United States Patent Application Publication 20250264162
Kind Code A1
Publication Date August 21, 2025
Inventor(s) Schlueter; Jared et al.

HIGH STABILITY REGULATOR

Abstract

A vent valve opens to provide a fluid path from a regulated pressure port to a vent port, a supply valve opens to provide a fluid path from the regulated pressure port to a supply pressure port. A control piston has a linear cam profile with a vent cam that opens the vent valve and a supply cam that opens the supply pressure valve.

Inventors: **Schlueter; Jared (Traverse City, MI), MIZELL; DAN (Traverse City, MI)**

Applicant: **The Oilgear Company** (Traverse City, MI)

Family ID: **1000008576819**

Appl. No.: **19/198881**

Filed: **May 05, 2025**

Related U.S. Application Data

parent US continuation 18491487 20231020 parent-grant-document US 12320438 child US 19198881
parent US division 17574141 20220112 parent-grant-document US 11828376 child US 18491487
us-provisional-application US 63136532 20210112

Publication Classification

Int. Cl.: **F16K17/04** (20060101); **F16K17/06** (20060101)

U.S. Cl.:

CPC **F16K17/0486** (20130101); **F16K17/065** (20130101); Y10T137/2607 (20150401)

Background/Summary

CROSS-REFERENCE TO RELATED CASES [0001] This application is a continuation of U.S. patent application Ser. No. 18/491,487 entitled HIGH STABILITY REGULATOR filed on Oct. 20, 2023 which is a divisional of U.S. patent application Ser. No. 17/574,141 filed Jan. 12, 2022, which claims the benefit of U.S. provisional patent application Ser. No. 63/136,532 entitled HIGH STABILITY REGULATOR, filed on Jan. 12, 2021, the contents of which are hereby incorporated by reference.

FIELD OF THE INVENTION
[0002] This disclosure relates to hydraulic circuits in general and, more specifically, to hydraulic pressure regulators.
BACKGROUND OF THE INVENTION
[0003] The hydraulic pressure regulator is a widely used piece of equipment in the fluid power industry. A primary function is to reduce a supply pressure to an equal or lower pressure that is more suitable for the equipment to which it supplies fluid. Another function of a regulator is to provide a relieving function to protect the system against excessive pressure in the regulated port. This is particularly useful in circuits that are static for long periods of time.
[0004] What is needed is a device that achieves the foregoing, and other aims, while delivering accurate regulated pressure while dealing with pressure spikes, other regulators in the circuit, high and low flow events, and other challenges.
SUMMARY OF THE INVENTION
[0005] The invention of the present disclosure, in one aspect thereof, comprises a hydraulic regulator having a vent valve that opens to provide a fluid path from a regulated pressure port to a vent port, a supply valve that opens to provide a fluid path from the regulated pressure port to a supply pressure port, and a control piston having a linear cam profile with a vent cam that opens the vent valve and a supply cam that opens the supply pressure valve. The vent cam and the supply cam are spaced apart axially along the control piston and the vent valve and the supply pressure valve are spaced apart from one another such that only one of the vent valve and the supply valve are opened at once.
[0006] The control piston may move in a first direction to open the vent valve and in a second, opposite direction to open the supply valve. The control piston may be exposed on a first end thereof to the regulated pressure port such that the piston moves in the first direction when a regulated pressure exceeds a predetermined limit. The control piston is exposed on a second, opposite end thereof, to a set spring. The control piston may move in the second direction when the regulated pressure on the first end exceeds a force of the set spring on the second end of the piston.
[0007] In some embodiments, the control piston is exposed on a second, opposite end thereof, to a hydraulic pilot pressure. The control piston may move in the second direction when the regulated pressure on the first end exceeds a force of the pilot pressure on the second end of the piston. A fluid pathway between the control piston and the pilot pressure may be damped by a check valve with an orifice.
[0008] In further embodiments, the control piston is exposed on a second, opposite end thereof to a spring and a hydraulic pilot pressure. The control piston may move in the second direction when the regulated pressure on the first end exceeds a force of the pilot pressure and a force of the spring on the second end of the piston.
[0009] The invention of the present disclosure, in another aspect thereof, comprises a hydraulic regulator having a pilot piston with an outer cam profile including a vent lobe at a first end of the cam profile and a first supply lobe on a distal second end of the cam profile, the vent lobe and the first supply lobe extending radially away from a flat medial portion of the cam profile. The

