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(54) **VALVELESS, MECHANICAL, PRESSURE REGULATING PUMP**

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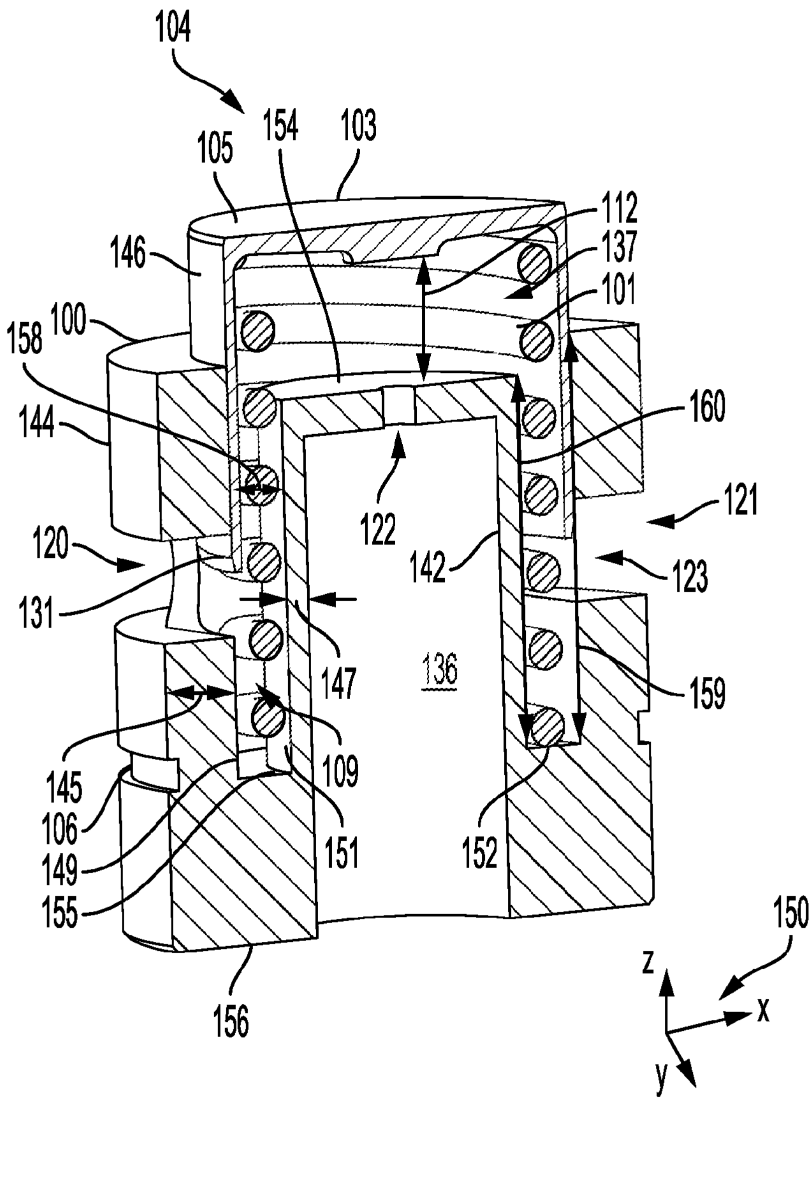
(57) **ABSTRACT**

Systems and methods are disclosed for a valveless, mechanical, pressure regulating pump for use in transmissions and other mechanical systems. The pressure regulating pump may comprise: a casing; a pump body comprising an outer cylindrical portion and an inner cylindrical portion, wherein the outer cylindrical portion includes one or more inlet ports and the inner cylindrical portion includes one or more outlet ports; a piston interposed between the outer cylindrical portion and the inner cylindrical portion and configured to move axially, the piston and the inner cylindrical portion defining a chamber; a first spring at least partially interposed between the piston and the inner cylindrical portion; and a second spring interposed between the casing and the pump body, wherein the pump body is configured to move axially relative to the casing and compress the second spring when a pressure in the chamber exceeds a pre-load of the second spring.



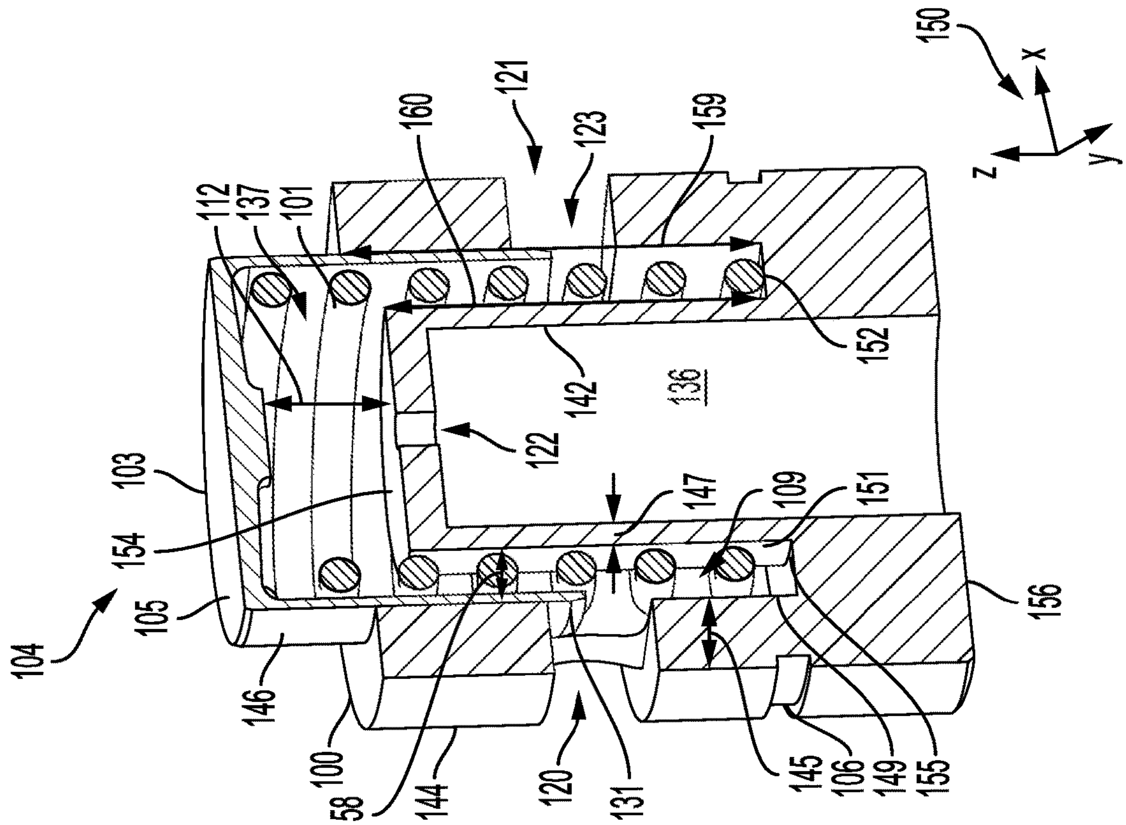

104
105
103
154
146
100
158
144
120
131
145
106
149
155
156
151
109
147
122
142
136
152
112
137
101
160
123
121
159
150
x
y
z

FIG. 1B

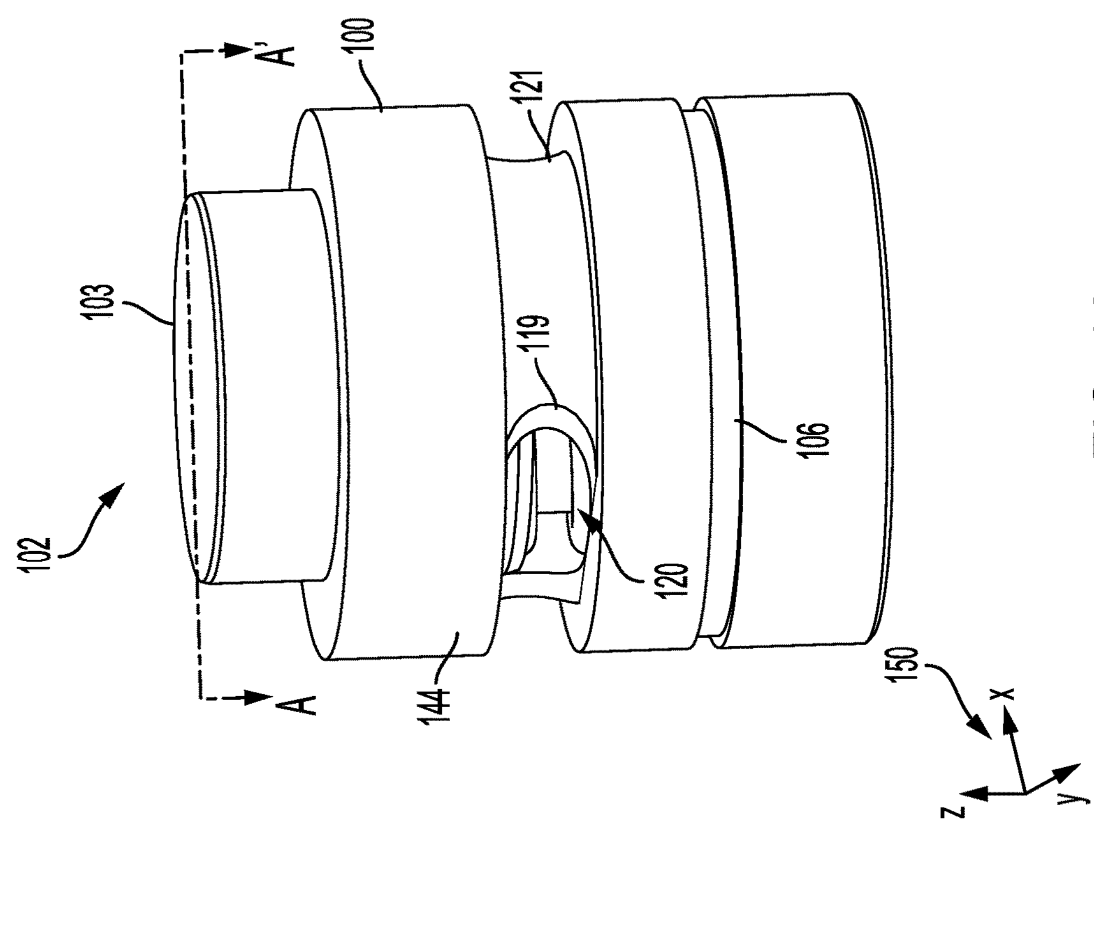

102
103
A'
A
100
121
119
120
144
106
150
x
y
z

FIG. 1A

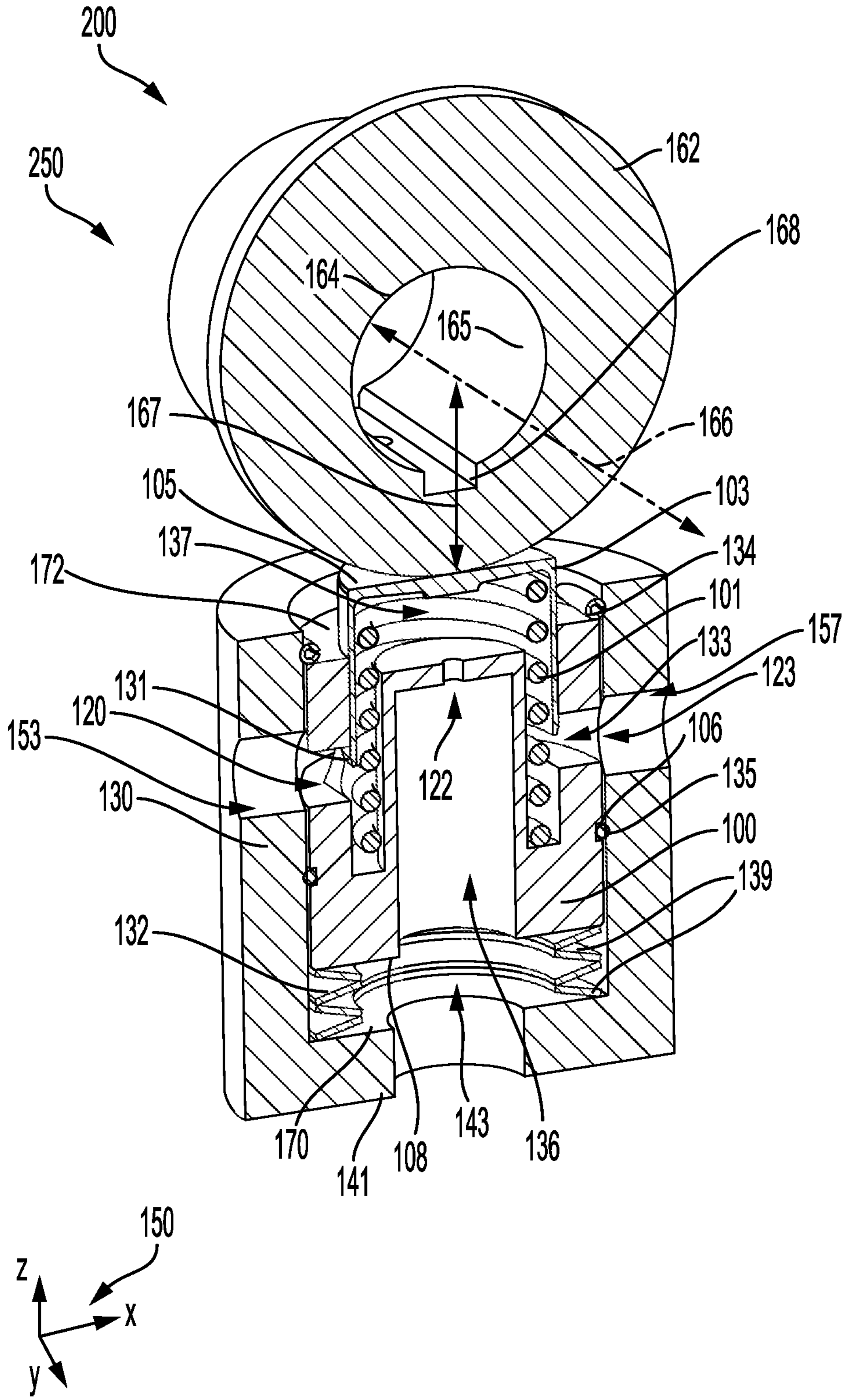

200
250
162
168
164
165
167
166
105
103
137
134
172
101
133
157
131
123
120
153
122
106
130
135
100
132
139
170
141
108
143
136
150
z
x
y

