing the cavity into a first adjustable chamber and a second adjustable chamber and a rod coupled to the piston; a linear actuator comprising a shaft coupled to the rod, wherein the linear actuator converts rotational motion to linear motion to linearly move the rod; and a motor assembly coupled to the linear actuator and operable to drive the linear actuator.

[0045] 2. A pump system, comprising: a piston cylinder pump comprising a piston located within a cavity of a cylinder body and dividing the cavity into a first adjustable chamber and a second adjustable chamber, wherein the piston comprises a first side opposite a second side and a rod coupled to the first side of the piston; a linear actuator comprising a shaft coupled to the rod, wherein the linear actuator converts rotational motion to linear motion to move the rod linearly; and an electric motor assembly coupled to the linear actuator and operable to drive the linear actuator; wherein the piston is moveable linearly in a two-stroke cycle that comprises a first stroke away from the linear actuator and a second stroke toward the linear actuator, wherein the first stroke is slower than the second stroke.

[0046] 3. A method for pumping a fluid, comprising: sequentially switching between a first stroke at a first stroke speed and a second stroke at a second stroke speed of a piston located within a cylinder body of a piston cylinder pump, wherein the second stroke speed is greater than the first stroke speed, and wherein the piston cylinder pump comprises a first adjustable chamber and a second adjustable chamber separated from each other by the piston; linearly moving the piston in a first direction to adjust from a first minimum volume of the first adjustable chamber at a start of the first stroke to a first maximum volume of the first adjustable chamber at an end of the first stroke; linearly moving the piston in a second direction opposite of the first direction to adjust from a second minimum volume of the second adjustable chamber at a start of the second stroke to a second maximum volume of the

second adjustable chamber at an end of the second stroke; and discharging fluid from the first and second adjustable chambers at substantially the same flowrate.

[0047] 4. The pump system and/or the method according to any one of paragraphs 1-3, wherein: the piston comprises a first side opposite a second side; the rod is coupled to the first side of the piston; the first adjustable chamber is located between the first side of the piston and a first inner surface of the cylinder body; and the second adjustable chamber is located between the second side of the piston and a second inner surface of the cylinder body.

[0048] 5. The pump system and/or the method according to any one of paragraphs 1-4, wherein the piston is configured to move in a two-stroke cycle.

[0049] 6. The pump system and/or the method according to paragraph 5, wherein the piston is linearly moveable away from the linear actuator during a first stroke at a first stroke speed and linearly moveable toward the linear actuator during a second stroke at a second stroke speed, wherein the second stroke speed is greater than the first stroke speed.

[0050] 7. The pump system and/or the method according to paragraph 6, wherein: the first adjustable chamber has a first minimum volume at a start of the first stroke; the second adjustable chamber has a second minimum volume at a start of the second stroke; and the first minimum volume is less than the second minimum volume.

[0051] 8. The pump system and/or the method according to paragraph 6, further comprising a first port in fluid communication with the first adjustable chamber, a second port in fluid communication with the second adjustable chamber, and wherein the first port and the second port discharge a fluid at substantially the same flowrate.

[0052] 9. The pump system and/or the method according to paragraph 6, further comprising a first port in fluid communication with the first adjustable chamber, a second port in fluid communication with the second adjustable chamber, and wherein the first port and the second port uptake a fluid at substantially the same flowrate.

[0053] 10. The pump system and/or the method according to any one of paragraphs 1-9, wherein the piston cylinder pump further comprises: a third port defined in the cylinder body and in fluid communication with the first adjustable chamber; a fourth port defined in the cylinder body and in fluid communication with the second adjustable chamber; a first valve fluidly coupled to and between the first port and a first feed line; a second valve fluidly coupled to and between the second port and a first discharge line; a third valve fluidly coupled to and between the third port and a second feed line; and a fourth valve fluidly coupled to and between the fourth port and a second discharge line.

[0054] 11. The pump system and/or the method according to any one of paragraphs 1-10, further comprising a control system operably coupled to the motor assembly, and wherein the motor assembly comprises an electric motor.

[0055] 12. The pump system and/or the method according to paragraph 11, wherein the control system comprises a module.

[0056] 13. The pump system and/or the method according to paragraph 11, wherein: the control system operable to sequentially switch between a first stroke at a first stroke speed of the piston and a second stroke at a second stroke speed of the piston; the first adjustable chamber comprises a first minimum volume at a start of the first stroke and a first maximum volume at an end of the first stroke and the second adjustable chamber comprises a second minimum volume at a start of the second stroke and a second maximum volume at an end of the second stroke; the first minimum volume is less than the second minimum volume; the first maximum volume is less than the second maximum volume; and the second stroke speed is greater than the first stroke speed.

[0057] 14. The pump system and/or the method according to any one of paragraphs 1-13, wherein the piston cylinder pump further comprises: a first valve fluidly coupled to and between the first adjustable chamber and a first feed line; a second valve fluidly coupled to and between the first adjustable chamber and a first discharge line; a third valve fluidly coupled to and between the second adjustable chamber and a second feed line; and a fourth valve fluidly coupled to and between the second adjustable chamber and a second discharge line.

[0058] 15. The pump system and/or the method according to any one of paragraphs 1-14, further comprising a first port in the cylinder body and in fluid communication with the first adjustable chamber, a first feed line, and a first discharge line; and a second port in the cylinder body and in fluid communication with the second adjustable chamber, a second feed line, and a second discharge line.

[0059] 16. The pump system and/or the method according to paragraph 15, wherein a first pair of valves controls the fluid communication between the first port and the first feed line and the first discharge line, and wherein a second pair of valves controls the fluid communication between the second port and the second feed line and the second discharge line.

[0060] 17. The pump system and/or the method according to paragraph 16, wherein the first pair of valves comprises a first valve located between the first port and the first feed line

and a second valve located between the first port and the first discharge line, and wherein the second pair of valves comprises a third valve located between the second port and the second fluid source, and a fourth valve located between the second port and the second fluid discharge.

[0061] 18. The pump system and/or the method according to any one of paragraphs 1-17, wherein the linear actuator comprises a screw actuator, a hydraulic actuator, a pneumatic actuator, or any combination thereof.