regulator has a first ball actuating a vent valve upon contact with the vent lobe, and a second ball actuating a first supply valve upon contact with the first supply lobe. The piston is biased to respond to a regulated pressure at a regulated port by moving axially first direction to bring the first ball in contact with the vent lobe when the regulated pressure exceeds a setpoint, and to respond to the regulated port pressure by moving axially in a second direction to bring the second ball in contact with the first supply lobe when the regulated pressure falls below the setpoint. Opening of the vent valve exposes the regulated port to vent, and opening of the first supply valve exposes the regulated port to a supply pressure. The outer cam profile is configured such that the vent valve and the first supply valve cannot open simultaneously.

[0010] In some embodiments, the vent lobe and the first supply lobe are offset from one another circumferentially on the outer cam profile. Some embodiments comprise a third ball actuating second supply valve upon contact with second supply lobe on the control piston. The second supply lobe may be on the second distal end of the cam profile. The first and second supply lobes may be offset circumferentially about 180 degrees from one another on the cam profile.

[0011] In some cases, the control piston is biased hydraulically. The regulator may also have a guide with an internal channel and fitted inside the outer cam profile, the internal channel providing the hydraulic bias of the control piston. In some cases, a channel passes axially through the control piston and provides the hydraulic bias to the control piston on a first end thereof opposite a second end exposed to the regulated pressure.

[0012] The invention of the present disclosure, in another aspect thereof, comprises a hydraulic actuator with a supply port, a vent port, and a regulated port. The regulator has a supply valve biased in a closed position that provides a fluid connection from the supply port to the regulated port when in an open position. It has a vent valve biased in a closed position that provides a fluid connection from the vent port to the regulated port when in an open position. It also has a control piston having a first end and a second end with a linear cam profile between the first end and the second end, the outer cam profile having a narrower medial portion, a vent lobe on a first end, and a supply lobe on a second end. A first end of the control piston receives a biasing force and the second end of the piston is exposed to the regulated port. The control piston moves the vent lobe into contact with the vent valve thereby opening it when a pressure at the regulated port exceeds a set point. The control piston moves the supply lobe into contact with the supply valve thereby opening it when the pressure at the regulated port falls below the set point. The supply valve and the vent valve are spaced with respect to the linear cam profile such that only one of the supply valve and the vent valve can be opened at once, but both the supply valve and the vent valve may be closed simultaneously.

[0013] In some embodiments, the control piston is spring biased on the first end thereof and receives a guide in a chamber in the second end thereof, the guide having an internal channel that with a fluid pathway to the regulated port.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIG. **1** is a cutaway view of a pilot stage of a high stability regulator according to the present disclosure.

[0015] FIG. **2** is a cutaway view of a main stage of a high stability regulator according to the present disclosure.

[0016] FIG. **3**A is a cutaway view of another embodiment of a high stability regulator according to aspects of the preset disclosure.

[0017] FIG. **3**B is another cutaway view of the high stability regulator of FIG. **3**A.

[0018] FIG. **4**A is a cutaway view of another embodiment of a high stability regulator according to