FIG. 2

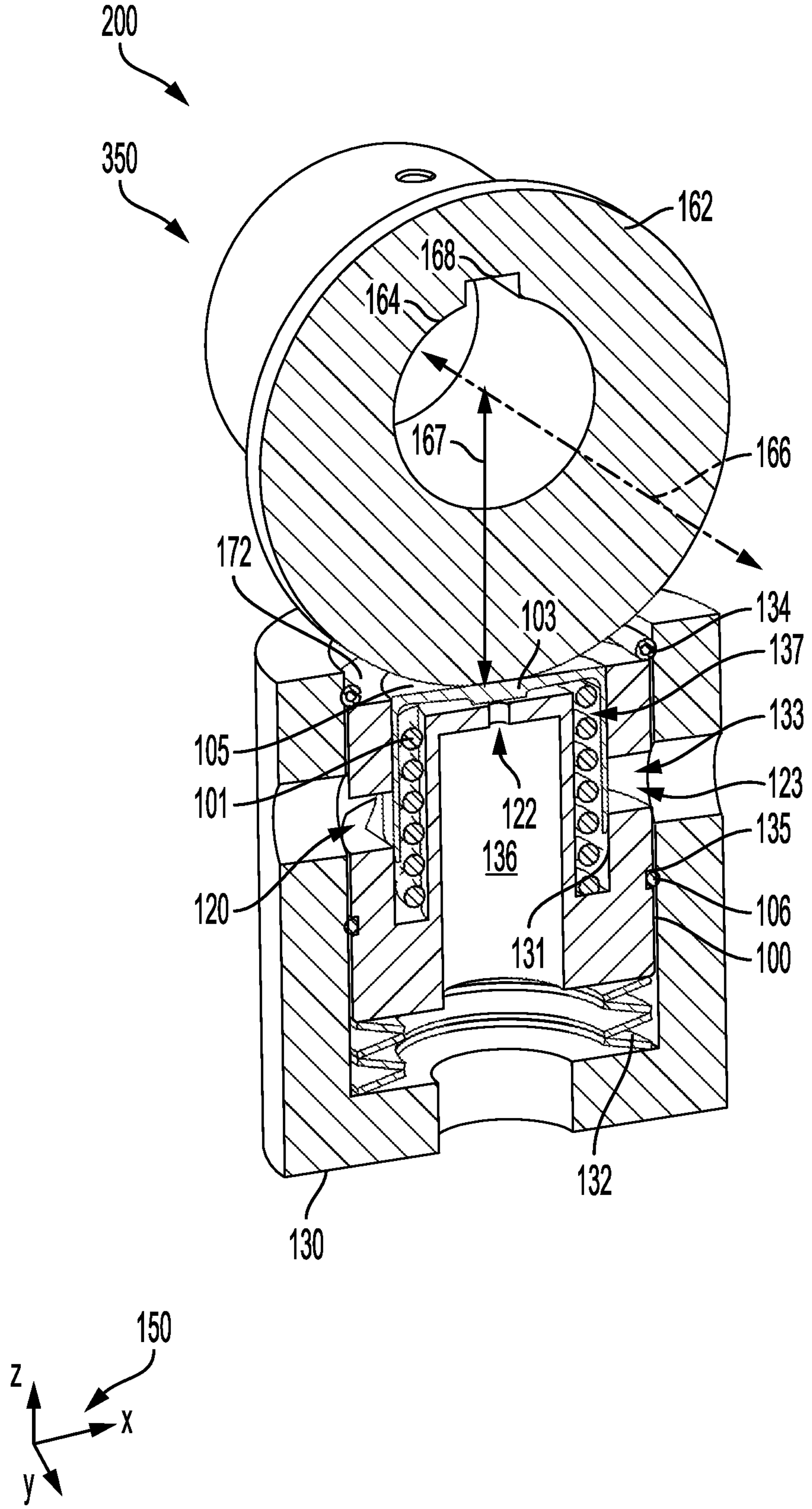

200
350
162
168
164
167
166
172
103
134
137
105
133
101
122
123
135
136
120
106
131
100
132
130
150
z
x
y

FIG. 3

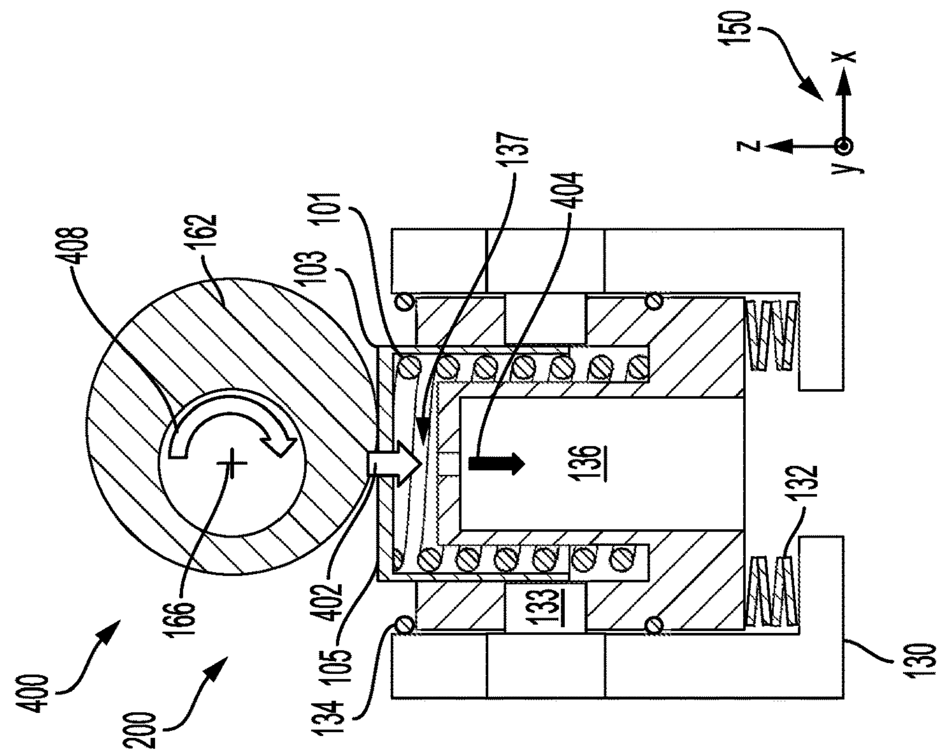

400
200
408
162
166
103
101
137
404
136
133
402
105
134
132
130
150
z
x
y

FIG. 4A

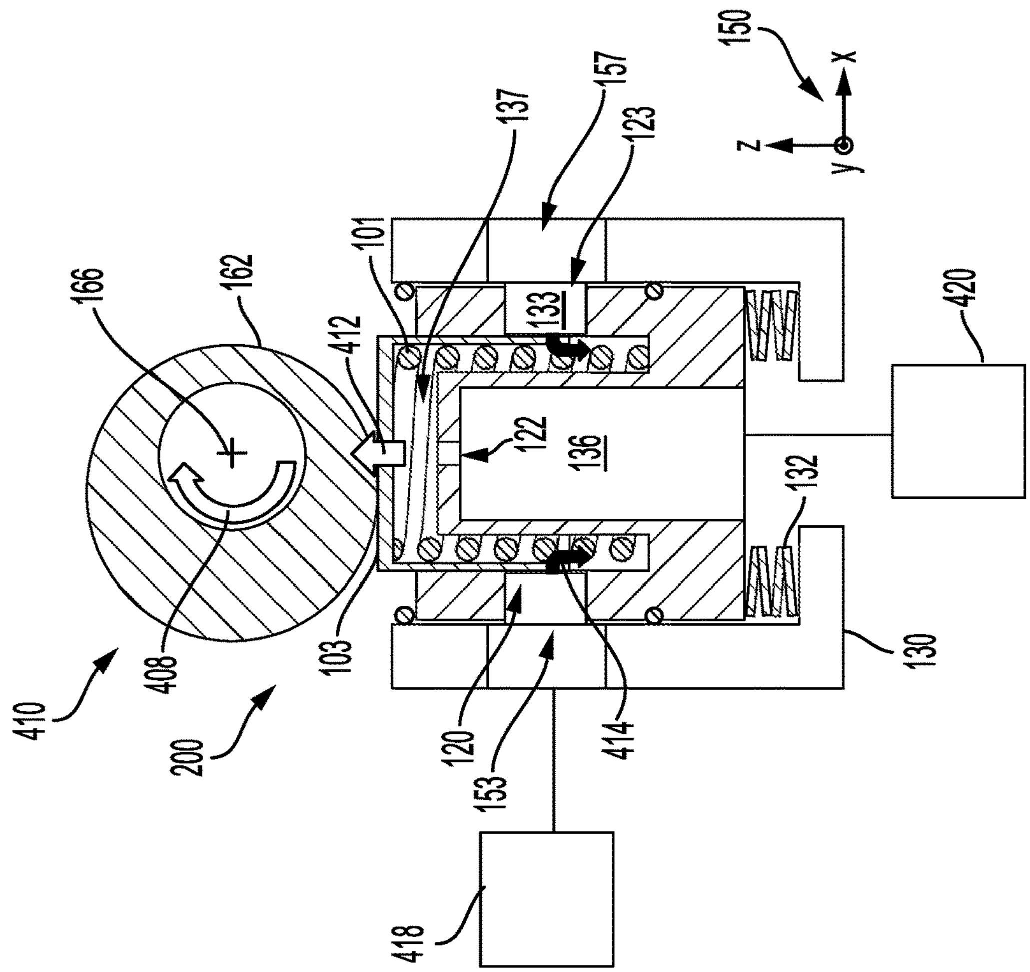

410
200
166
162
408
412
103
101
137
122
136
133
123
157
120
153
414
132
130
418
420
150
z
x
y

FIG. 4B

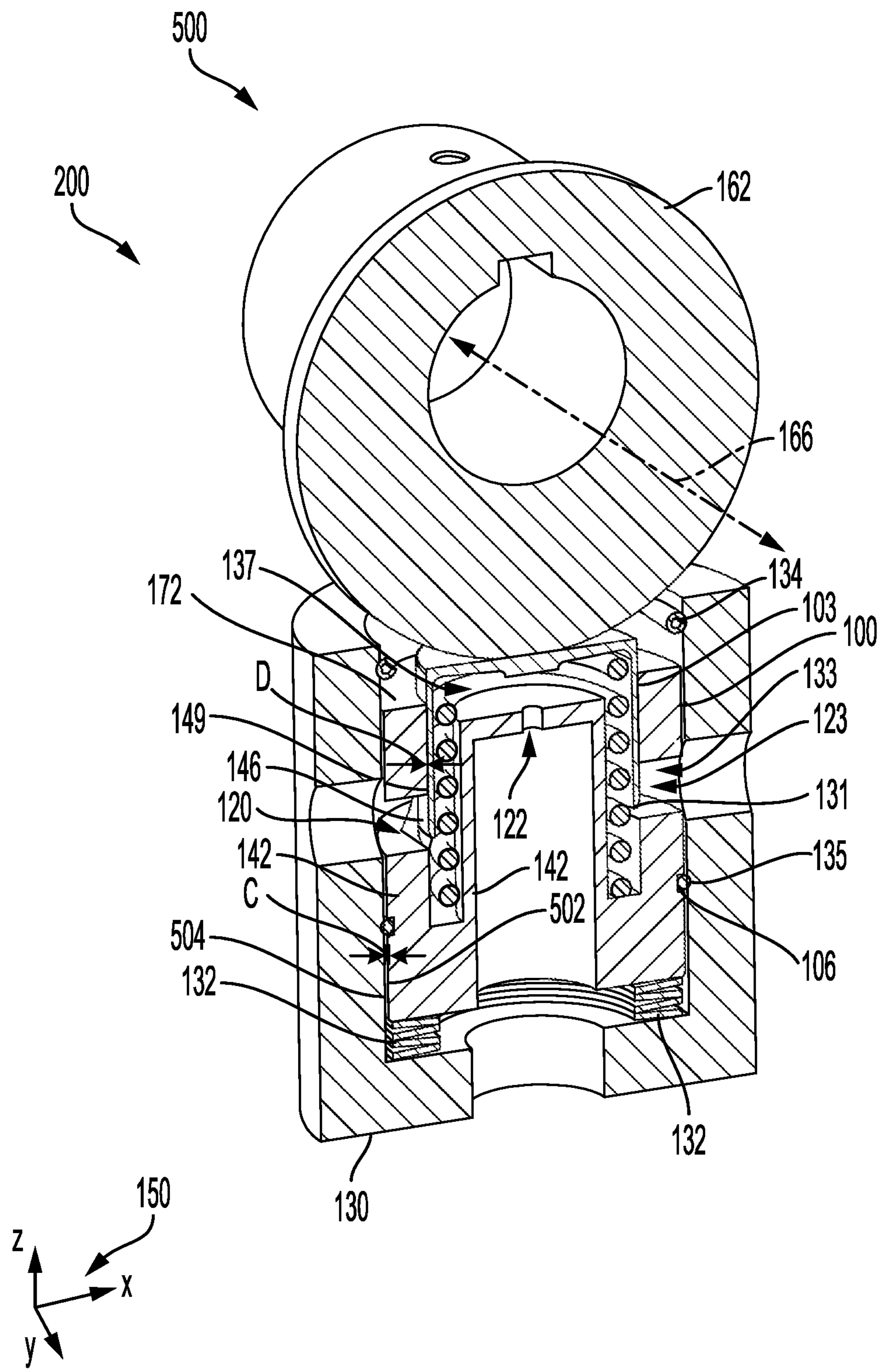

500
200
162
166
137
134
172
103
100
D
133
149
123
146
131
120
122
142
142
135
C
502
504
106
132
132
130
150
z
x
y