[0062] 19. The pump system and/or the method according to any one of paragraphs 1-18, wherein the linear actuator comprises a ball screw actuator.

[0063] 20. The pump system and/or the method according to any one of paragraphs 1-19, further comprising a position feedback sensor coupled to at least one of the piston cylinder pump, the linear actuator, and the motor assembly.

[0064] 21. The pump system and/or the method of paragraph 20, wherein the position feedback sensor is configured to determine volumetric flowrate.

[0065] 22. The pump system and/or the method according to any one of paragraphs 1-21, wherein the motor assembly comprises a servomotor.

[0066] 23. The pump system and/or the method according to any one of paragraphs 1-22, wherein: the first adjustable chamber comprises a first minimum volume at a start of the first stroke and a first maximum volume at an end of the first stroke and the second adjustable chamber comprises a second minimum volume at a start of the second stroke and a second maximum volume at an end of the second stroke; and the first maximum volume is less than the second maximum volume.

[0067] 24. The pump system and/or the method according to any one of paragraphs 1-22, wherein the piston cylinder pump further comprises: a first port defined in the cylinder body and in fluid communication with the first adjustable chamber; a second port defined in the cylinder body and in fluid communication with the second adjustable chamber; a third port defined in the cylinder body and in fluid communication with the first adjustable chamber; a fourth port defined in the cylinder body and in fluid communication with the second adjustable chamber; a first valve fluidly coupled to and between the first port and a first feed line; a second valve fluidly coupled to and between the second port and a first discharge line; a third valve fluidly coupled to and between the third port and a second feed line; and a fourth valve fluidly coupled to and between the fourth port and a second discharge line.

[0068] 25. The pump system and/or the method according to any one of paragraphs 1-24, wherein each of the valves is a check valve.

[0069] 26. The pump system and/or the method according to any one of paragraphs 1-25, wherein a first three-way valve is configured to control the fluid communication between the first port and the first fluid source and the first fluid discharge, and wherein a second three-way valve is configured to control the fluid communication between the second port and the second fluid source and the second fluid discharge.

[0070] 27. The pump system and/or the method according to any one of paragraphs 1-26, wherein the cylinder body comprises steel, stainless steel, iron, nickel, chromium, alloys thereof, or any mixture thereof.

[0071] 28. The pump system and/or the method according to any one of paragraphs 1-27, wherein the cylinder body comprises 316 stainless steel.

[0072] 29. The pump system and/or the method according to any one of paragraphs 1-28, wherein the pump system has a flowrate of about 0.1 gallons per minute (gpm) to about 500 gpm.

[0073] 30. The pump system and/or the method according to any one of paragraphs 1-29, wherein the pump system has a flowrate of about 0.1 gpm to about 40 gpm.

[0074] 31. The pump system and/or the method according to any one of paragraphs 1-30, wherein the piston has a lateral speed of about 0.04 inches per second to about 50 inches per second within the cylinder body.

[0075] 32. The pump system and/or the method according to any one of paragraphs 1-31, wherein the piston has a lateral speed of about 0.1 inches per second to about 15 inches per second within the cylinder body.

[0076] 33. The pump system and/or the method according to any one of paragraphs 1-32, wherein the linear actuator has a rotational speed of about 0.5 rpm to about 5,000 rpm.

[0077] 34. The pump system and/or the method according to any one of paragraphs 1-33, wherein the linear actuator has a rotational speed of about 6 rpm to about 2,300 rpm.

[0078] This discussion is directed to various embodiments of the invention. The drawing figures are not necessarily to scale. Certain features of the embodiments can be shown exaggerated in scale or in somewhat schematic form and some details of conventional elements may not be shown in the interest of clarity and conciseness. Although one or more of these embodiments can be preferred, the embodiments disclosed should not be interpreted, or otherwise used, as limiting the scope of the disclosure, including the claims. It is to be

fully recognized that the different teachings of the embodiments discussed can be employed separately or in any suitable combination to produce desired results. In addition, one skilled in the art will understand that the description has broad application, and the discussion of any embodiment is meant only to be exemplary of that embodiment, and not intended to intimate that the scope of the disclosure, including the claims, is limited to that embodiment.

[0079] Within this document, a reference identifier can be used as a general label, for example "101," for a type of element and alternately used to indicate a specific instance or characterization, for example "101A" and "101B," of that same type of element.

[0080] Certain terms are used throughout the description and claims to refer to particular features or components. As one skilled in the art will appreciate, different persons may refer to the same feature or component by different names. This document does not intend to distinguish between components or features that differ in name but not function, unless specifically stated. In the discussion and in the claims, the terms "including" and "comprising" are used in an open-ended fashion, and thus should be interpreted to mean "including, but not limited to..." Also, the term "couple" or "couples" is intended to mean either an indirect or direct connection. The use of "top," "bottom," "above," "below," and variations of these terms is made for convenience, but does not require any particular orientation of the components.

[0081] Certain embodiments and features have been described using a set of numerical upper limits and a set of numerical lower limits. It should be appreciated that ranges including the combination of any two values, e.g., the combination of any lower value with any upper value, the combination of any two lower values, and/or the combination of any two upper values are contemplated unless otherwise indicated. Certain lower limits, upper limits and ranges appear in one or more claims below. All numerical values are "about" or "approximately" the indicated value, and take into account experimental error and variations that would be expected by a person having ordinary skill in the art.

[0082] Reference throughout this specification to "one embodiment," "an embodiment," or similar language means that a particular feature, structure, or characteristic described in connection with the embodiment can be included in at least one embodiment of the present disclosure. Thus, appearances of the phrases "in one embodiment," "in an embodiment," and similar language throughout this specification may, but do not necessarily, all refer to the same embodiment.

[0083] Although the present invention has been described with respect to specific details, it is not intended that such details should be regarded as limitations on the scope of the invention, except to the extent that they are included in the accompanying claims.

Claims

What is claimed is:

1. A pump system, comprising:

a piston cylinder pump comprising a piston located within a cavity of a cylinder body and dividing the cavity into a first adjustable chamber and a second adjustable chamber and a rod coupled to the piston;
a linear actuator comprising a shaft coupled to the rod, wherein the linear actuator converts rotational motion to linear motion to linearly move the rod; and
a motor assembly coupled to the linear actuator and operable to drive the linear actuator.