aspects of the present disclosure.
[0019] FIG. **4**B is another cutaway view of the high stability regulator of FIG. **4**A.
[0020] FIG. **5** is a simplified schematic of a hydraulic circuit incorporating a hydraulically set regulator according to the present disclosure.
[0021] FIG. **6** is a simplified schematic of a hydraulic circuit incorporating a manually set regulator according to the present disclosure.
DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS
[0022] With some regulators, over time, supply pressure can slowly leak into and raise the regulated pressure. When the regulated pressure raises high enough, a relief function may be designed to connect the regulated pressure to a vent port and lower the pressure back down to a desired level.
[0023] The set point of a hydraulic regulator may be controlled in two ways. The first is to use a spring and adjustment screw assembly to manually change the set point. The other is what's commonly referred to as a pilot regulator. This type uses hydraulic pressure to create the bias force required rather than a spring. This can allow the operator of the system to remotely change the regulator set point if needed.
[0024] Regulators according to some embodiments of the present disclosure may utilize both a main stage regulating poppet as well as a relieving poppet to accomplish regulating functionality. Some regulators according to the present disclosure also have a pilot stage regulator. FIG. **1** illustrates one such pilot stage regulator **100** in cross section. This pilot stage **100** both regulates and relieves, but allows the overall regulator design (i.e., a main stage) to be more accurate and stable. It also allows the design to have a smaller spring, especially when designed for high pressures.
[0025] According to various embodiments, a regulator or regulator system may use the pilot stage **100** to accomplish small flow requirements. When this cannot satisfy demands, the pilot stage **100** may imbalance a main stage regulator (as shown in FIG. **2** and discussed below) to handle higher flow rates.
[0026] The pilot stage regulator **100** of FIG. **1** is shown as a manually adjustable regulator. A spring **114** which creates a bias force that can be adjusted to alter the setpoint of the regulator **100**. Spring force of the spring **114**, and ultimately the regulator set pressure, can be manually changed by using mechanism **120** (which may comprise a screw mechanism) to compress or decompress the spring **114**. A housing **115** that contains the spring **114** can be altered, as known in the art, to allow a hydraulic connection to apply pressure to create the bias force on the pilot regulator **100**.
[0027] As illustrated the pilot regulator **100** comprises a housing **101** to which the spring housing **115** may be affixed. Pressure or bias force from spring **114** may be transferred to a spring seat **113** and onward to bearing **119**. A vent port **125** may be provided in the body **101** to prevent the bearing **119** from becoming hydraulically locked or otherwise being unable to move freely in response to forces applied thereto. Force from bearing **119** creates the bias force controlling the movement of a pilot piston **102**. This force is balanced by the regulated pilot pressure in the pilot stage body **101** and bearing against the piston **102** that resists the force applied by the spring **114**. A tap into body **101** (out of frame) provides a connection to the regulated pressure side of the piston **102** (on the right, as drawn).
[0028] When the regulated pilot pressure falls below the set point, or, in other words, the force that regulated pressure creates on the pilot piston **102** falls below the spring force, the pilot piston **102** will move away from the spring force (to the right, as shown). A ball **104** rides along a contoured slide **130** affixed to other otherwise integrated with the piston **102**. The slide **130** may be configured as a tubular member (accommodating the piston **103** inside) but have a varying outer diameter such that the ball **141** may be displaced by an orthogonal displacement of the piston **103**. In other embodiments, the slide **130** may be formed as part of the piston **103**. As illustrated, the distal ends of the slide **130** comprise wider or inclined ends, or inclined profiles **131**, **132** separated

by a relatively narrower central portion. However, differencing profiles for the slide **130** could be utilized so long as they are arranged to displace balls and open supply or vent ports according to the function described herein.

[0029] In the illustrated embodiment, as the pilot piston **102** moves away from the bearing **119**, the ball **141** rides up the inclined profile **131** and pushes a regulator pilot poppet **103**, biased closed by spring **106**, off an associated seat **105** to open a flow path from a supply source (out of frame, supplying supply pressure to the poppet **103** opposite the ball **104** to the regulated port). By opening the regulated pilot port in this manner, it allows for well controlled throttling of the flow into this port, which drastically reduces the potential for oscillation of the poppet **103**.

[0030] In some scenarios, supply pressure can leak into the regulated pilot region and slowly raise the pressure. If the pressure in the regulated pilot region increases above the set point, the force applied by the spring **114** is no longer enough to resist the force on the pilot piston **102**. The pilot piston **102** then begins to compress the spring **114** and move to the left (toward the bearing **119**). As the piston moves, a ball **142** rides up incline **132** (wider portion of slide **130**) and begins to open the relieving poppet **133**, biased closed by spring **136**. As poppet **133** lifts off a seat **135**, the regulated pilot pressure is connected to the vent region (on the opposite side of poppet **133** from ball **135**) and begins flowing to vent. Regulated pressure will continue flowing to vent as long as there is a force imbalance between the pilot piston **102** and the spring **114**.