FIG. 5

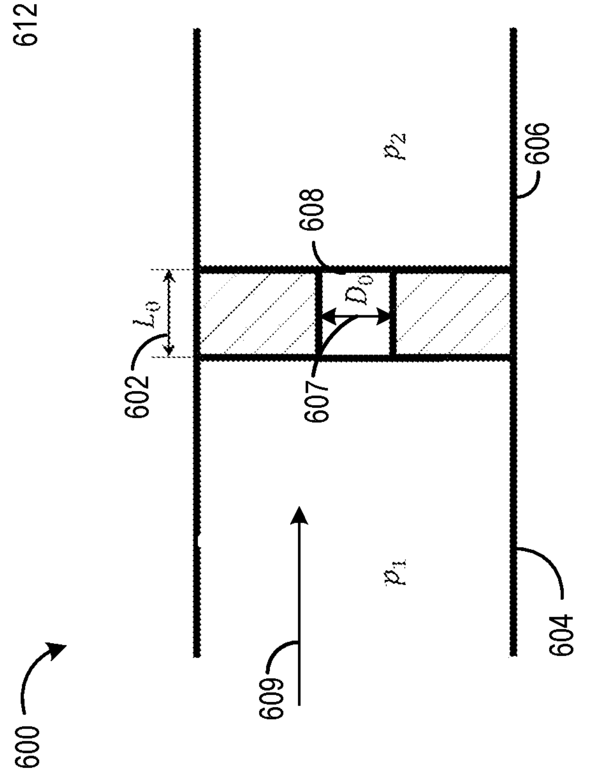

600
602
L_0
608
D_0
607
606
604
609
p_1
p_2

FIG. 6A

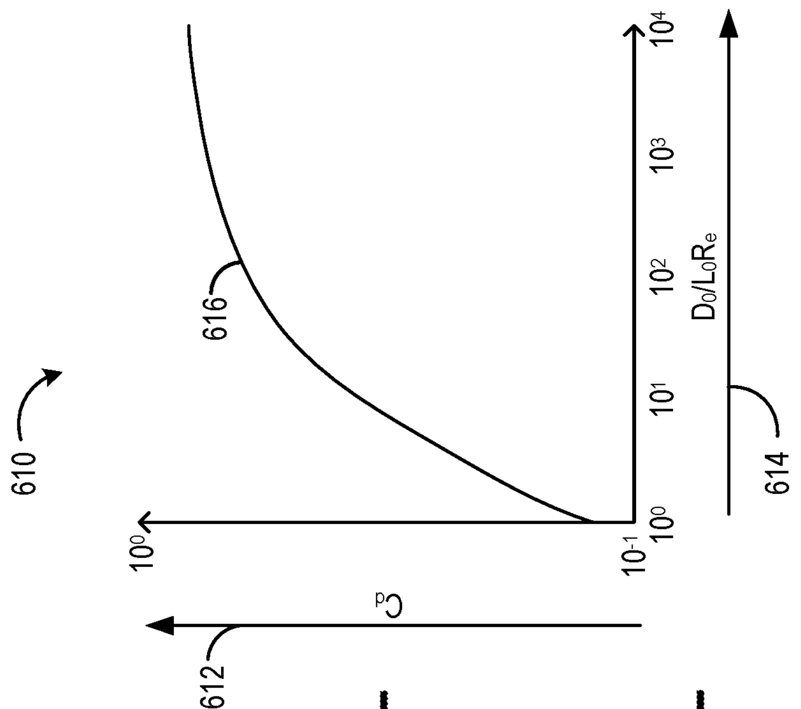

610
612
C_d
10^0
10^{-1}
10^0
10^1
10^2
10^3
10^4
D_0/L_0R_e
616
614

FIG. 6B

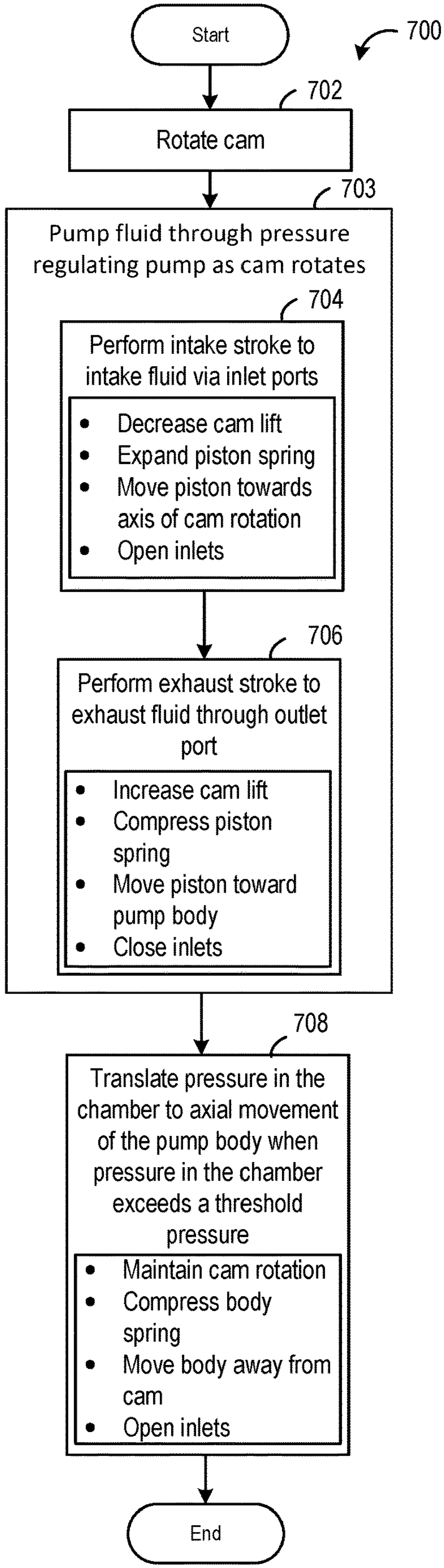

Start
700
702
Rotate cam
703
Pump fluid through pressure regulating pump as cam rotates
704
Perform intake stroke to intake fluid via inlet ports
• Decrease cam lift
• Expand piston spring
• Move piston towards axis of cam rotation
• Open inlets
706
Perform exhaust stroke to exhaust fluid through outlet port
• Increase cam lift
• Compress piston spring
• Move piston toward pump body
• Close inlets
708
Translate pressure in the chamber to axial movement of the pump body when pressure in the chamber exceeds a threshold pressure
• Maintain cam rotation
• Compress body spring
• Move body away from cam
• Open inlets
End

FIG. 7

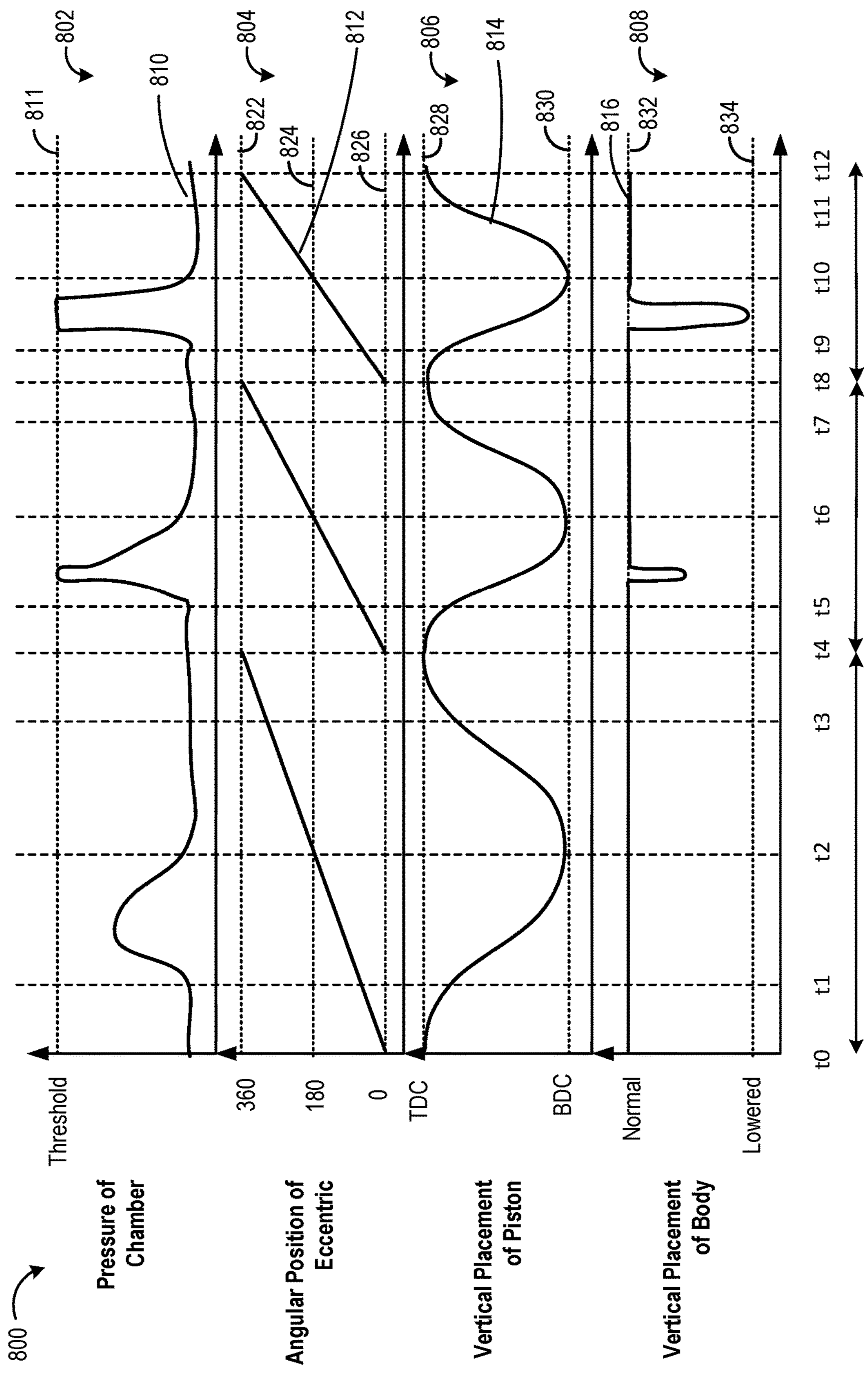

800
Pressure of Chamber
Angular Position of Eccentric
Vertical Placement of Piston
Vertical Placement of Body
Threshold
360
180
0
TDC
BDC
Normal
Lowered
802
804
806
808
810
811
812
814
816
822
824
826
828
830
832
834
t0
t1
t2
t3
t4
t5
t6
t7
t8
t9
t10
t11
t12