2. The pump system of claim 1, wherein:

the piston comprises a first side opposite a second side;
the rod is coupled to the first side of the piston;
the first adjustable chamber is located between the first side of the piston and a first inner surface of the cylinder body; and
the second adjustable chamber is located between the second side of the piston and a second inner surface of the cylinder body.

3. The pump system of claim 2, wherein the piston is linearly moveable away from the linear actuator during a first stroke at a first stroke speed and linearly moveable toward the linear actuator during a second stroke at a second stroke speed, wherein the second stroke speed is greater than the first stroke speed.

4. The pump system of claim 3, wherein:

the first adjustable chamber has a first minimum volume at a start of the first stroke;
the second adjustable chamber has a second minimum volume at a start of the second stroke; and
the first minimum volume is less than the second minimum volume.

5. The pump system of claim 3, further comprising a first port in fluid communication with the first adjustable chamber, a second port in fluid communication with the second adjustable

chamber, and wherein the first port and the second port discharge a fluid at substantially the same flowrate.

6. The pump system of claim 1, further comprising a control system operably coupled to the motor assembly, and wherein the motor assembly comprises an electric motor.

7. The pump system of claim 6, wherein:

the control system operable to sequentially switch between a first stroke at a first stroke speed of the piston and a second stroke at a second stroke speed of the piston;

the first adjustable chamber comprises a first minimum volume at a start of the first stroke and a first maximum volume at an end of the first stroke and the second adjustable chamber comprises a second minimum volume at a start of the second stroke and a second maximum volume at an end of the second stroke;

the first minimum volume is less than the second minimum volume;

the first maximum volume is less than the second maximum volume; and

the second stroke speed is greater than the first stroke speed.

8. The pump system of claim 1, wherein the piston cylinder pump further comprises:

a first valve fluidly coupled to and between the first adjustable chamber and a first feed line;

a second valve fluidly coupled to and between the first adjustable chamber and a first discharge line;

a third valve fluidly coupled to and between the second adjustable chamber and a second feed line; and

a fourth valve fluidly coupled to and between the second adjustable chamber and a second discharge line.

9. The pump system of claim 1, further comprising a first port in the cylinder body and in fluid communication with the first adjustable chamber, a first feed line, and a first discharge line; and a second port in the cylinder body and in fluid communication with the second adjustable chamber, a second feed line, and a second discharge line.

10. The pump system of claim 9, wherein a first pair of valves controls the fluid communication between the first port and the first feed line and the first discharge line, and wherein a second pair of valves controls the fluid communication between the second port and the second feed line and the second discharge line.
11. The pump system of claim 10, wherein the first pair of valves comprises a first valve located between the first port and the first feed line and a second valve located between the first port and the first discharge line, and wherein the second pair of valves comprises a third valve located between the second port and the second fluid source, and a fourth valve located between the second port and the second fluid discharge.
12. The pump system of claim 1, wherein the linear actuator comprises a screw actuator, a hydraulic actuator, a pneumatic actuator, or any combination thereof.
13. The pump system of claim 1, wherein the linear actuator comprises a ball screw actuator.
14. The pump system of claim 1, further comprising a position feedback sensor coupled to at least one of the piston cylinder pump, the linear actuator, and the motor assembly.
15. The pump system of claim 1, wherein the motor assembly comprises a servomotor.
16. A pump system, comprising:
- a piston cylinder pump comprising a piston located within a cavity of a cylinder body and dividing the cavity into a first adjustable chamber and a second adjustable chamber, wherein the piston comprises a first side opposite a second side and a rod coupled to the first side of the piston;
 - a linear actuator comprising a shaft coupled to the rod, wherein the linear actuator converts rotational motion to linear motion to move the rod linearly; and
 - an electric motor assembly coupled to the linear actuator and operable to drive the linear actuator;
- wherein the piston is moveable linearly in a two-stroke cycle that comprises a first stroke away from the linear actuator and a second stroke toward the linear actuator, wherein the first stroke is slower than the second stroke.

17. The pump system of claim 16, wherein:
- the first adjustable chamber has a first minimum volume at a start of the first stroke and a first maximum volume at an end of the first stroke;
 - the second adjustable chamber has a second minimum volume at a start of the second stroke and a second maximum volume at an end of the second stroke; and
 - the first maximum volume is less than the second maximum volume.
18. The pump system of claim 16, wherein the piston cylinder pump further comprises:
- a first port defined in the cylinder body and in fluid communication with the first adjustable chamber;
 - a second port defined in the cylinder body and in fluid communication with the second adjustable chamber;
 - a third port defined in the cylinder body and in fluid communication with the first adjustable chamber;
 - a fourth port defined in the cylinder body and in fluid communication with the second adjustable chamber;
 - a first valve fluidly coupled to and between the first port and a first feed line;
 - a second valve fluidly coupled to and between the second port and a first discharge line;
 - a third valve fluidly coupled to and between the third port and a second feed line; and
 - a fourth valve fluidly coupled to and between the fourth port and a second discharge line.
19. The pump system of claim 18, wherein each of the valves is a check valve.
20. A method for pumping a fluid, comprising:
- sequentially switching between a first stroke at a first stroke speed and a second stroke at a second stroke speed of a piston located within a cylinder body of a piston cylinder pump, wherein the second stroke speed is greater than the first stroke speed, and wherein the piston cylinder pump comprises a first adjustable chamber and a second adjustable chamber separated from each other by the piston;

linearly moving the piston in a first direction to adjust from a first minimum volume of the first adjustable chamber at a start of the first stroke to a first maximum volume of the first adjustable chamber at an end of the first stroke;

linearly moving the piston in a second direction opposite of the first direction to adjust from a second minimum volume of the second adjustable chamber at a start of the second stroke to a second maximum volume of the second adjustable chamber at an end of the second stroke; and

discharging fluid from the first and second adjustable chambers at substantially the same flowrate.