[0031] Once the regulated pressure has dropped enough to balance the forces, the pilot piston **102** moves to the right and the relieving poppet **133** re-seats under pressure from spring **136** onto the seat **135** to stop the flow to vent. It will be appreciated that the operating principal of the relieving function is similar to the regulated pilot function in that it creates a stable and controlled pilot pressure even if there is leakage into the pilot region.

[0032] One function of the pilot regulator **100** is to provide a stable pilot pressure for a main stage of regulator for high flow events. FIG. **2** is a cross section of one such main stage regulator **200**. It should also be understood that, in some cases, the main stage regulator **200** can be used other pilot sources, or without a separate regulated pilot stage (e.g., by using a spring setpoint).

[0033] The main stage regulator **200** may have a control piston **203**, operating within a body **201**. Pilot pressure from pilot port **250** creates a bias force to the right (away from the port **250**). A spring **220** that creates a counter bias force to center the control piston **203**. If the force created by the regulated pressure (on the side of piston **203**, port out of frame) exceeds the force created by the pilot pressure **250**, the control piston **203** will move to the left, or toward the pilot pressure and away from the direction of the spring **220**. When the regulated pressure is sufficiently low, the pilot pressure creates enough force to compress spring **220** and move the control piston **203** to the right, toward the spring **220**.

[0034] The control piston **203** is fitted with a carriage **202**. The carriage **202** may be a tubular member though which the piston **203** is fitted. In some embodiments, the carriage **202** may be an integral component with the piston **203**. The carriage **203** may have a smaller diameter along a medial portion and a larger diameter on the ends or distal portion. To that end, the distal portions may form ramped inclines **252**, **254**. To ensure that balls **243**, **244** track properly along the carriage **202** for displacement by the ramped inclines **252**, **254**, slots or tracks **253**, **254** may be defined in the carriage **202**

[0035] When the control piston **203** moves right, or away from the pilot pressure, the ball **243** is displaced away from the piston **203** by incline **252**. The ball **243**, on a regulating poppet **205**, will begin to push the poppet **205** against spring **208** and off of an associated seat **206** and allow supply pressure to flow to the regulated port (supply port out of frame). As regulated pressure rises, it will begin to resist the force of the pilot pressure and move the control piston **203** back to the left (toward the pilot port). As it moves, the ball **243** follows the contour of the carriage **202** and lowers, allowing the regulating poppet **205** to reseat on the seat **206**, and stop flow from supply port to the regulated port.

[0036] When there is an event that causes the regulated pressure to rise above the pilot pressure, the control piston **203** becomes imbalanced and moves toward the pilot port **250**. As the piston **203** moves, ball **244** follows the contour of the carriage **202** and encounters incline **254** and is displaced away from the piston **203**. The ball **244**, being in contact with poppet **213**, unseats poppet **213** from seat **210** compressing spring **221**. This creates a flow path from the regulated pressure port to vent port (out of frame). As the regulated pressure flows out the vent port, the pressure in the regulated region falls. As it falls, the forces on the control piston **203** become balanced with pilot pressure, and the spring **220** re-centers the control piston **203**. As the ball **244** follows the contour of the carriage **202**, the relieving poppet **213** reseats on the seat **210** and stops the flow of fluid out the vent port.

[0037] Referring now to FIG. **3**A a cutaway view of another embodiment of a high stability regulator **300** according to aspects of the preset disclosure is shown. FIG. **3**B is another cutaway view of the high stability regulator **300** rotated 90 degrees. The regulator **300** is manually set and comprises a body **302** affixed to a spring housing **304**. The body **302** and housing **304** contain most or all of the operational components. Preloading or tension applied to spring **306** within housing **304** may dictate the ultimate regulated pressure provided by the regulator **300**. The regulated pressure may be adjusted by spring adjustment mechanism **308**, which may comprise a screw type adjustment or other mechanism.