FIG. 8A

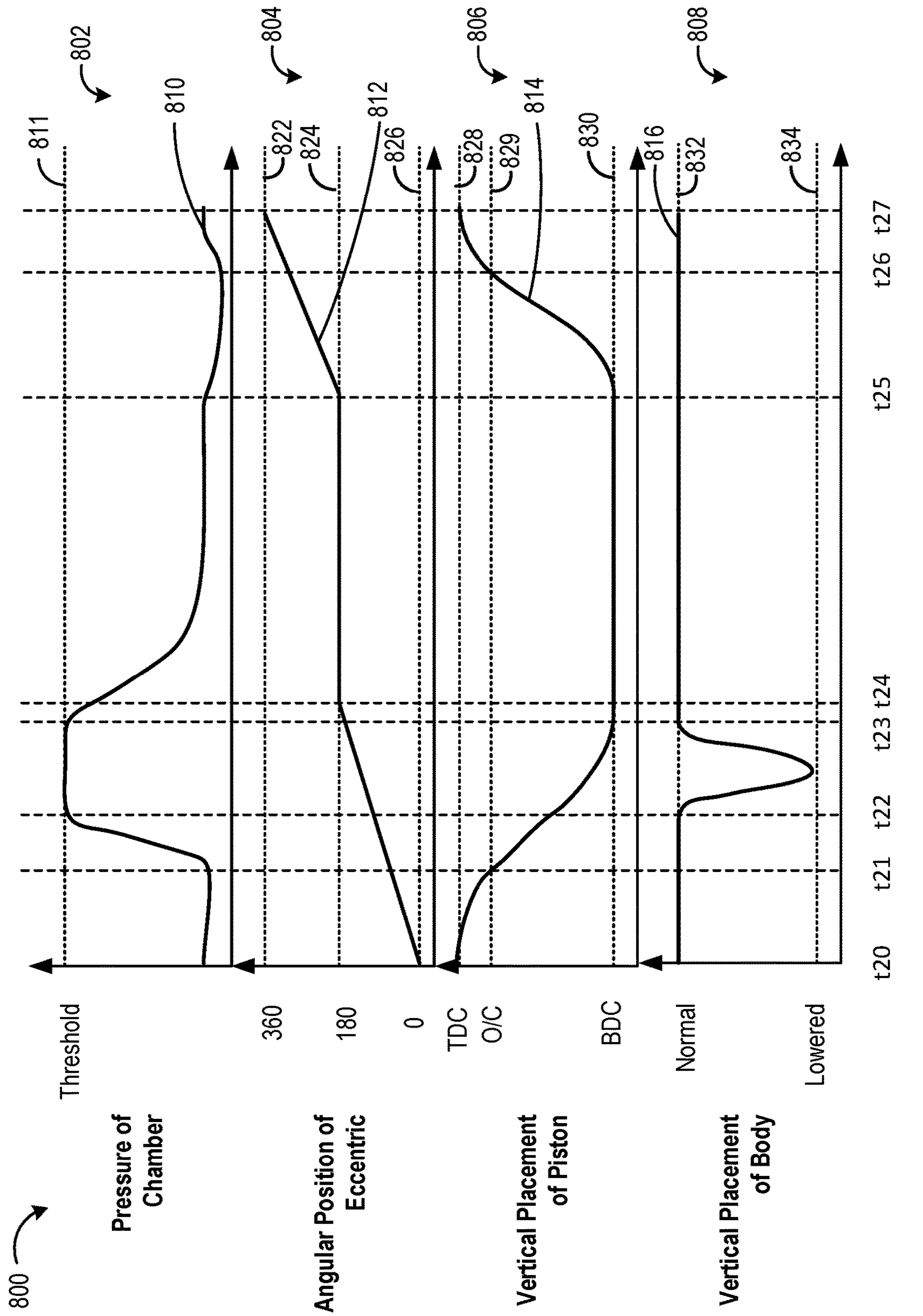

800
Pressure of Chamber
Threshold
802
810
811
Angular Position of Eccentric
360
180
0
804
812
822
824
826
Vertical Placement of Piston
TDC
O/C
BDC
806
814
828
829
830
Vertical Placement of Body
Normal
Lowered
808
816
832
834
t20
t21
t22
t23
t24
t25
t26
t27

FIG. 8B

VALVELESS, MECHANICAL, PRESSURE REGULATING PUMP

TECHNICAL FIELD

[0001] The present description relates generally to systems and methods for a valveless, mechanical, pressure regulating pump for use in transmissions and other mechanical systems.

BACKGROUND AND SUMMARY

[0002] Dry-sump transmission lubrication targets lubrication toward transmission elements and avoids inefficient splashing of oil as in other lubrication methods by using a scavenge pump and a displacement pump. The scavenge pump lifts fluid from the sump to a calm reservoir and the displacement pump feeds a calibrated amount of oil from the calm reservoir to transmission elements. To meet the functional demands of a dry-sump transmission, the scavenge pump may be self-priming, large enough to dry the sump, and able to transfer a two-phase flow.

[0003] The inventors herein have identified problems with existing scavenge pumps for dry-sump transmission lubrication. With electric pumps, risk of leakage is increased. For example, if an electric pump is inside a transmission, electric cables need to pass through a housing of the transmission such that the electric pump may be electrically coupled. In another example, if an electric pump is outside the transmission, a mechanical and/or hydraulic connection must pass through the housing. Parts passing through the housing may lead to additional potential degradation points in sealing, therefore increasing chance of leaks. Mechanically driven pumps (e.g., cam actuated) may be entirely within the housing to prevent leakage due to parts passing through the housing, but mechanically driven pumps are subject to excessive pressure chamber build-up, unless check valves are incorporated to prevent pressure exceeding a threshold. Valves may add complexity to a pump, which increases resource demand of manufacturing and potential degradation points.

[0004] Thus, embodiments are disclosed herein that solve at least some of the issues described above with a valveless, mechanical, pressure regulating pump. In one embodiment, the pressure regulating pump may include a casing; a pump body accommodated within the casing, the pump body comprising an outer cylindrical portion and an inner cylindrical portion, wherein the outer cylindrical portion includes one or more inlet ports and the inner cylindrical portion includes one or more outlet ports; a piston interposed between the outer cylindrical portion and the inner cylindrical portion and configured to move axially relative to the one or more inlet ports, the piston and a top of the inner cylindrical portion defining a chamber; a first spring at least partially interposed between the piston and the inner cylindrical portion; and a second spring interposed between the casing and a bottom of the pump body, wherein the pump body is configured to move axially relative to the casing and compress the second spring when a pressure in the chamber exceeds a pre-load of the second spring. In this way, when the pressure in the chamber exceeds the pre-load of the second spring, the pump body may move downwards to adjust a vertical position of the inlet ports, thereby decreasing flow rate and ultimately decreasing the pressure in the chamber to ensure operation within a pressure range at or below a threshold pressure.

[0005] By removing demand for valves to regulate pressure of the pressure regulating pump, the pressure regulating pump may incorporate fewer parts, thereby decreasing design complexity. The pressure regulating pump may be mechanically driven by a cam, for example, and reversibility of cam rotation may further increase versatility for varying configurations in applications of the pressure regulating pump. In this way, the pressure regulating pump may fit within a variety of systems without parts such as electrical cables extending through a housing of the systems. The pressure regulating pump described herein meets several demands of a scavenge pump for dry-sump transmission lubrication including that the scavenge pump be self-priming, have adequate displacement, and accommodate two-phase flow, while solving at least some of issues described above with current scavenge pumps. Thus, the pressure regulating pump may be used within a transmission, and may also be used in other mechanical systems wherein suction of a fluid, such as oil, may be desired.

[0006] It should be understood that the summary above is provided to introduce in simplified form a selection of concepts that are further described in the detailed description. It is not meant to identify key or essential features of the claimed subject matter, the scope of which is defined uniquely by the claims that follow the detailed description. Furthermore, the claimed subject matter is not limited to implementations that solve any disadvantages noted above or in any part of this disclosure.

BRIEF DESCRIPTION OF THE FIGURES

[0007] FIG. **1**A shows a body and piston of a pressure regulating pump according to an embodiment of the present disclosure.

[0008] FIG. **1**B shows a cross section view of the body and piston of FIG. **1**A.

[0009] FIG. **2** shows the pressure regulating pump in a top dead center (TDC) position.

[0010] FIG. **3** shows the pressure regulating pump in a bottom dead center (BDC) position.

[0011] FIG. **4**A shows the pressure regulating pump during an exhaust stroke which includes transitioning from the TDC position shown in FIG. **2** to the BDC position shown in FIG. **3**.

[0012] FIG. **4**B shows the pressure regulating pump during an intake stroke which includes transitioning from the BDC position shown in FIG. **3** to the TDC position shown in FIG. **2**.

[0013] FIG. **5** shows the pressure regulating pump in a pressure regulating position.

[0014] FIG. **6**A shows a view of an orifice, such as an outlet port of the pressure regulating pump.

[0015] FIG. **6**B shows a graph of a flow coefficient for an orifice, such as the orifice in FIG. **6**A.

[0016] FIG. **7** shows a flowchart of an example method of operating a pressure regulating pump.

[0017] FIGS. **8**A and **8**B show an example timeline diagram of operation of a pressure regulating pump over a first period of time and a second period of time, respectively.

DETAILED DESCRIPTION

[0018] The present disclosure relates to systems and methods for a pressure regulating pump. The pressure regulating pump may include a body and a piston wherein the piston may move axially relative to the body in order to pump fluid through the pressure regulating pump. An example of the body and the piston are depicted in FIGS. **1**A and **1**B, along with a first spring which guides movement of the piston. The body and the piston are further shown in FIG. **2**, which also includes a cam which causes movement of the piston, as well as a casing and a second spring which may provide pressure regulation during pumping of fluid through the pressure regulating pump. FIG. **2** specifically shows a top dead center (TDC) position of the pressure regulating pump, and FIG. **3** shows a bottom dead center (BDC) position of the pressure regulating pump. FIG. **4**A shows the pressure regulating pump during an exhaust stroke in which fluid is pushed out of the pump through one or more outlet ports during transition from the TDC position of FIG. **2** to the BDC position of FIG. **3**. Conversely, fluid may enter the pressure regulating pump through one or more inlet ports during an intake stroke as described in reference to FIG. **4**B. The pressure regulating pump may be positioned in a mechanical system such that fluid enters the pump from a first portion of the mechanical system which is fluidly coupled to the inlet ports, and exits the pump to a second portion of the mechanical system which is fluidly coupled to the outlet ports. As a non-limiting example, the mechanical system may be a transmission, where the first portion is a sump, and the second portion is a calm reservoir. During the exhaust stroke, pressure in a chamber of the pressure regulating pump may increase beyond a desired pressure range, such as below a threshold. Specifically, a pressure differential across the one or more outlet ports, such as the orifice shown in FIG. **6**A, may increase due to the relationships between fluid properties, flow rate, and orifice geometry as shown in a graph in FIG. **6**B of a discharge coefficient across the orifice. Thus, the pressure regulating pump may be adapted to maintain a pressure of the chamber of the pump at or below a threshold pressure by vertical movement of the pump body and hence the inlet ports, as shown in a pressure regulating position as shown in FIG. **5** in order. A method by which a pressure regulating pump, such as the pressure regulating pump of FIGS. **2-5**, may operate is shown in FIG. **7**, including performing an intake stroke, an exhaust stroke, and regulating pressure. FIGS. **8**A and **8**B show timeline diagrams of events of interest during operation of the pressure regulating pump.

[0019] A pressure regulating pump may include a body, an example of which is shown in FIGS. **1**A and **1**B. Specifically, FIG. **1**A shows a first view **102** of a body **100** which may include a first inlet port **120** positioned on an intake groove **121**, and a second groove **106**. FIG. **1**A further shows a piston **103**, which may be cylindrical and configured to be at least partially within the body **100**. FIG. **1**B shows a cross section view **104** of the body **100** and the piston **103** along section A-A' as shown in FIG. **1**A, and FIG. **1**B additionally shows a piston spring **101**. FIGS. **1**A and **1**B also show reference axes **150** including an x-axis, y-axis, and z-axis. In one example, the z-axis may be parallel to a direction of gravity such that a negative z-direction may be the same as the direction of gravity. Additionally or alternatively, the z-axis may be a direction of axial movement of the piston **103** relative to the body **100**. The reference axes are further shown in FIGS. **1**B-**5**.

[0020] The body **100** may include an outer cylindrical portion **144** with intake groove **121** having first inlet port **120** and a second inlet port **123** positioned thereon. The intake groove **121** may be a section of the outer cylindrical portion **144** of the body **100** with a reduced diameter. Consequently, the intake groove **121** may have a smaller thickness than the rest of the outer cylindrical portion **144**. The first inlet port **120** and the second inlet port **123** may be arranged opposite one another (e.g., across a diameter of the outer cylindrical portion **144** parallel to the x-axis) along the intake groove **121**. The first inlet port **120** and the second inlet port **123** may each be circular in shape, at least in some embodiments. Further, the first inlet port **120** may have a chamfered edge **119** defining an opening of the inlet port **120**. For example, the chamfered edge **119** may be curved such that the opening is circular. Due to the chamfered edge **119**, the opening may gradually decrease in size (e.g., diameter) along the thickness towards the interior of the body **100** (e.g., in the positive x-direction) of the intake groove **121**. The second inlet port **123** may have a similarly shaped chamfered edge (not shown). The curved, chamfered edges (e.g., chamfered edge **119**) may allow fluid to flow into the body **100** through the first inlet port **120** and the second inlet port **123** more smoothly than could be achieved with sharp corners (e.g., 90 degree corner edges). In some examples, the first inlet port **120** and the second inlet port **123** may be drilled tangentially with respect to the body **100** such that the first inlet port **120** and the second inlet port **123** are elongated in the y-direction compared to the z-direction. In other embodiments, the first inlet port **120** and the second inlet port **123** may have other shapes, sizes, and or arrangements. For example, in some embodiments, the inlet ports may be elliptical, rectangular, or other shapes according to a desired flow of fluid therethrough. In another example, body **100** may include three or more inlet ports arranged radially around the outer cylindrical portion **144** of body **100** on intake groove **121**, or the body **100** may only include one inlet port. The outer cylindrical portion **144** may further include the second groove **106** which may be configured (e.g., sized, shaped) to accept a sealing ring, such as sealing ring **135** shown in FIGS. **2-5**.