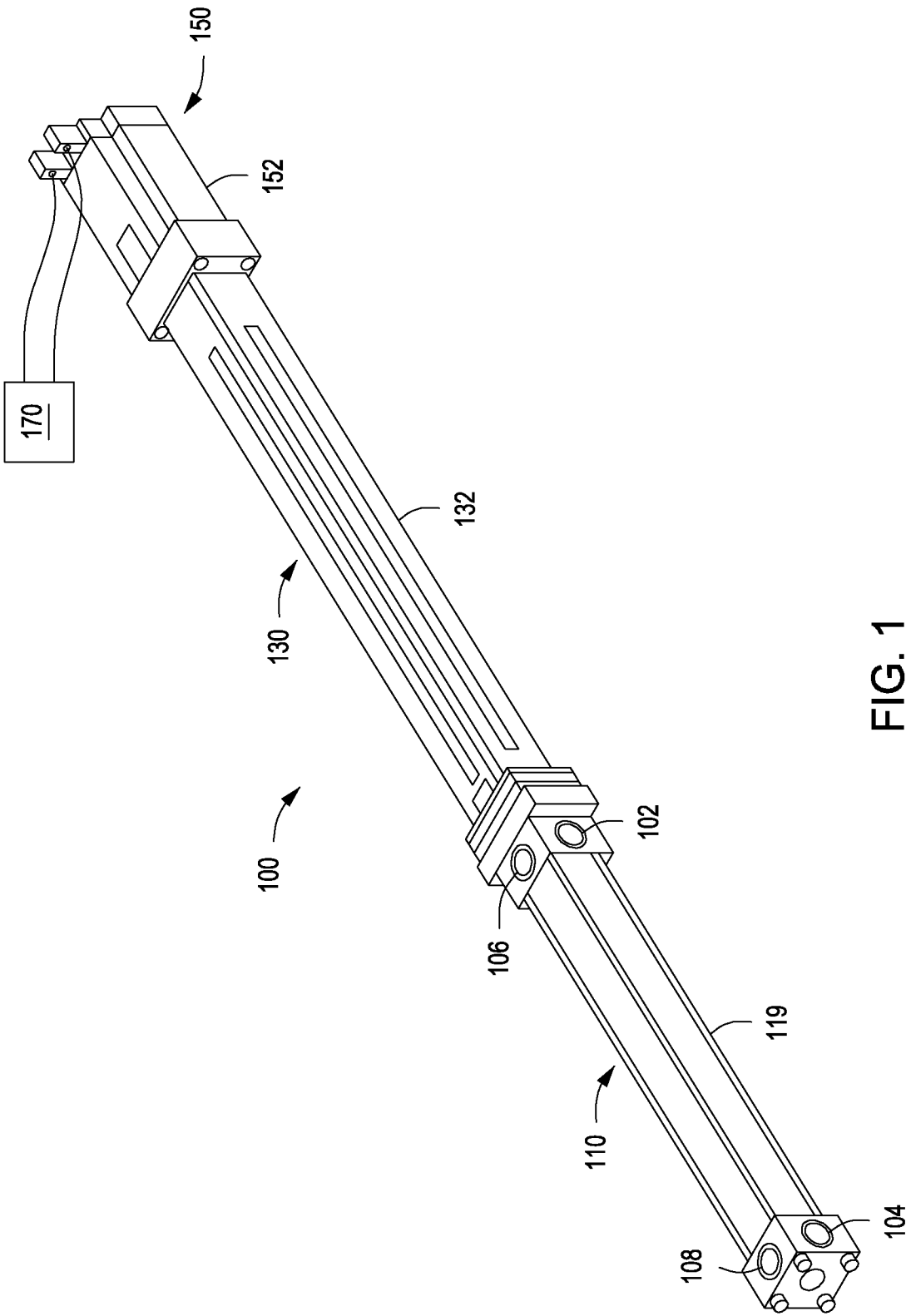


FIG. 1

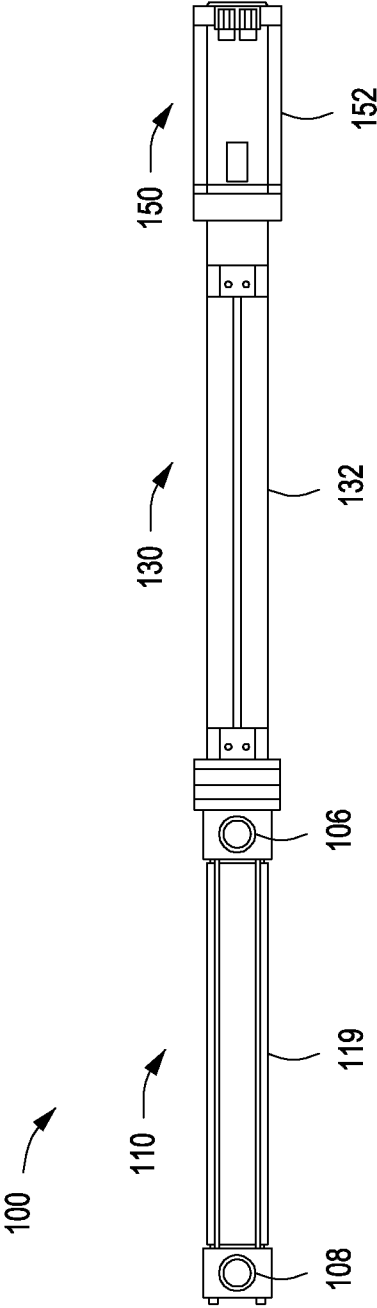


FIG. 2A

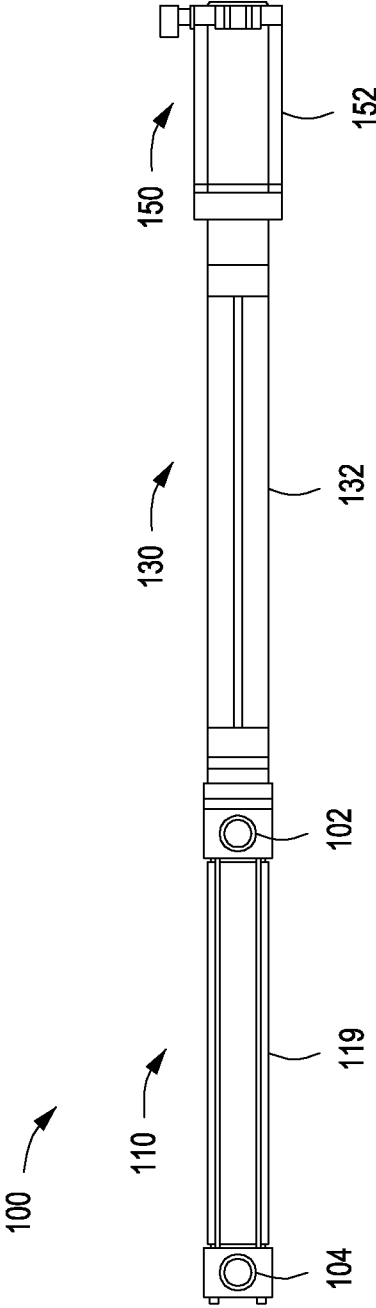


FIG. 2B

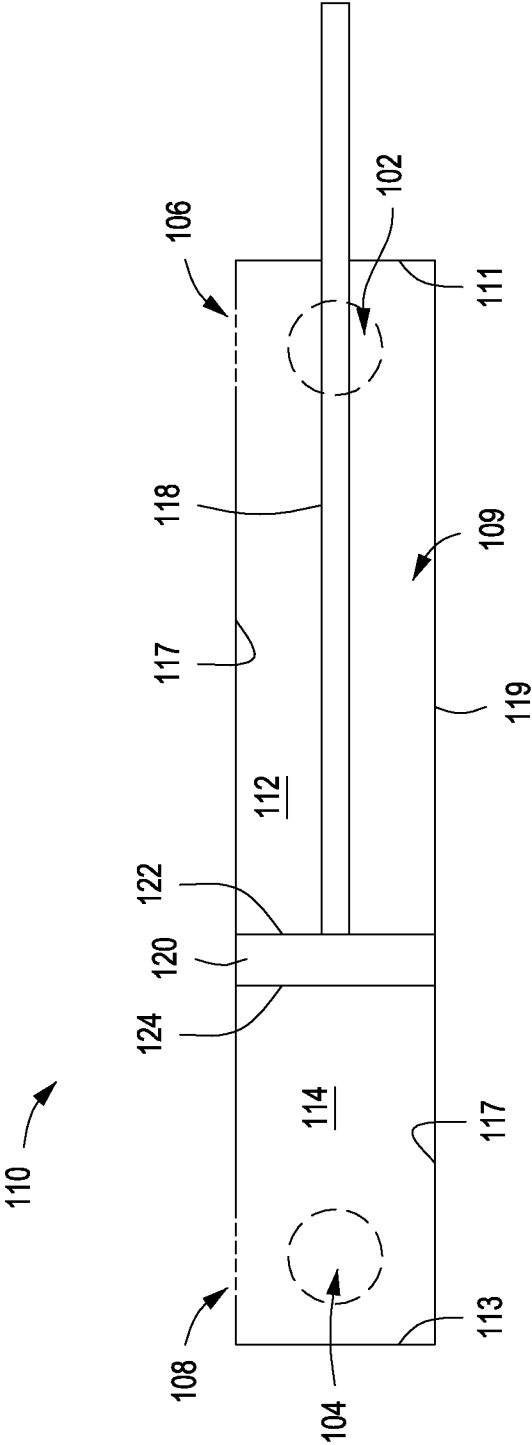


FIG. 2C

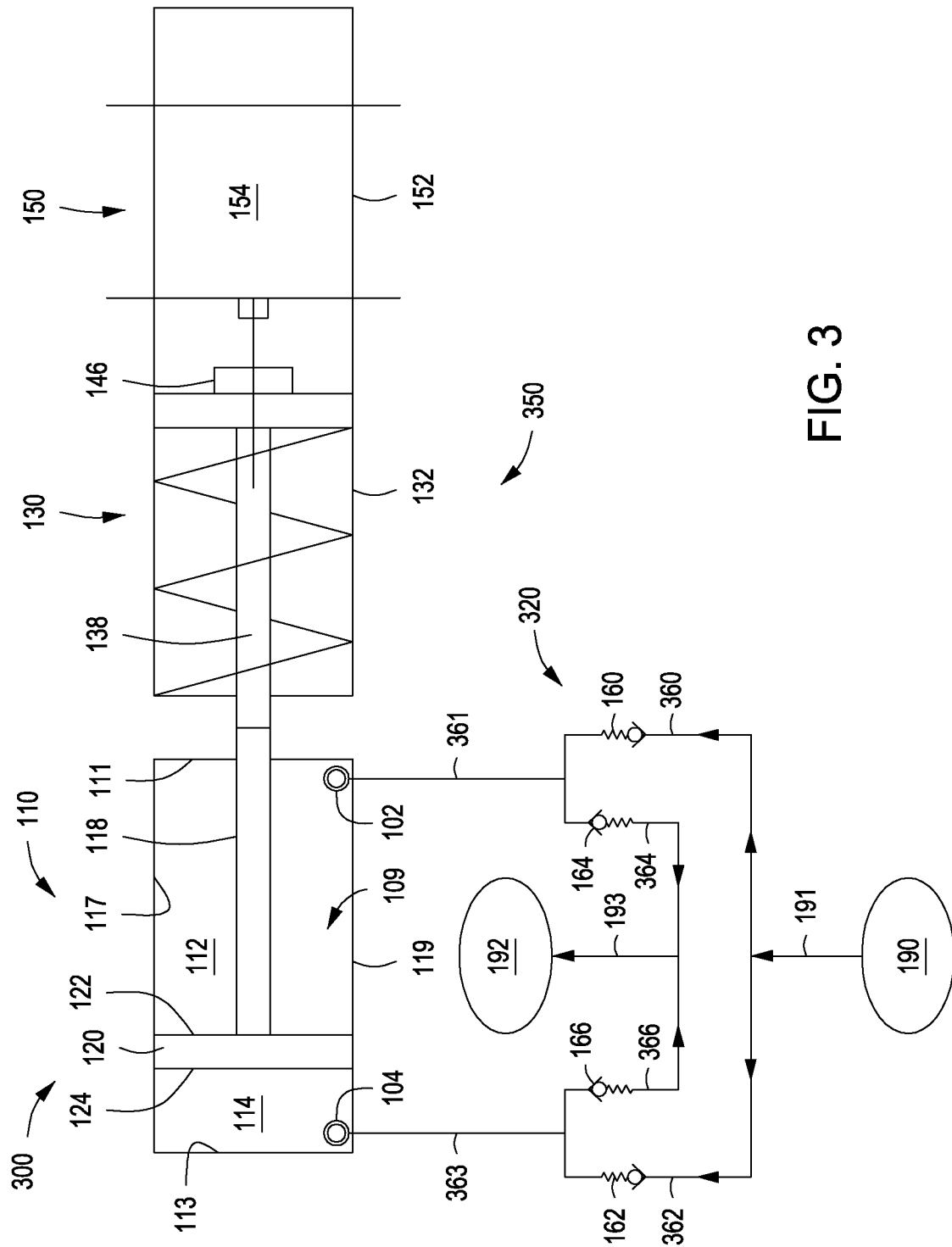


FIG. 3

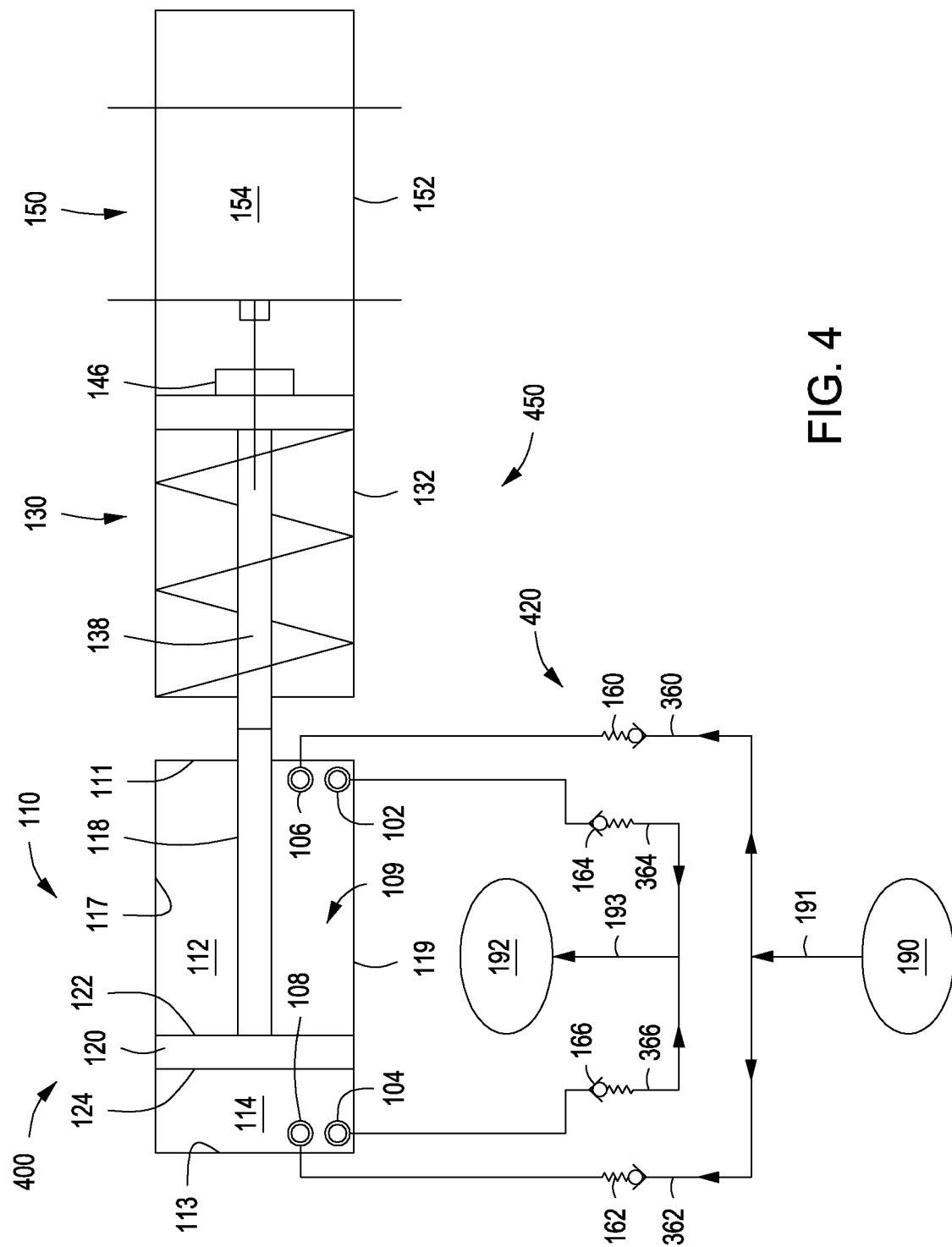


FIG. 4

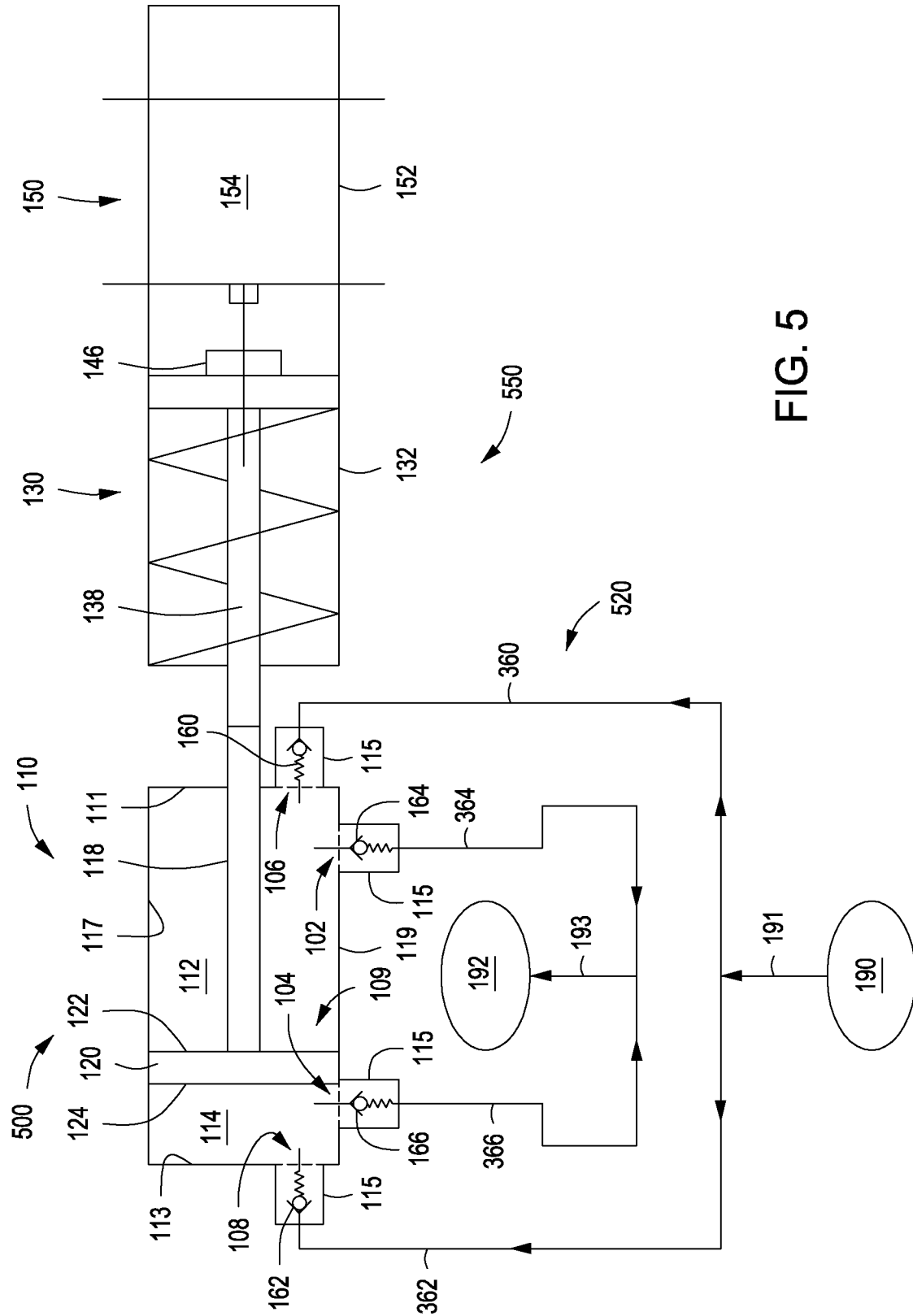


FIG. 5

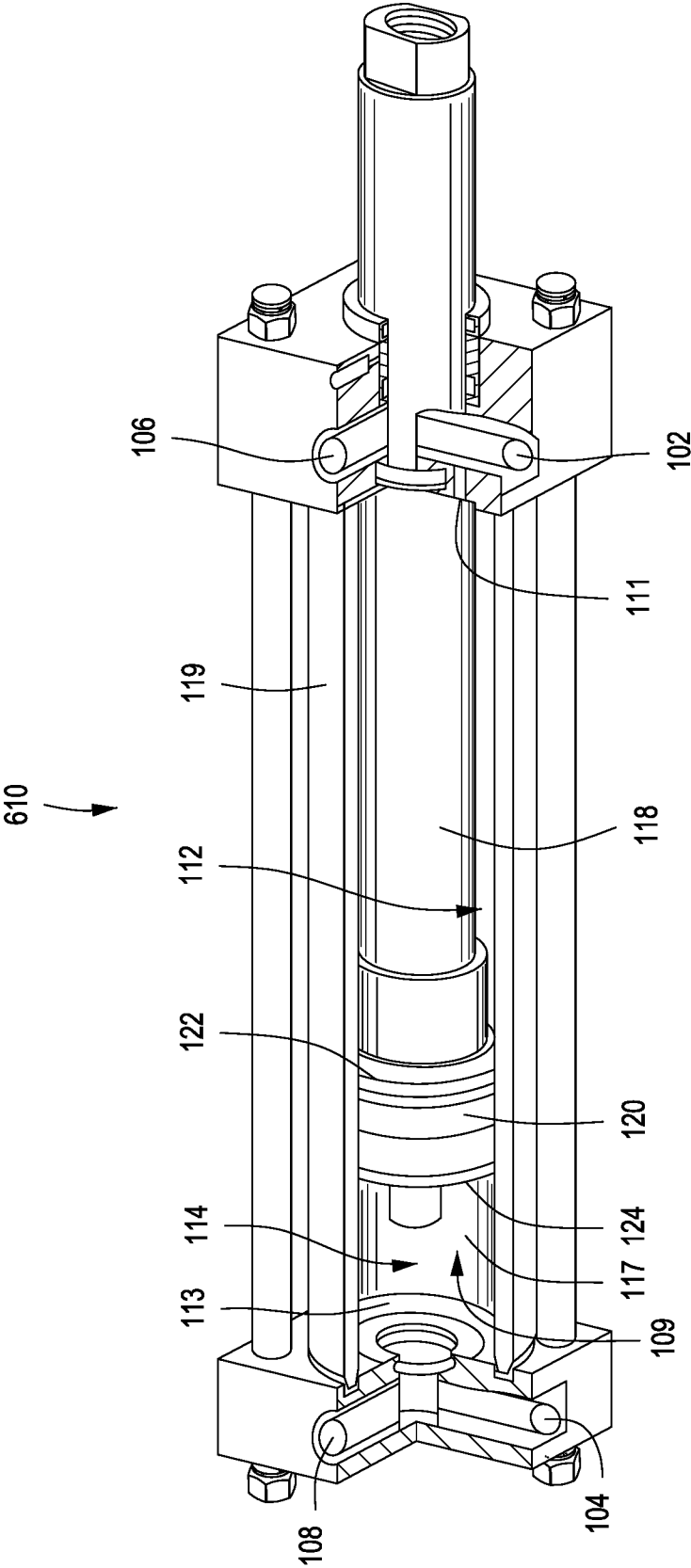
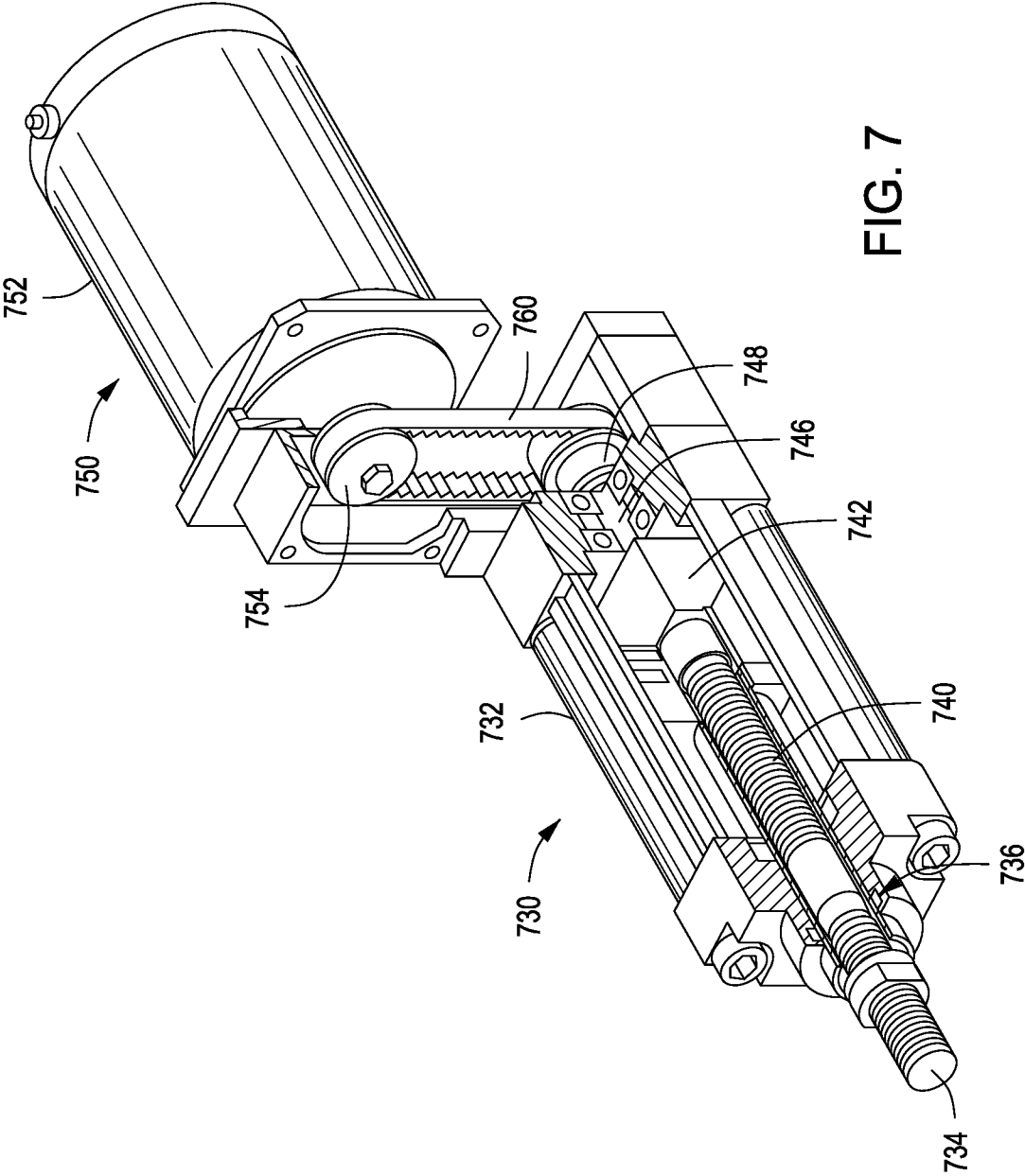


FIG. 6