[0038] The spring **306** may fit against a spring seat **307** which contacts a control piston **310**. The control piston **310** may comprise a stem **320** on a first end, which contacts the spring seat **307**, and a cam **322** on an opposite end. The cam **322** may have a profile providing a vent lobe **324** that can slide into contact with a vent valve **328**. The vent valve **328** may have a ball **329** that rides on the cam **322** in a slot **326** defined in the cam. The slot **322** may lead into the vent lobe **324** and may or may not be cut into the lobe **324** itself.

[0039] The vent valve **328** may be biased in a closed configuration by a spring **331** acting to press a poppet **330** against a seat **334** when the ball **329** is not pressed outward from the cam **322** by the lobe **324** (when the control piston is sufficiently pressed by spring **306** to allow the ball **329** to ride in the slot **326** but not on the lobe **324**). The poppet **330** may contact the seat **334** on a peripheral lip **332** that has a profile sufficiently thin to flex slightly against the seat **334**. The seat **334** may be steeply angled with respect to the direction of movement of the poppet **330** (e.g., steeper than 45 degrees) such that the lip **332** fits against the seat **334** and seals with relatively little pressure from the spring **331**.

[0040] The cam **322** may also provide one or more supply lobes **341** and associated slots **342**. These may be offset circumferentially from the vent lobe **324** by about 90 degrees on the cam **322** but still aligned with the direction of movement of the control piston **310** to open and close associated supply pressure valves **340**. The supply lobes **341** may be located on an opposite end (axially) of the cam **322** from the vent lobe **324**. In this manner there are lobes on opposite end of the cam **322** but a medial portion **323** does not open either the exhaust valve or the supply valves **340** with the associated balls of the respective valves occupying the slots **326**, **342** but not being displaced such that the valves **328**, **340** are open. The supply valves **340** may have a similar construction as the vent valve **328**, being spring biased closed, having a lipped poppet, and a steeply angled seat.

[0041] The cam **322**, in addition to external features, may also have an internal pressure cavity **333** and/or a pressure face **352** that may ensure that the control piston **310** responds adequately to pressure changes in the regulated pressure reaching regulated pressure port **312**. In some embodiments, the cavity **333** and/or pressure face are defined within the stem **320**. The piston **310** may ride or slide on a guide **316**. The guide **316** and/or body **302** may have channels **314** defined therein that lead to a guide channel **318** leading to the pressure cavity **333**. In this way the pressure cavity **333** and/or pressure face **352** is in fluid communication with regulated pressure to move the control piston **310**.