[0021] The body **100** may further include an inner cylindrical portion **142**, a hollow center of which may form discharge compartment **136**. Inner cylindrical portion **142** may be positioned centrally within a hollow center of outer cylindrical portion **144**. Thus, the inner cylindrical portion **142** may be housed within the outer cylindrical portion **144**. Further, the body **100** may include a body base **156** of cylindrical shape, and the inner cylindrical portion **142** and outer cylindrical portion **144** may extend axially therefrom. For example, the inner cylindrical portion **142** and outer cylindrical portion **144** may be physically connected via the body base **156**. The inner cylindrical portion **142** may extend a smaller height **160** from the base than a height **159** by which the outer cylindrical portion **144** extends from the body base **156**. Additionally, the inner cylindrical portion **142** may have a smaller thickness **147** than the thickness **145** of the outer cylindrical portion. An outer cylindrical surface **151** of the inner cylindrical portion **142** may be spaced away from an inner cylindrical surface **149** of the outer cylindrical portion **144** by a distance **158** and a top **154** of the inner cylindrical portion **142** (e.g., a top surface of the inner cylindrical portion **142**) may be spaced from the piston **103** by a varying distance **112** with a chamber **137** therebetween. A cylindrical cavity **109** may be formed between the inner cylindrical portion **142** and the outer cylindrical portion **144**, and defined by the inner cylindrical surface **149** of the outer cylindrical portion **144**, the outer cylindrical surface **151** of the inner cylindrical portion **142**, and a top surface **155** of the body base **156**. As such, the cylindrical cavity **109** may be in fluid communication with the chamber **137**. The inner cylindrical portion **142** may include an outlet port **122** positioned at and extending through the top **154** of the inner cylindrical portion **142**. The outlet port **122** may be positioned vertically higher than the first inlet port **120** and second inlet port **123**. The outlet port **122** may be an orifice sized to ensure desired fluid flow across the orifice as will be discussed further in regards to FIGS. **6**A and **6**B. The chamber **137** and discharge compartment **136** may be fluidly coupled via the outlet port **122**. For example, fluid, such as oil and/or air, may flow from chamber **137** to the discharge compartment **136** through the outlet port **122** in the negative z-direction. In other examples, the inner cylindrical portion **142** may include more than one outlet port, such as two or more outlet ports.

[0022] The piston **103** may be a bucket tappet that is cylindrical in shape with a circular top **105** and a cylindrical wall **146** having a skirt edge **131** at a bottom of the wall **146**. In some embodiments, a diameter of the piston **103** may be between 30 and 33 millimeters, inclusively. A cavity of the piston **103** may form part of chamber **137**, and the cavity may be configured to accept piston spring **101**. Piston spring **101** and the piston **103** may be configured to fit between the outer cylindrical portion **144** and inner cylindrical portion **142** of the body **100** such that outer cylindrical portion **144** may circumferentially surround at least part of the piston **103**, the piston **103** may circumferentially surround at least part of piston spring **101**, and piston spring **101** may circumferentially surround inner cylindrical portion **142**. In some examples, the piston spring **101** may be in face sharing contact with the inner cylindrical portion **142**. In other examples, the piston spring **101** may be spaced away from the inner cylindrical portion **142** to reduce friction due to movement of piston spring **101**. Further, a first end of the piston spring **101** may be coupled to the piston **103** at a first point of connection (not shown in FIG. **1**B), and a second end of the piston spring **101** may be coupled to the body **100** at a second point of connection **152**. The first point of connection is on a surface at the top **105**. The second point of connection **152** is on the top surface **155** of the body base **156** between the inner cylindrical portion **142** and the outer cylindrical portion **144**. When attached at the second point of connection **152**, the piston spring **101** may contact the top surface **155** via the second point of connection **152**.

[0023] In the configuration shown in FIG. **1**B, the outer cylindrical portion **144** and inner cylindrical portion **142** may accommodate the piston **103** as the piston **103** moves (e.g., along the z-axis) during compression and expansion of the piston spring **101** and constrain movement of piston **103** along the x-axis and y-axis. In this way, the skirt edge **131** of the piston **103** may be lowered and raised to increase and decrease, respectively, coverage of the first inlet port **120** and the second inlet port **123**. For example, the piston spring **101** may be compressed and the piston **103** moved downwards (e.g., in the negative z-direction), such that the skirt edge **131** may be lowered to further cover the first inlet port **120** and the second inlet port **123**. Consequently, the volume of chamber **137** may be decreased. In another example, the piston spring **101** may be expanded and the piston **103** moved upwards, such that the skirt edge **131** may be raised to decrease coverage of the first inlet port **120** and the second inlet port **123**. Therefore, the volume of chamber **137** may increase. Movement of elements of the pressure regulating pump, including the piston spring **101** and piston **103**, are described further below in regards to FIGS. **2**-**4**B.

[0024] Turning to FIG. **2**, a pressure regulating pump **200** is shown, including the body **100**, piston spring **101**, and piston **103** of FIGS. **1**A-B. Some labels shown in FIGS. **1**A-B may not be included in FIG. **2** for clarity. The pressure regulating pump **200** may further include a cam **162**, a casing **130**, a body spring **132**, one or more end stop devices **134**, and a sealing ring **135**. The casing **130** may be cylindrical in shape and circumferentially surround the body **100** such that the body **100** may be within a hollow interior of the casing **130**. Thus, the body **100** may be housed within the casing **130**. The casing **130** may include a casing base **141** at the bottom of the body. The casing base **141** may have a cylindrical shape and a hollow interior with an inner diameter that is less than an inner diameter of the hollow interior of the rest of the casing **130**. In some examples, the inner diameter of the casing base **141** (e.g., the inner diameter of the hollow interior of the casing base **141**) may be substantially the same (e.g., within 5%) as an inner diameter of the inner cylindrical portion of the body **100**. In some examples, the casing **130** may be a casting of a transmission in which the pressure regulating pump is employed. The casing **130** may be in a fixed location (e.g., relative to the axis of rotation **166**) such that the casing **130** does not move due to movement of other elements of the pressure regulating pump **200**.

[0025] A space formed by the intake groove **121** of the body **100** and the casing **130** together form a suction annulus **133**. The suction annulus **133** may be fluidly connected to a first portion of a mechanical system, for example a transmission sump (not shown), via one or more holes in the casing **130**, such as a first hole **153** and a second hole **157**, in some examples. The first hole **153** and the second hole **157** may have a suitable shape, including circular, elliptical, or the like. In some examples, the first hole **153** and the second hole **157** may be drilled tangentially in the casing **130** such that their shapes resemble the first inlet port **120** and the second inlet port **123**. In other examples, the first hole **153** and the second hole **157** may be machined differently. In some examples, the one or more holes may have different geometry from the inlet ports.

[0026] The one or more holes may each align with an inlet port, in some examples. For example, the first hole **153** may align with the first inlet port **120** and the second hole **157** may align with the second inlet port **123** such that center points thereof are aligned along a common axis (e.g., parallel to the x-axis). Further, the one or more holes may each have a cross-sectional area perpendicular to the axis (e.g., in a y-z plane) greater than or equal to a cross-sectional area perpendicular to the axis of the inlet port which the hole aligns with. For example, the first hole **153** may be sized to have an equal or larger cross-sectional area than that of the first inlet port **120**, and the second hole **157** may be sized to have an equal or larger cross-sectional area than that of the second inlet port **123**.

[0027] In other examples, the one or more holes (e.g., the first hole **153** and the second hole **157**) may not be aligned with the inlet ports (e.g., the first inlet port **120** and the second inlet port **123**). For example, the casing **130** may include more or fewer holes than inlet ports and/or the holes may be offset from the inlet ports. In such an example, a total cross-sectional area of the holes (e.g., a sum of the cross-sectional areas of each hole) may be greater than or equal to a total cross-sectional area of the inlet ports (e.g., a sum of the cross-sectional areas of each inlet port).

[0028] A sealing ring **135** (e.g., an O-ring) may be positioned in second groove **106** of the body **100** such that a seal is formed between the casing **130** and body **100** at the sealing ring **135**. In this way, fluid in the suction annulus **133** may not be able to flow between the body **100** and casing **130** past the sealing ring **135** (e.g., towards the body spring **132** and discharge compartment **136**). In at least some embodiments, the seal formed by sealing ring **135** may be a hermetic seal. The suction annulus **133** may also fluidly couple to the chamber **137** via first inlet port **120** and second inlet port **123**, at least in some positions of the piston **103**, including a top dead center (TDC) position **250** of pressure regulating pump **200** shown in FIG. **2**.

[0029] The body spring **132** may be positioned between the body **100** and the casing base **141** of the casing **130** such that the body spring **132** may be above a top surface **170** of the casing base **141** of the casing **130** and the body **100** may be above a top of the body spring **132**. Further, a first end of the body spring **132** may be physically coupled to a bottom surface **108** of the body **100** and a second end of the body spring **132** may be physically coupled to the top surface **170** of the casing base **141**. The first end of the body spring **132** may be in a relatively positive z-direction compared to the second end of the body spring **132**, and compression and/or expansion of the body spring **132** may occur parallel to the z-axis in response to movement of other elements of the pressure regulating pump. In at least some embodiments, the body spring **132** may comprise one or more cup springs in series with each of a plurality of cups **139** aligned axially with one another, forming an opening **143** through the center of the body spring **132** as an extension of the discharge compartment **136** formed by the inner cylindrical portion **142** of the body **100**. For example, the body spring **132** may include four cup springs each with an outer diameter of 40 mm, an inner diameter of 14.3 mm, and a thickness of 1.25 mm. In other examples, different dimensions may be used. In other embodiments, the body spring **132** may be a single spring such as a compression, helical, or spiral spring. Further, the body spring **132** may be an elastic body acting as spring, in some examples.

[0030] One or more end stop devices **134** may be physically coupled to inner surfaces of the casing **130**, such that vertical movement of the body **100** relative to the casing **130** is limited by the one or more end stop devices **134**. For example, the body spring **132** may push the body **100** towards the cam **162** until a top **172** of the body **100** contacts the one or more end stop devices **134** and further upwards motion of the body **100** may be prevented. In some embodiments, the one or more end stop devices **134** may be a ring (and thus the one or more end stop devices **134** may include a single stop device). In other embodiments, the one or more end stop devices **134** may include two or more end stop devices, such as two or more segments (e.g., elastic pins) arranged radially around, and in physical contact with, the inner wall of the outer cylindrical portion **144**.

[0031] The cam **162** may be cylindrical in shape and may include an opening **164** defined by an inner cylindrical surface **165** through which a shaft (not shown) may extend along the y-axis. The cam **162** may further include a notch **168** in the opening **164** (e.g., formed by the inner cylindrical surface **165**) wherein a radially protruding portion of the shaft with complementary geometry may lock with the notch **168**, allowing for rotation of the shaft to cause substantially (e.g., within 5%) the same angular speed of the cam **162** about a shared axis of rotation **166**. In some examples, the shaft may be formed integrally with the cam **162**. The opening **164** may be circular and offset from a center (e.g., in an x-z plane cross section) of the cam **162**, and the axis of rotation **166** may be fixed in a center of the opening **164**. In this way, the cam **162** may rotate asymmetrically such that the cam **162** may extend radially by different distances depending on an angular position of the cam **162**. Rotation of the cam **162** may occur in a clockwise or counter clockwise direction around axis of rotation **166** to operate the pressure regulating pump **200**, which may allow the pressure regulating pump **200** to be employed in a variety of system configurations, for example within a transmission. Rotation of the cam **162** and the shaft may be driven by a suitable rotating source such as an engine, an electric machine, an input shaft of the transmission, or the like. In other examples, the pressure regulating pump **200** may include a cam-follower and a lever arm.

[0032] The cam **162** may be in direct physical contact with the top **105** of piston **103**, and the cam **162** may be eccentric such that the cam **162** may change a position (e.g., along the z-axis) of piston **103** relative to the body **100** as the cam **162** is rotated by the shaft. In other words, the piston **103** may be moved axially as a result of radial movement of the cam **162** due to rotation of the cam **162**. As such, energy may be transferred to pressure regulating pump **200** via cam **162**. The piston spring **101** may be positioned as described with respect to FIGS. 1A-B and may press against piston **103** (e.g., in a positive z-direction) in opposition to the cam **162** pressing against piston **103** (e.g., in a negative z-direction). Thus, the piston **103** may be spring-loaded such that the piston spring **101** may push upwards with the spring force in opposition to the downward force exerted by the cam **162** on the piston **103**. Further, upward movement of the piston **103** may occur due to the spring force of the piston spring **101** and downward movement of the piston may occur under force of the cam **162**. In FIG. **2**, the pressure regulating pump **200** is shown specifically in a TDC position **250**, which includes the piston **103** at a topmost position (e.g., most positive z-location) due to a varying distance **167** between the axis of rotation **166** and top **105** of piston **103** (e.g., in a z-direction) being minimized. The skirt edge **131** of piston **103** may be at a topmost position, such that the first inlet port **120** and second inlet port **123** may be covered by the wall **146** of piston **103** less than in at least some other pressure regulating pump positions, such as a bottom dead center position (as described in more detail below). The first inlet port **120** and the second inlet port **123** may be at least partially uncovered in the TDC position. In some examples, the piston **103** may not cover the first inlet port **120** and second inlet port **123** at all in the TDC position because the skirt edge **131** may be at the top of or above the first inlet port **120** and second inlet port **123**. In other examples, the piston **103** may partially cover the first inlet and second inlet port **123** in the TDC position. The body spring **132** may be more extended in the TDC position compared to other positions of the pressure regulating pump, such that the body **100** is pushed upwards by the body spring **132** against the one or more end stop devices **134**.

[0033] The angular position of the cam **162** with minimum cam lift as shown in FIG. **2** and described above will be referenced herein as a "reference angular position," and understood to be a rotation of the cam by 0 degrees. The reference angular position may serve as a comparison in regards to other positions further described below.