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/063002**A. CLASSIFICATION OF SUBJECT MATTER****F04B 17/03(2006.01)i, F04B 47/06(2006.01)i, F04B 15/02(2006.01)i, F04D 13/10(2006.01)i, F04B 53/10(2006.01)i, F04B 53/14(2006.01)i**

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F04B 17/03; F02C 3/22; G06F 15/20; F04B 13/00; F04B 49/00; F04B 7/00; F02C 7/22; G03D 5/04; F04B 47/06; F04B 15/02; F04D 13/10; F04B 53/10; F04B 53/14

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: piston, cylinder, pump, measure, linear actuator, motor, chamber, feed line, discharge line, check valve

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005-0036896 A1 (NAVARRO, RAMON M.) 17 February 2005 See paragraphs [0015], [0044]-[0046], [0050], [0055], [0057] and figures 1-4, 14.	1-13, 15-20
Y		14
Y	US 5056036 A (VAN BORK, ERIK C.) 08 October 1991 See column 3, lines 16-18 and figure 1B.	14
A	US 4990058 A (ESLINGER, DAVID M.) 05 February 1991 See column 4, line 20 - column 6, line 32 and figure 1.	1-20
A	JP 2002-257033 A (MITSUBISHI PAPER MILLS LTD.) 11 September 2002 See paragraphs [0009]-[0018] and figures 1, 2.	1-20
A	EP 1005607 B1 (INDUSTRIEANLAGEN-BETRIEBSGESELLSCHAFT M.B.H.) 25 June 2003 See claim 1 and figure 1.	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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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

17 August 2017 (17.08.2017)

Date of mailing of the international search report

17 August 2017 (17.08.2017)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea



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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/063002

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2005-0036896 A1	17/02/2005	US 7074020 B2 WO 2005-024229 A2 WO 2005-024229 A3	11/07/2006 17/03/2005 28/07/2005
US 5056036 A	08/10/1991	CA 2066581 A1 CA 2066581 C EP 0496803 A1 EP 0496803 B1 WO 91-06062 A1	21/04/1991 10/10/2000 05/08/1992 04/06/1997 02/05/1991
US 4990058 A	05/02/1991	None	
JP 2002-257033 A	11/09/2002	None	
EP 1005607 B1	25/06/2003	DE 19736337 A1 DE 19736337 C2 EP 1005607 A1 WO 99-10640 A1	25/02/1999 12/07/2001 07/06/2000 04/03/1999