[0042] In operation, if the regulated pressure falls below a setpoint as determined by the adjustment of the spring **306**, the control piston **310** will be pushed away by the spring **306** (leftward in the drawings). The supply lobes **341** of the cam **322** will open the supply valves in a linear and controlled fashion exposing regulated pressure and the regulated pressure port **340** to supply pressure (supply port out of frame). This will tend to increase regulated pressure until the control piston returns (rightward in the drawing) to press back against the spring **306** and allowing the supply pressure valves **340** to close.
[0043] If the regulated pressure increases beyond a setpoint determined by the adjustment of the spring **306**, the control piston will press against and moved toward the spring **306** until the vent lobe **324** opens the vent valve **328**, which exposes regulated pressure to vent (vent port out of frame) in a linear and controlled fashion. This will lower the regulated pressure until the force of the spring **306** returns the control piston **310** away from the direction of the spring (leftward as drawn) and allows the vent valve **328** to close.
[0044] Referring now to FIG. **4**A, a cutaway view of another embodiment of a high stability regulator **400** according to aspects of the present disclosure is shown. FIG. **4**B a cutaway view of the high stability regulator **400** rotated about 90 degrees. The regulator **400** may be hydraulically controlled as to setup or regulated pressure output. To that end, a pilot port **450** is provided in a body **402** of the regulator which feeds into internal passage **430** for operation upon a control piston **410**.
[0045] The control piston **410** may comprise a stem **420** having an internal passage **418** that allows for fluid communication to a pilot pressure face **416** on an opposite end of the piston **410**. A spring **404** may be received by a seat **412** of the piston **410** and provide for gross control over a setpoint of the valve **400**.
[0046] The piston **410** has a cam portion **422** adjacent to the stem **420** that provides a profile with a vent lobe **424** that can engage with and open a vent valve **328** thereby exposing the regulated port **312** to vent (vent port out of frame). Offset from circumferentially on the cam **422** (by about 90 degrees in both directions as shown) is a pair of supply cams **441**. The supply cams **441** may each engage with and open a pair of supply valves **340**. A medial portion **423** of the cam **422** allows the vent valve **328** and both supply valves **340** to remain closed. The vent cam **424** and the supply cams **441** are on opposite ends (axially) of the cam **422**. Slots or channels may be provided in the cam **422** to receive and guide balls associated with the valves **328**, **340**.
[0047] The vent valve **328** and the supply valves **340** may be substantially similar or identical in construction to those described with respect to the regulator **300**. Additionally, although both regulators **300**, **400** are shown with one vent valve **328** and two supply valves, **340**, other embodiments can differ in number and placement of valves.
[0048] Regulated pressure is controlled at least in part by pilot pressure and spring tension from the spring **404**. In the event that regulated pressure becomes high and exceeds the setpoint, the piston **410** may be pushed against the spring and the hydraulic pilot pressure (moved leftward as shown). In this case, the vent cam **424** will open the closed-biased vent valve **328** which exposed regulated pressure to vent, thereby reducing the regulated pressure and allowing the control piston to move back such that the cam **424** moves away from the vent valve **328** closing it again.
[0049] In the event that regulated pressure drops, the spring **404** and pilot pressure moves the control piston away from the direction of the spring and the cams **441** open the closed-biased supply pressure valves **340**, thereby exposing the regulated pressure to supply pressure. Supply pressure may increase the regulated pressure which will move the piston back (leftward as shown) against the spring **404** and pilot pressure, which will close the supply pressure valves **340** again.
[0050] The ramped profiles of the cams **424**, **441** open and close the associated valves in a linear and controlled manner. To further control and/or dampen movement of the control piston **410**, pilot pressure may enter the regulator **400** via a check valve **432** with a bypass orifice in the channel **430**. The check valve **432** may comprise a ball check valve. In such case check valve **432** may have

a seat **434** defining one or more slots acting as an orifice. The associated ball, when seated against the seat **434**, substantially slows, but does not stop, fluid flow. In this manner pilot pressure may always be increased if needed and the piston **410** is not hydraulically locked. However, in the event that regulated pressure drops it may need to be restored quickly. To that end the check valve **432** is forced open by the displacement of fluid by the control piston **410** and the control piston **410** is not substantially impeded by back pressure in the channel **430**.

[0051] The design of regulators according to the present disclosure provide smooth and accurate setting of a regulated pressure. The linear motion of control pistons and the associated linear camming actions, as well as the distances the pistons of the various embodiments travel between valve openings creates a very damped valve. With high dampening comes stability. Regulators according to the present disclosure work well with pressure spikes, multiple regulators in series, high flow events, and low flow events.

[0052] The present disclosure is not intended to be limited with respect to applications of the disclosed high stability regulators. FIG. **5** illustrates that, in a very simple example, a hydraulically controlled regulator (such as regulators **200**/**400**) have a supply port **504** that is regulated as described above to produce a predictable and stable pressure at a regulator port **506**. A vent port **508** may be utilize as described. Control of the regulator **200**/**400** may be via a pilot port **502** as described. As show in FIG. **6**, in the case of a manually set regulator (e.g., regulator **300**), supply pressure port **504** is regulated to supply stable and predictable pressures at regulated port **508**. Vent port **508** may also be used but pilot port **502** may be absent or unused.

[0053] It should be appreciated that not every machining operation, flow path, seal, gasket, fastener, or other component that would be needed to implement regulators as described herein is described in detail. Such components and expertise is known in the art, and thus embodiments of the present disclosure can readily be implemented without undue experimentation based on the components and functionality described.

[0054] It is to be understood that the terms “including”, “comprising”, “consisting” and grammatical variants thereof do not preclude the addition of one or more components, features, steps, or integers or groups thereof and that the terms are to be construed as specifying components, features, steps or integers.

[0055] If the specification or claims refer to “an additional” element, that does not preclude there being more than one of the additional element.