[0034] FIG. **3** shows the pressure regulating pump **200** of FIG. **2** in a bottom dead center (BDC) position **350**. FIG. **3** is labeled similarly and repeated elements will not be introduced, however, some part numbers from FIG. **2** have been excluded from FIG. **3** for clarity. The BDC position **350** may include cam **162** in a position rotated 180 degrees (e.g., clockwise or counter clockwise around axis of rotation **166**) compared to the reference angular position, resulting in the varying distance **167** being maximized, piston spring **101** being compressed, and piston **103** being at a bottom-most position (e.g., in a negative z-direction). Thus, the piston **103** may be movable between the TDC position **250** and BDC position **350**. The body **100** may be in a same position as in the TDC position **250** of FIG. **2** with body spring **132** pushing the body **100** upwards against the one or more end stop devices **134**. In some embodiments, the top **105** of the piston **103** may align (e.g., in an x-y plane) with the top **172** of the body **100** in the BDC position. Additionally or alternatively, the piston **103** may remain spaced away from the body **100** in the BDC position **350**, but relatively less so than in TDC position **250** as shown in FIG. **2**.

[0035] Consequently, the first inlet port **120** and second inlet port **123** may be closed by the piston **103** due to the skirt edge **131** of the piston **103** being at the bottom of or below the first inlet port **120** and second inlet port **123**. Said another way, the fluidic connection between the suction annulus **133** and the chamber **137** via first inlet port **120** and second inlet port **123** may be blocked by the piston **103** in BDC position **350** of the pressure regulating pump **200**.

[0036] FIGS. **4**A and **4**B show an exhaust stroke **400** and an intake stroke **410** of the pressure regulating pump **200**. The exhaust stroke **400** may be a transition from TDC position **250** of FIG. **2** to BDC position **350** of FIG. **3**, and conversely the intake stroke may be a transition from BDC position **350** of FIG. **3** to TDC position **250** of FIG. **2**. In transitioning between the TDC and BDC as described above, the piston **103** may move, the piston spring **101** be compressed and/or expanded, and other elements remain in a same position. For example, the body **100** and casing **130** may not move relative to the axis of rotation **166**. Movement of the body **100** may occur in response to pressure exceeding a threshold pressure, as will be described below with reference to FIG. **5**. The pressure regulating pump **200** may continue to oscillate between the TDC and BDC positions according to rotation of the cam **162**, with the speed at which piston **103** moves being related to the angular speed of cam **162** rotation.

[0037] Starting with the exhaust stroke **400**, the cam **162** may rotate, for example in a clockwise direction as shown by arrow **408**, between the reference angular position and 180 degrees therefrom which may exert a force of the piston **103** in a downward direction indicated by arrow **402**. Consequently, the piston may be moved downwards (e.g., in a negative z-direction) such that skirt edge **131** of the piston **103** may move downwards indicated by arrow **404**, increasing coverage of the first inlet port **120** and second inlet port **123**. As the skirt edge **131** reaches the bottom of the first inlet port **120** and second inlet port **123**, the first inlet port **120** and second inlet port **123** fluidly separate the suction annulus **133** from the chamber **137**, thereby increasing pressure in the chamber **137**. Increasing pressure to the chamber **137** may cause flow of fluid from the chamber **137** to the discharge compartment **136** through the outlet port **122**. As such, a first portion of the exhaust stroke, where the first inlet port **120** and/or the second inlet port **123** are not fully closed by the piston **103**, may not contribute to flow of fluid towards the discharge compartment **136**. In contrast, a second portion of the exhaust stroke where the first inlet port **120** and the second inlet port **123** are fully closed may contribute to flow being delivered by the pressure regulating pump **200**, for example to a storage tank or calm reservoir. The first portion is hereby referred to as an inactive portion, and the second portion is hereby referred to as an active portion.

[0038] During the intake stroke **410**, the piston spring **101** may push piston **103** away from body **100**, in a direction indicated by arrow **412**, which may generate suction to draw fluid (e.g., lubricant, oil, air) through the suction annulus **133** and into the chamber **137** as the chamber **137** expands in volume. The stiffness of piston spring **101** may be chosen based on mass of piston **103**, force exerted on the piston that is due to suction action, and/or a desired acceleration of piston **103**, which depends on camshaft velocity and the camshaft profile. As the piston **103** is raised, first inlet port **120** and second inlet port **123** are opened to fluidly couple the suction annulus with chamber **137**, allowing fluid to enter the chamber **137** from the suction annulus **133** as indicated by arrows **414**. The first inlet port **120** and the second inlet port **123** may be shaped with a greater width (e.g., dimension parallel with the y-axis) than height (e.g., dimension parallel with the z-axis) as described above such that an amount of fluid entering the pressure regulating pump **200** during the intake stroke is maximized without increasing the portion of the intake stroke in which the first inlet port and the second inlet port are not closed by the piston **103**.

[0039] FIG. **4**B further includes a first portion **418** and a second portion **420** of a mechanical system in which the pressure regulating pump **200** may be placed. The first portion **418** may be a first fluid reservoir and the second portion **420** may be a second fluid reservoir, where it is desired that fluid be removed from the first fluid reservoir and added to the second fluid reservoir. For examples where the mechanical system is a transmission, the first portion **418** may be a transmission sump, the second portion **420** may be a calm reservoir, and the fluid may be oil. The first portion **418** may fluidly couple to the chamber **137** via the first inlet port **120**, the second inlet port **123**, the first hole **153**, and the second hole **157** when the first inlet port **120** and the second inlet port **123** are not covered by the piston **103**. The second portion **420** may fluidly couple to the discharge compartment **136**. In this way, the pressure regulating pump **200** may pump fluid from the first portion **418** to the second portion **420**.

[0040] As the cam **162** rotates, the pressure regulating pump **200** may continue to oscillate between the positions according to rotation of the cam **162**. The speed at which the piston **103** moves is related to the angular speed of cam **162** rotation which may be driven by an engine, an electric machine, an input shaft of a transmission, or the like. The pressure regulating pump **200** (and specifically the piston **103**) may move back and forth between a TDC position and BDC position. However, there are factors which may cause pressure of the chamber **137** to increase beyond a threshold pressure when the first inlet port **120** and the second inlet port **123** are closed, including flow rate and temperature of the fluid. The factors which may increase pressure of the chamber **137** are described further below following a brief description of fluid across an orifice in regards to FIGS. **6**A-**6**B, as well as equation (1) and equation (2) below.

$$Q = C_d \frac{\pi D_o^2}{4} \sqrt{\frac{2(p_1 - p_2)}{\rho}} \tag{1}$$

$$R_e = \frac{\rho v D}{\mu} \tag{2}$$

[0041] Equation (1) shows relationships between a pressure differential (p_2-p_1) across an orifice, a volumetric flow rate of a fluid (Q) flowing through the orifice, a density of the fluid (ρ), and a discharge coefficient (C_d) across the orifice. For example, the pressure differential (p_2-p_1) is directly related to the volumetric flow rate (Q) and the density of the fluid (ρ), and inversely related to the discharge coefficient (C_d). FIG. **6**A shows a cross section view **600** of an example orifice **608** with a length **602** (L_o) and a diameter **607** (D_o), through which a fluid may flow from a first side **604** to a second side **606** in a direction indicated by arrow **609**. As such, a first pressure (p_1) of the first side **604** may be greater than a second pressure (p_2) of the second side **606**. As an example, the orifice **608** may represent the outlet port **122** of FIGS. **1**A-**5** such that the first side **604** may be the chamber **137** and the second side may be the discharge compartment **136**. FIG. **6**B displays a graph **610** showing discharge coefficient (C_d) (depicted along the y axis) plotted as a function of a ratio of the orifice diameter (D_o) and the orifice length (L_o) times the Reynolds number (R_e) of the fluid (depicted along the x axis). A curve **616** shows the discharge coefficient (C_d) for fluid flowing through an orifice, such as the orifice **608** shown in FIG. **6**A or the outlet port **122** shown in FIGS. **1**A-**5**. The discharge coefficient (C_d) increases along the y-axis of graph **610** in direction **612** and a ratio of the orifice diameter (D_o) and the orifice length (L_o) times the Reynolds number (R_e) of the fluid increases along the x-axis of graph **610** in direction **614**. The Reynolds number (R_e) depends on velocity, viscosity, and density of the fluid as shown by equation (2), as well as geometry of a system in which the fluid flows. Thus, the discharge coefficient (C_d) is dependent on fluid properties (e.g., viscosity and density), fluid flow rate (e.g., volumetric flow rate), as well as the orifice geometry (e.g., orifice diameter and orifice length). For example, the discharge coefficient is directly related to the diameter of the orifice (D_o) and Reynolds number (R_e), and indirectly related to the length of the orifice (L_o), as shown by curve **616**.

[0042] For example, returning to FIGS. **4**A-**4**B, cam **162** rotating with high rotational speed may lead to a high volumetric flow of fluid through the outlet port **122** orifice, increasing the difference in pressure between the pressure of the chamber **137** and the pressure of the discharge compartment **136**. Thus, the pressure of chamber **137** may exceed a desired pressure range during the portion of the exhaust stroke in which the first inlet port **120** and second inlet port **123** are closed, for example when the speed of the cam **162** is relatively high. Additionally or alternatively, a change in temperature of the fluid flowing through the pressure regulating pump **200** may affect the pressure build-up in the chamber **137**. For example, a lower temperature of the fluid moving through the pressure regulating pump **200** may reduce the viscosity of the fluid and/or increase the density of the fluid. Because the pressure differential is inversely related to the Reynolds number, the pressure differential is directly related to the viscosity of the fluid and indirectly related to the density of the fluid; therefore, pressure of the chamber **137** may increase due to the lower temperature of the fluid.

[0043] Therefore, the pressure regulating pump **200** may include a pressure relief mechanism, including compression of the body spring **132** and downward movement of the body **100** in response to pressure of the chamber **137** meeting or exceeding a threshold pressure, to prevent pressure from exceeding the threshold pressure. To elaborate, the pressure regulating pump **200** may move to a pressure regulating position such that first inlet port **120** and second inlet port **123** may open when pressure of the chamber **137** is at least at the threshold pressure.

[0044] FIG. **5** shows the pressure regulating pump **200** in a pressure regulating position **500**, wherein pressure of the chamber **137** has exceeded the threshold pressure in the exhaust stroke and as a result, the body spring **132** may be compressed and body **100** may be moved downwards compared to the positions of FIGS. **2**-**4**B. In this way, pressure of the chamber **137** exceeding the threshold pressure may overcome a spring load of the body spring **132**, causing the body spring **132** to be partially compressed and body **100** to be pushed downwards. The movement of the body **100** may occur relative to the casing **130** and axis of rotation **166** which may both remain in the same position. The sealing ring **135** may slide with the second groove **106** as the body **100** moves relative to the casing **130**. To allow for relative movement of the body **100** downwards in the casing **130**, a clearance C between an outer circumferential surface **502** of the body **100** and an inner circumferential surface **504** of the casing **130** may be between 0.1 mm and 0.3 mm. In some examples, the clearance C may be substantially equivalent (e.g., within 5%) to a clearance D between an outer surface of the wall **146** of the piston **103** and an inner cylindrical surface **149** of the outer cylindrical portion **144** of the body **100**. The piston **103** may be in the same position as in BDC position **350** of FIG. **3** due to the cam **162** having the same angular position of approximately 180 degrees from the reference angular position. For example, the top **172** of the body **100** may be below the top **105** of the piston **103**. Further, when in the pressure regulating position, the top **172** of the body **100** may be spaced away or offset from the one or more end stop devices **134**. Thus, the body **100** moving downwards relative to the piston **103** may cause the first inlet port **120** and the second inlet port **123** to be lowered at least partially below the skirt edge **131** of the piston, thereby fluidly coupling the suction annulus **133** with the chamber **137**, and reducing pressure of the chamber **137** to below the threshold pressure. Thus, the downward movement of the body **100** may increase a length of the inactive portion of the exhaust stroke and decrease a length of the active portion of the exhaust stroke. Consequently, a volumetric efficiency of the pressure regulating pump **200** may be decreased, and thus the volumetric flow rate of the fluid through the outlet port **122** may be decreased, thereby reducing the pressure of chamber **137** to below the threshold pressure. Additionally, in the pressure regulating position, the top of the inner cylindrical portion **142** may be lowered, and thus the volume of the chamber **137** may be increased, further contributing to a reduction in pressure of the chamber **137**. As such, the pressure regulating pump **200** may self-regulate a displacement of the pressure regulating pump **200** in order to operate within the desired pressure range.

[0045] Therefore, the pressure regulating pump **200** may be able to regulate the pressure of the chamber **137**, such that the pressure of the chamber **137** may be prevented from exceeding the threshold pressure without using any valves. More specifically, the ability of the body **100** to move depending on the pressure of the chamber **137** may allow the pressure regulating pump **200**, which does not include any valves, to regulate pressure of the chamber **137** (e.g., to maintain the pressure of the chamber **137** at or below the threshold pressure). Thus, the pressure regulating pump **200** may be referred to as a valveless pressure regulating pump.

[0046] Turning to FIG. **7**, a flowchart illustrating a method for operating a pressure regulating pump, such as pressure regulating pump **200**, is shown. For example, the method **700** may be used to pump fluid through a pressure regulating pump. More specifically, the method **700** may be used to pump oil from a transmission sump to a clam reservoir via the pressure regulating pump **200**.

[0047] At **702**, a cam positioned to adjust a position of a piston of the pressure regulating pump is rotated. For example, cam **162** of the pressure regulating pump **200** as shown in FIGS. **2-5** may be rotated about axis of rotation **166** by a camshaft, which may be rotationally coupled to parts of the transmission. The cam may rotate with a constant rotational speed. Additionally or alternatively, the cam may rotate with varying rotational speed. For example, the cam may rotate at a first angular speed for a first amount of time, and in response to a change in transmission operation (e.g., a gear shift) the cam may rotate with a second rotational speed for a second amount of time. Rotation of the cam may cause pumping of fluid through the pressure regulating pump in subsequent steps.