[0056] It is to be understood that where the claims or specification refer to “a” or “an” element, such reference is not be construed that there is only one of that element.

[0057] It is to be understood that where the specification states that a component, feature, structure, or characteristic “may”, “might”, “can” or “could” be included, that particular component, feature, structure, or characteristic is not required to be included.

[0058] Where applicable, although state diagrams, flow diagrams or both may be used to describe embodiments, the invention is not limited to those diagrams or to the corresponding descriptions. For example, flow need not move through each illustrated box or state, or in exactly the same order as illustrated and described.

[0059] Methods of the present invention may be implemented by performing or completing manually, automatically, or a combination thereof, selected steps or tasks.

[0060] The term “method” may refer to manners, means, techniques and procedures for accomplishing a given task including, but not limited to, those manners, means, techniques and procedures either known to, or readily developed from known manners, means, techniques and procedures by practitioners of the art to which the invention belongs.

[0061] The term “at least” followed by a number is used herein to denote the start of a range beginning with that number (which may be a range having an upper limit or no upper limit, depending on the variable being defined). For example, “at least 1” means 1 or more than 1. The term “at most” followed by a number is used herein to denote the end of a range ending with that

number (which may be a range having 1 or 0 as its lower limit, or a range having no lower limit, depending upon the variable being defined). For example, "at most 4" means 4 or less than 4, and "at most 40%" means 40% or less than 40%.
[0062] When, in this document, a range is given as "(a first number) to (a second number)" or "(a first number)-(a second number)", this means a range whose lower limit is the first number and whose upper limit is the second number. For example, 25 to 100 should be interpreted to mean a range whose lower limit is 25 and whose upper limit is 100. Additionally, it should be noted that where a range is given, every possible subrange or interval within that range is also specifically intended unless the context indicates to the contrary. For example, if the specification indicates a range of 25 to 100 such range is also intended to include subranges such as 26-100, 27-100, etc., 25-99, 25-98, etc., as well as any other possible combination of lower and upper values within the stated range, e.g., 33-47, 60-97, 41-45, 28-96, etc. Note that integer range values have been used in this paragraph for purposes of illustration only and decimal and fractional values (e.g., 46.7-91.3) should also be understood to be intended as possible subrange endpoints unless specifically excluded.
[0063] It should be noted that where reference is made herein to a method comprising two or more defined steps, the defined steps can be carried out in any order or simultaneously (except where context excludes that possibility), and the method can also include one or more other steps which are carried out before any of the defined steps, between two of the defined steps, or after all of the defined steps (except where context excludes that possibility).
[0064] Further, it should be noted that terms of approximation (e.g., "about", "substantially", "approximately", etc.) are to be interpreted according to their ordinary and customary meanings as used in the associated art unless indicated otherwise herein. Absent a specific definition within this disclosure, and absent ordinary and customary usage in the associated art, such terms should be interpreted to be plus or minus 10% of the base value.
[0065] Thus, the present invention is well adapted to carry out the objects and attain the ends and advantages mentioned above as well as those inherent therein. While the inventive device has been described and illustrated herein by reference to certain preferred embodiments in relation to the drawings attached thereto, various changes and further modifications, apart from those shown or suggested herein, may be made therein by those of ordinary skill in the art, without departing from the spirit of the inventive concept the scope of which is to be determined by the following claims.

Claims

1. A hydraulic regulator comprising: a vent valve that opens to provide a fluid path from a regulated pressure port to a vent port; a supply valve that opens to provide a fluid path from the regulated pressure port to a supply pressure port; and a control piston having a linear cam profile with a vent cam that opens the vent valve and a supply cam that opens the supply pressure valve; wherein the vent cam and the supply cam are spaced apart axially along the control piston and the vent valve and the supply pressure valve are spaced apart from one another such that only one of the vent valve and the supply valve are opened at once.
2. The hydraulic regulator of claim 1, wherein the control piston moves in a first direction to open the vent valve and in a second, opposite direction to open the supply valve.
3. The hydraulic regulator of claim 2, wherein the control piston is exposed on a first end thereof to the regulated pressure port such that the piston moves in the first direction when a regulated pressure exceeds a predetermined limit.
4. The hydraulic regulator of claim 3, wherein the control piston is exposed on a second, opposite end thereof, to a set spring.
5. The hydraulic regulator of claim 4, wherein the control piston moves in the second direction when the regulated pressure on the first end exceeds a force of the set spring on the second end of