[0048] At **703**, fluid is pumped through the pressure regulating pump as the cam rotates. Pumping fluid through the pressure regulating pump may include performing an intake stroke (e.g., intake stroke **410** of FIG. **4**B) to intake fluid via inlet ports of the pump, as indicated at **704**. For example, fluid (e.g., oil and/or air) from a transmission sump may enter the pressure regulating pump **200** through the first inlet port **120** and the second inlet port **123**. The cam may be rotated during the intake stroke such that cam lift is decreased, the piston is moved towards the axis of cam rotation, and the piston spring is expanded. Consequently, the inlet ports may be opened for fluid to flow into the pressure regulating pump therethrough.

[0049] Pumping fluid through the pressure regulating pump may further include performing an exhaust stroke (e.g., exhaust stroke **400** of FIG. **4**A) to exhaust the fluid through an outlet port of the pump, as indicated at **706**. For example, the fluid may be discharged from the pressure regulating pump **200** through the outlet port **122** into the discharge compartment, and then to a calm reservoir. The cam may be rotated during the exhaust stroke such that the cam lift is increased, the piston spring is compressed, and the piston is moved away from the axis of cam rotation. As a result, the inlet ports may be closed during the active portion of the exhaust stroke, and fluid may be forced out of the pressure regulating pump by a pressure difference across the outlet port.

[0050] At **708**, pressure in the chamber of the pump is translated to axial movement of the pump body when pressure in the chamber exceeds a threshold pressure. For example, the body **100** of pressure regulating pump **200** may move away from the cam **162** due to compression of the body spring **132** in response to pressure of the chamber **137** meeting or exceeding the threshold pressure. Consequently, the length of the inactive portion of the exhaust stroke may be increased, thus reducing pressure back to below the threshold pressure. Once the pressure in the chamber is reduced to the threshold pressure or below, the body spring may urge (e.g., move) the body upwards, towards the cam.

[0051] Turning to FIG. **8**A, a timeline diagram **800** is shown for operation of a pressure regulating pump, such as the pressure regulating pump **200** shown in FIGS. **1**A-**5**, over a first period of time between t**0** and t**12**. The timeline diagram **800** includes three example cycles of rotation of a cam, such as cam **162** which rotates about axis of rotation **166** as shown in FIGS. **2-5** during the first time period. As used herein, a cycle of rotation of the cam includes a full rotation from the reference angular position defined above, or rotation from 0 degrees to 360 degrees. The timeline diagram **800** shows a first plot **802** including a first curve **810** for a pressure of a chamber over time, a second plot **804** including a second curve **812** for an angular position of the eccentric, a third plot **806** including a third curve **814** for a vertical displacement of a piston, and a fourth plot **808** including a fourth curve **816** for a vertical displacement of a body. The first plot **802** includes a threshold pressure **811**. The second plot **804** further includes a 0 degree reference line **826**, a 180 degree reference line **824**, and a 360 degree reference line **822**. The third plot **806** further includes a TDC reference line **828** and a BDC reference line **830**. The fourth plot **808** further includes a normal reference line **832** and a lowered reference line **834**.

[0052] Axes of each plot (e.g., first plot **802**, second plot **804**, third plot **806**, and fourth plot **808**) may increase in the directions indicated by arrows of the axes. For example, time may increase horizontally along all four plots from t**0** to t**12** with intervals between the times marked. It is to be understood that time represents relative time such that t**1** is some time after t**0**, t**2** is some time after t**1**, and so on, but does not indicate specific or proportional quantities of time unless specified in the description below. Further, the timeline diagram **800** shows an example of various measurements during operation of a pressure regulating pump but does not limit the operation of pressure regulating pumps. For example, between t**0** and t**4**, the third curve **814** showing vertical placement of piston is curved similar to a sinusoidal wave. However, with different cam shapes in different embodiments, this curve may appear differently. Similarly, the pressure of the chamber shown by the first curve **810** may behave differently (e.g., change faster or slower, change more or less) from the example shown in timeline diagram **800** depending on a variety of factors, including the cam shape and rotational speed, fluid properties and flow rate, and relative proportions of components of the pressure regulating pump. Thus, unless specified in the description below as specifically increasing or decreasing a certain amount or to a certain pressure, such as the threshold pressure **811**, the first curve **810** does not restrict the dynamics of pressure in a pressure regulating pump.

[0053] In one example, briefly referring to FIGS. **1-5** in addition to FIG. **8**A, if the pressure regulating pump being operated in timeline diagram **800** is pressure regulating pump **200**, the pressure of the chamber shown in the first plot **802** may correspond to the pressure of chamber **137**, the eccentric may be cam **162**, the piston may be piston **103**, and the body may be body **100**. In the same example, the third curve **814** for the vertical placement of the piston may correspond to the position of piston **103** along the z-axis as indicated by reference axes **150**; likewise, the fourth curve **816** for the vertical placement of the body may correspond to the position of body **100** along the z-axis. As such, the TDC position may be TDC position **250** of FIG. **2** and the BDC position may be BDC position **350** shown in FIG. **3**. Additionally, the normal vertical placement of the fourth plot **808** may be the position of body **100** when in contact with end stop devices **134** while the lowered position may be the position of body **100** under maximum compression of body spring **132**. The threshold pressure **811** may be the pressure at which the spring load of body spring **132** is overcome.

[0054] Returning to FIG. **8**A and beginning with a first cycle occurring between t**0** and t**4**, the eccentric starts at t**0** at a 0-degree angular position (e.g., the reference angular position) which corresponds to a TDC position of the piston, and relatively low pressure. Between to and t**1**, the pressure regulating pump is in the inactive portion of a first exhaust stroke, as described with reference to FIG. **4**A. At t**1**, the piston is lowered enough that inlet ports of the pressure regulating pump may be covered, thus pressure of the chamber begins to build during the active portion of the exhaust stroke between t**1** and t**2**.

[0055] Between t**1** and t**2**, the pressure regulating pump is in the active portion of the first exhaust stroke such that the chamber is closed from fluid entering by the inlet ports being covered by the piston. The pressure build-up (e.g., due to a decrease in volume of the chamber) as seen by the increase in the first curve **810** may drive fluid from the chamber to the discharge compartment, thus pushing fluid out of the pump through the outlet port. For example, oil may flow from the chamber to the discharge compartment and subsequently to a calm reservoir.

[0056] Between t**2** and t**4**, the pressure regulating pump is in a first intake stroke. At t**3**, the inlet ports are opened, restoring the fluidic coupling between the chamber and the exterior of the pump via one or more holes in the casing (e.g., the first hole **153** and the second hole **157** of FIGS. **2-5**) and the inlet ports. Thus, the piston moves upwards back towards the TDC marked by the TDC reference line **828** and the pressure is reduced in the chamber as suction builds. During the intake stroke, the reduction in pressure drives fluid flow from outside the pressure regulating pump to inside the pressure regulating pump, more specifically into the chamber of the pressure regulating pump, via the inlet ports and holes. For example, oil may flow into the chamber of the pressure regulating pump from a transmission sump via one or more inlet ports and one or more holes.

[0057] The pressure does not reach the threshold pressure **811** at any point in time between t**0** and t**4** as shown by the first curve **810**. Therefore, the body remains in the normal vertical placement marked by normal reference line **832** during the first cycle, while the piston moves vertically according to cam rotation, causing fluctuations in pressure shown by first curve **810** between t**4** and t**5**. For example, the piston is at the TDC position when the angular position is 0 degrees, or when the second curve **812** connects with the reference line **826** or the reference line **822**, and the piston is at the BDC position when the angular position is 180 degrees, or when the second curve **812** intersects the reference line **824**. Additionally, between t**0** and t**4** the pressure of the chamber decreases during the corresponding intake stroke (e.g., transition from BDC to TDC), and decreases during the active portion of the intake stroke (e.g., a portion of the transition from TDC to BDC). At t**4**, the first cycle ends with the piston returned back to the TDC position and the cam angular position back at the reference angular position as shown in the third plot **806** and the second plot **804**, respectively.

[0058] A second cycle occurs between t**4** and t**8**, with a second exhaust stroke between t**4** and t**6** and a second intake stroke between t**6** and t**8**. The second cycle may be over a shorter period of time than the first cycle. That is, the time between t**4** and t**8** may be less than the time between to and t**4**. At t**5**, the inlet ports are closed, causing an increase in pressure during the active portion of the second exhaust stroke between t**5** and t**6** as seen by the first curve **810**. Further, the pressure of the chamber reaches the threshold pressure **811** between t**5** and t**6**. For example, during the second cycle, the cam rotational speed may be higher and/or the temperature of the fluid may be lower than during the first cycle in which the threshold pressure was not reached, thus resulting in a higher pressure in the chamber that reaches the threshold pressure. As such, the body is moved downwards towards the lowered position marked by the lowered reference line **834** between t**5** and t**6** to extend the active portion of the second exhaust stroke and thereby reduce the pressure of the chamber to below the threshold pressure **811**. As described with reference to FIG. **5**, the movement of the body may be initiated by compression of the body spring in response to pressure shown by the first curve **810** exceeding the threshold pressure **811**. Between t**5** and t**6**, the body is also raised back to the normal position marked by normal reference line **832** as the pressure of the chamber shown by the first curve **810** is reduced to below the threshold pressure **811**. When the angular positon of the cam shown by the second curve **812** exceeds 180 degrees or crosses the 180 degree reference line **824** at t**6**, the pressure regulating pump transitions from the second exhaust stroke to the second intake stroke such that the pressure of the chamber shown by the first curve **810** continues to decrease thereafter.

[0059] A third cycle occurs between t**8** and t**12**, including a third exhaust stroke between t**8** and t**10** and a third intake stroke between t**10** and t**12**. The third cycle may be shorter than the second cycle. For example, the time between t**8** and t**12** may be less than the time between t**4** and t**8**. The angular position of the cam and the vertical placement of the piston follow similar paths as to the second cycle between t**4** and t**8**, although over a relatively smaller amount of time, while the pressure and the vertical displacement of the body change differently. As such, it is shown that the pressure may not follow the same pattern between cycles wherein the pressure reaches the threshold due to factors which affect chamber pressure. For example, the cam may rotate with greater rotational speed between t**8** and t**12** than between t**4** and t**8**. Additionally or alternatively, the temperature of the fluid being pumped by the pressure regulating pump may be lower between t**8** and t**12** than between t**4** and t**8**.

[0060] Operating conditions that affect the pressure build-up in the chamber (e.g., cam rotational speed and temperature of fluid being pumped) may be different between cycles. Consequently, whether the pressure regulating pump moves to the pressure regulating position to prevent exceeding the threshold pressure may be dependent on the operating conditions, in at least some examples. For example, the cam rotational speeds during the second cycle and the third cycle may be higher than the cam rotational speed during the first cycle. Additionally or alternatively, the temperature of the fluid being pumped may be lower during the second cycle and the third cycle than during the first cycle. As a result, the threshold pressure was met in the second and third cycles, but not the first cycle. Thus, the pressure in the chamber may reach the threshold pressure during some cycles, and the pressure regulating pump may move to the pressure regulating position in response.

[0061] Turning to FIG. **8**B, the timeline diagram **800** is shown over a second time period from t**20** to t**27** which may occur before or after t**0** to t**12** as shown in FIG. **8**A. Further, there may be time intervals between the periods shown in FIG. **8**A (e.g., the first time period from t**0** to t**12**) and FIG. **8**B (e.g., the second time period between t**20** and t**27**). The timeline diagram **800** includes plots, curves, and lines as shown in FIG. **8**A which are labeled accordingly. The timeline diagram **800** further shows a O/C reference line **829** on the third plot **806** in FIG. **8**B indicating piston vertical placement where the inlet ports are opened or closed.

[0062] A fourth cycle occurs between t**20** and t**27**, with a fourth exhaust stroke between t**20** and t**24** and a fourth intake stroke between t**25** and t**27**. The fourth cycle begins at t**20** with the piston at a TDC position, the body in a normal vertical placement, and the cam at the reference angular position. Between t**20** and t**21**, the pressure regulating pump is in an inactive portion of the fourth exhaust stroke. At t**21**, the inlet ports are closed as shown by the third curve **814** intersecting the O/C reference line **829** and moving towards the BDC reference line **830**. Thus, the pressure begins increasing at t**21**, and reaches the threshold pressure **811** at t**22**. In response, at t**22**, the body begins to move downwards to increase volume in the chamber, therefore preventing further increase of pressure in the chamber. The body returns to normal vertical placement at t**23**, and pressure begins to decrease. Then at t**24**, the piston reaches the BDC position as the cam reaches a 180 degree angular position. In other examples where the threshold pressure is reached, the piston BDC position may be reached before the body returns to the normal placement and pressure is reduced.

[0063] The timeline diagram **800** shows a larger space between t**24** and t**25** than may be proportional to other time intervals to more clearly illustrate the timing and causation of pressure reduction. The pressure of the chamber may be further reduced, even following the return of the body to the normal vertical placement, while at the BDC position due to fluid flowing out of the chamber through the one or more outlet ports. At t**25**, the fourth intake stroke begins, thus causing a further decrease in pressure as the volume of the chamber is increased, followed by an increase in pressure after t**26** as fluid flows into the chamber due to the inlet ports being opened at t**26**.