the piston.
6. The hydraulic regulator of claim 3, wherein the control piston is exposed on a second, opposite end thereof, to a hydraulic pilot pressure.
7. The hydraulic regulator of claim 6, wherein the control piston moves in the second direction when the regulated pressure on the first end exceeds a force of the pilot pressure on the second end of the piston.
8. The hydraulic regulator of claim 7, wherein a fluid pathway between the control piston and the pilot pressure is damped by a check valve with an orifice.
9. The hydraulic regulator of claim 3, wherein the control piston is exposed on a second, opposite end thereof to a spring and a hydraulic pilot pressure.
10. The hydraulic regulator of claim 9, wherein the control piston moves in the second direction when the regulated pressure on the first end exceeds a force of the pilot pressure and a force of the spring on the second end of the piston.
11. A hydraulic regulator comprising: a pilot piston with an outer cam profile including a vent lobe at a first end of the cam profile and a first supply lobe on a distal second end of the cam profile, the vent lobe and the first supply lobe extending radially away from a flat medial portion of the cam profile; a first ball actuating a vent valve upon contact with the vent lobe; and a second ball actuating a first supply valve upon contact with the first supply lobe; wherein the piston is biased to respond to a regulated pressure at a regulated port by moving axially first direction to bring the first ball in contact with the vent lobe when the regulated pressure exceeds a setpoint, and to respond to the regulated port pressure by moving axially in a second direction to bring the second ball in contact with the first supply lobe when the regulated pressure falls below the setpoint; wherein opening of the vent valve exposes the regulated port to vent, and opening of the first supply valve exposes the regulated port to a supply pressure; and wherein the outer cam profile is configured such that the vent valve and the first supply valve cannot open simultaneously.
12. The hydraulic regulator of claim 11, wherein the vent lobe and the first supply lobe are offset from one another circumferentially on the outer cam profile.
13. The hydraulic regulator of claim 11, further comprising a third ball actuating second supply valve upon contact with second supply lobe on the control piston.
14. The hydraulic regulator of claim 13, wherein the second supply lobe is on the second distal end of the cam profile.
15. The hydraulic regulator of claim 14, wherein the first and second supply lobes are offset circumferentially about 180 degrees from one another on the cam profile.
16. The hydraulic actuator of claim 11, wherein the control piston is biased hydraulically.
17. The hydraulic actuator of claim 16, further comprising a guide having an internal channel and fitted inside the outer cam profile, the internal channel providing the hydraulic bias of the control piston.
18. The actuator of claim 16, further comprising a channel passing axially through the control piston and providing the hydraulic bias to the control piston on a first end thereof opposite a second end exposed to the regulated pressure.
19. A hydraulic actuator comprising: a supply port, a vent port, and a regulated port; a supply valve biased in a closed position, that provides a fluid connection from the supply port to the regulated port when in an open position; a vent valve biased in a closed position that provides a fluid connection from the vent port to the regulated port when in an open position; and a control piston having a first end and a second end with a linear cam profile between the first end and the second end, the outer cam profile having a narrower medial portion, a vent lobe on a first end, and a supply lobe on a second end; wherein a first end of the control piston receives a biasing force and the second end of the piston is exposed to the regulated port; wherein the control piston moves the vent lobe into contact with the vent valve thereby opening it when a pressure at the regulated port exceeds a set point; wherein the control piston moves the supply lobe into contact with the supply

valve thereby opening it when the pressure at the regulated port falls below the set point; and wherein the supply valve and the vent valve are spaced with respect to the linear cam profile such that only one of the supply valve and the vent valve can be opened at once, but both the supply valve and the vent valve may be closed simultaneously.

20. The hydraulic actuator of claim 19, wherein the control piston is spring biased on the first end thereof and receives a guide in a chamber in the second end thereof, the guide having an internal channel that with a fluid pathway to the regulated port.