[0064] As shown in timeline diagram **800** in FIGS. **8**A and **8**B, the pressure regulating pump maintains pressure of the chamber at or below the threshold pressure **811**. Thus, the pressure regulating pump may self-regulate pressure of the chamber by adjusting the displacement of the pressure regulating pump without the use of any valves (e.g., pressure regulating valves, pressure relief valves, counterbalance valves, and the like). In other words, the pressure of the chamber may be translated to axial movement of the body to maintain the pressure at or below the threshold pressure (e.g., threshold pressure **811**).

[0065] The technical effect of the pressure regulating pump disclosed herein is to pump fluid through the pressure regulating pump and maintain a pressure of a chamber within the pressure regulating pump at or below a threshold pressure without using valves. Thus, the pressure regulating pump may reduce complexity compared to a pump which is used in combination with valves for pressure regulation. Further, the pressure regulating pump may be mechanically actuated such that the pressure regulating pump may be accommodated within a transmission housing. Further still, the pressure regulating pump may be appropriate for pumping oil from a transmission sump to a calm reservoir due to the adequate displacement, and ability to accommodate two-phase flow. Thus, the pressure regulating pump may reduce complexity of the system in which the pressure regulating pump is incorporated, such as a transmission, and reduce resource demand compared to other pumps due to eliminating use of valves.

[0066] The disclosure also provides support for a pump, comprising: a casing, a pump body accommodated within the casing, the pump body comprising an outer cylindrical portion and an inner cylindrical portion, wherein the outer cylindrical portion includes one or more inlet ports and the inner cylindrical portion includes one or more outlet ports, a piston interposed between the outer cylindrical portion and the inner cylindrical portion and configured to move axially relative to the one or more inlet ports, the piston and a top of the inner cylindrical portion defining a chamber, a first spring at least partially interposed between the piston and the inner cylindrical portion, and a second spring interposed between the casing and a bottom of the pump body, wherein the pump body is configured to move axially relative to the casing and compress the second spring when a pressure in the chamber exceeds a pre-load of the second spring. In a first example of the system, the inner cylindrical portion is housed within the outer cylindrical portion and spaced apart from the outer cylindrical portion by a cylindrical cavity, and wherein the cylindrical cavity is in fluid communication with the chamber. In a second example of the system, optionally including the first example, the inner cylindrical portion has a hollow interior defining a discharge compartment, and wherein the discharge compartment is fluidly coupled to the chamber via the outlet port. In a third example of the system, optionally including one or both of the first and second examples, the one or more inlet ports are configured to be fluid communication with the cylindrical cavity. In a fourth example of the system, optionally including one or more or each of the first through third examples, the piston is movable between a top dead center (TDC) position and a bottom dead center (BDC) position, wherein at the TDC position, the one or more inlet ports are at least partially uncovered to provide fluid communication between the one or more inlet ports and the cylindrical cavity, and wherein at the BDC position, the one or more inlet ports are covered by the piston and fluid communication between the one or more inlet ports and the cylindrical cavity is blocked. In a fifth example of the system, optionally including one or more or each of the first through fourth examples, the second spring comprises one or more cup springs arranged in series. In a sixth example of the system, optionally including one or more or each of the first through fifth examples, the system further comprises: one or more end stop devices coupled to the casing and configured to stop upward movement of the pump body. In a seventh example of the system, optionally including one or more or each of the first through sixth examples, the pump is housed in a transmission, wherein the one or more inlet ports are fluidly coupled to a sump of the transmission, and wherein the outlet port is fluidly coupled to a calm reservoir of the transmission. In an eighth example of the system, optionally including one or more or each of the first through seventh examples, the pump is configured to move axially via rotation of a cam coupled to a shaft. In a ninth example of the system, optionally including one or more or each of the first through eighth examples, the pump does not include any valves.

[0067] The disclosure also provides support for a method for a pressure regulating pump, comprising: maintaining a pressure of a pump chamber of the pressure regulating pump at or below a threshold pressure by translating the pressure of the pump chamber to axial movement of a pump body of the pressure regulating pump, the pump body including a cylindrical cavity housing a spring-loaded piston and configured to fluidly couple one or more inlet ports of the pump body to an outlet port. In a first example of the method, the method further comprises: pumping a fluid with the pressure regulating pump, the pumping including intaking the fluid to the pump chamber via the one or more inlet ports during an intake stroke of the piston and exhausting the fluid from the pump chamber via the outlet port during an exhaust stroke of the piston. In a second example of the method, optionally including the first example, the pump body is housed in a casing with a body spring coupled between the pump body and the casing, and wherein maintaining the pressure of the pump chamber at or below the threshold pressure by translating the pressure of the pump chamber to axial movement of the pump body comprises, when the pressure of the pump chamber exceeds a pre-load of the body spring, axially moving the pump body via the pressure in the pump chamber. In a third example of the method, optionally including one or both of the first and second examples, the moving of the pump body moves the one or more inlet ports relative to the piston. In a fourth example of the method, optionally including one or more or each of the first through third examples, the method further comprises: moving the piston during the exhaust stroke via rotation of a cam on a camshaft.

[0068] The disclosure also provides support for a valveless pressure regulating pump, comprising: a pump body including one or more inlet ports and an outlet port, a spring-loaded piston at least partially accommodated within the pump body and configured to pump fluid into and out of a pump chamber formed between the piston and the pump body, and a casing housing the piston and the pump body, wherein the pump body is configured to move axially relative to the casing. In a first example of the system, the pump body is configured to move vertically downward when a pressure of the pump chamber exceeds a pre-load of a spring coupled between the pump body and the casing. In a second example of the system, optionally including the first example, the pump chamber is fluidly coupled to a discharge compartment via the outlet port and is fluidly coupled to a fluid supply via the one or more inlet ports. In a third example of the system, optionally including one or both of the first and second examples, the piston is movable between a top dead center (TDC) position and a bottom dead center (BDC) position, wherein at the BDC position, the one or more inlet ports are covered by the piston and fluid communication between the fluid supply and the pump chamber is blocked, and wherein at the TDC position, the one or more inlet ports are at least partially uncovered to provide fluid communication between the fluid supply and the pump chamber. In a fourth example of the system, optionally including one or more or each of the first through third examples, the pump body is cylindrical and the casing is cylindrical, and wherein the one or more inlet ports are positioned in an annular recess of the pump body, the annular recess and the casing collectively defining a suction annulus.

[0069] FIGS. **1**A-**5** show example configurations with relative positioning of the various components. FIGS. **1**A-**3** and **5** are shown approximately to scale; though other relative dimensions may be used. If shown directly contacting each other, or directly coupled, then such elements may be referred to as directly contacting or directly coupled, respectively, at least in one example. Similarly, elements shown contiguous or adjacent to one another may be contiguous or adjacent to each other, respectively, at least in one example. As an example, components laying in face-sharing contact with each other may be referred to as in face-sharing contact. As another example, elements positioned apart from each other with only a space there-between and no other components may be referred to as such, in at least one example. As yet another example, elements shown above/below one another, at opposite sides to one another, or to the left/right of one another may be referred to as such, relative to one another. Further, as shown in the figures, a topmost element or point of element may be referred to as a "top" of the component and a bottommost element or point of the element may be referred to as a "bottom" of the component, in at least one example. As used herein, top/bottom, upper/lower, above/below, may be relative to a vertical axis of the figures and used to describe positioning of elements of the figures relative to one another. As such, elements shown above other elements are positioned vertically above the other elements, in one example. As yet another example, shapes of the elements depicted within the figures may be referred to as having those shapes (e.g., such as being circular, straight, planar, curved, rounded, chamfered, angled, or the like). Additionally, elements co-axial with one another may be referred to as such, in one example. Further, elements shown intersecting one another may be referred to as intersecting elements or intersecting one another, in at least one example. Further still, an element shown within another element or shown outside of another element may be referred as such, in one example. In other examples, elements offset from one another may be referred to as such.

[0070] Features described as axial may be approximately parallel with an axis referenced unless otherwise specified.

As used herein, the terms "approximately" is construed to mean plus or minus five percent of the range unless otherwise specified. Features described as counter-axial may be approximately perpendicular to the axis referenced unless otherwise specified. Features described as radial may circumferentially surround or extend outward from an axis, such as the axis referenced, or a component or feature described prior as being radial to a referenced axis, unless otherwise specified.

[0071] Features described as longitudinal may be approximately parallel with an axis that is longitudinal. A lateral axis may be normal to a longitudinal axis. Features described as lateral may be approximately parallel with the lateral axis. A vertical axis may be normal to a lateral axis and a longitudinal axis. Features described as vertical may be approximately parallel with a vertical axis.

[0072] The following claims particularly point out certain combinations and sub-combinations regarded as novel and non-obvious. These claims may refer to "an" element or "a first" element or the equivalent thereof. Such claims should be understood to include incorporation of one or more such elements, neither requiring nor excluding two or more such elements. Other combinations and sub-combinations of the disclosed features, functions, elements, and/or properties may be claimed through amendment of the present claims or through presentation of new claims in this or a related application. Such claims, whether broader, narrower, equal, or different in scope to the original claims, also are regarded as included within the subject matter of the present disclosure.

1. A pump, comprising:
- a casing;
- a pump body accommodated within the casing, the pump body comprising an outer cylindrical portion and an inner cylindrical portion, wherein the outer cylindrical portion includes one or more inlet ports and the inner cylindrical portion includes one or more outlet ports;
- a piston interposed between the outer cylindrical portion and the inner cylindrical portion and configured to move axially relative to the one or more inlet ports, the piston and a top of the inner cylindrical portion defining a chamber;
- a first spring at least partially interposed between the piston and the inner cylindrical portion; and
- a second spring interposed between the casing and a bottom of the pump body, wherein the pump body is configured to move axially relative to the casing and compress the second spring when a pressure in the chamber exceeds a pre-load of the second spring.

2. The pump of claim **1**, wherein the inner cylindrical portion is housed within the outer cylindrical portion and spaced apart from the outer cylindrical portion by a cylindrical cavity, and wherein the cylindrical cavity is in fluid communication with the chamber.

3. The pump of claim **2**, wherein the inner cylindrical portion has a hollow interior defining a discharge compartment, and wherein the discharge compartment is fluidly coupled to the chamber via the outlet port.

4. The pump of claim **2**, wherein the one or more inlet ports are configured to be fluid communication with the cylindrical cavity.

5. The pump of claim **4**, wherein the piston is movable between a top dead center (TDC) position and a bottom dead center (BDC) position, wherein at the TDC position, the one or more inlet ports are at least partially uncovered to provide fluid communication between the one or more inlet ports and the cylindrical cavity, and wherein at the BDC position, the one or more inlet ports are covered by the piston and fluid communication between the one or more inlet ports and the cylindrical cavity is blocked.

6. The pump of claim **1**, wherein the second spring comprises one or more cup springs arranged in series.

7. The pump of claim **1**, further comprising one or more end stop devices coupled to the casing and configured to stop upward movement of the pump body.

8. The pump of claim **1**, wherein the pump is housed in a transmission, wherein the one or more inlet ports are fluidly coupled to a sump of the transmission, and wherein the outlet port is fluidly coupled to a calm reservoir of the transmission.

9. The pump of claim **1**, wherein the pump is configured to move axially via rotation of a cam coupled to a shaft.

10. The pump of claim **1**, wherein the pump does not include any valves.

11. A method for a pressure regulating pump, comprising:
- maintaining a pressure of a pump chamber of the pressure regulating pump at or below a threshold pressure by translating the pressure of the pump chamber to axial movement of a pump body of the pressure regulating pump, the pump body including a cylindrical cavity housing a spring-loaded piston and configured to fluidly couple one or more inlet ports of the pump body to an outlet port.

12. The method of claim **11**, further comprising pumping a fluid with the pressure regulating pump, the pumping including intaking the fluid to the pump chamber via the one or more inlet ports during an intake stroke of the piston and exhausting the fluid from the pump chamber via the outlet port during an exhaust stroke of the piston.

13. The method of claim **12**, wherein the pump body is housed in a casing with a body spring coupled between the pump body and the casing, and wherein maintaining the pressure of the pump chamber at or below the threshold pressure by translating the pressure of the pump chamber to axial movement of the pump body comprises, when the pressure of the pump chamber exceeds a pre-load of the body spring, axially moving the pump body via the pressure in the pump chamber.

14. The method of claim **13**, wherein the moving of the pump body moves the one or more inlet ports relative to the piston.

15. The method of claim **13**, further comprising moving the piston during the exhaust stroke via rotation of a cam on a camshaft.

16. A valveless pressure regulating pump, comprising:
- a pump body including one or more inlet ports and an outlet port;
- a spring-loaded piston at least partially accommodated within the pump body and configured to pump fluid into and out of a pump chamber formed between the piston and the pump body; and
- a casing housing the piston and the pump body, wherein the pump body is configured to move axially relative to the casing.

17. The pump of claim **16**, wherein the pump body is configured to move vertically downward when a pressure of the pump chamber exceeds a pre-load of a spring coupled between the pump body and the casing.

18. The pump of claim **16**, wherein the pump chamber is fluidly coupled to a discharge compartment via the outlet port and is fluidly coupled to a fluid supply via the one or more inlet ports.

19. The pump of claim **18**, wherein the piston is movable between a top dead center (TDC) position and a bottom dead center (BDC) position, wherein at the BDC position, the one or more inlet ports are covered by the piston and fluid communication between the fluid supply and the pump chamber is blocked, and wherein at the TDC position, the one or more inlet ports are at least partially uncovered to provide fluid communication between the fluid supply and the pump chamber.

20. The pump of claim **16**, wherein the pump body is cylindrical and the casing is cylindrical, and wherein the one or more inlet ports are positioned in an annular recess of the pump body, the annular recess and the casing collectively defining a suction annulus.

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