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(54) **ACTIVE OIL INJECTION SYSTEM FOR A DIAPHRAGM COMPRESSOR**

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F04B 45/053 (2006.01)
F04B 39/02 (2006.01)
(Continued)

(52) **U.S. Cl.**

CPC ***F04B 45/053*** (2013.01); ***F04B 39/02*** (2013.01); ***F04B 39/06*** (2013.01); ***F04B 39/16*** (2013.01);
(Continued)

(58) **Field of Classification Search**

CPC F04B 45/053; F04B 39/02; F04B 39/06; F04B 39/16; F04B 53/08; F04B 23/06;
(Continued)

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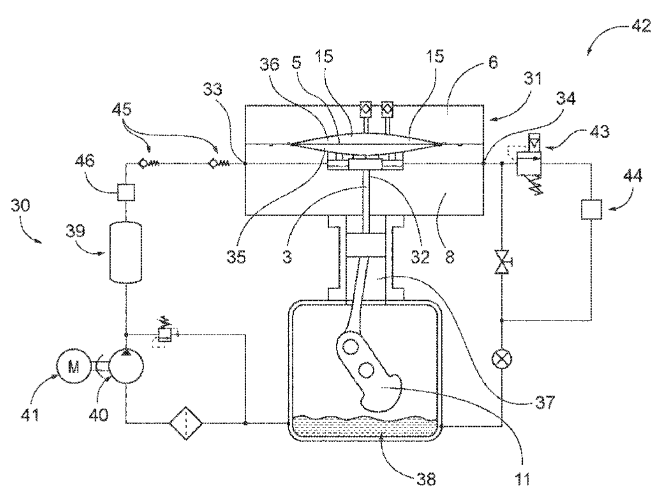
(57) **ABSTRACT**

Devices and methods for operating a diaphragm compressor. Embodiments of the present disclosure comprise an oil piston being driven to pressurize work oil against the diaphragm of the compressor. In embodiments, an injection pump provides a supplemental flow of work oil in the region of pressurized fluid, and such pump may be part of an actively controlled system. In embodiments, a pressure relief valve vents an overpump flow of work oil, and such valve may be variable. Embodiments provide feedback and control mechanisms, including control of the injection pump and the relief valve.

24 Claims, 12 Drawing Sheets



(51) **Int. Cl.**

F04B 39/06	(2006.01)
F04B 39/16	(2006.01)
F04B 43/073	(2006.01)
F04B 45/04	(2006.01)
F04B 49/22	(2006.01)
F04B 53/06	(2006.01)
F04B 53/08	(2006.01)
F04B 53/14	(2006.01)

(52) **U.S. Cl.**

CPC ***F04B 43/073*** (2013.01); ***F04B 45/043*** (2013.01); ***F04B 45/0533*** (2013.01); ***F04B 45/0536*** (2013.01); ***F04B 49/22*** (2013.01); ***F04B 53/06*** (2013.01); ***F04B 53/14*** (2013.01); *F04B 53/08* (2013.01); *F04B 2201/0201* (2013.01); *F04B 2201/0202* (2013.01); *F04B 2205/05* (2013.01)

(58) **Field of Classification Search**

CPC F04B 45/043; F04B 45/0533; F04B 45/0536; F04B 49/03

USPC 417/199.1

See application file for complete search history.

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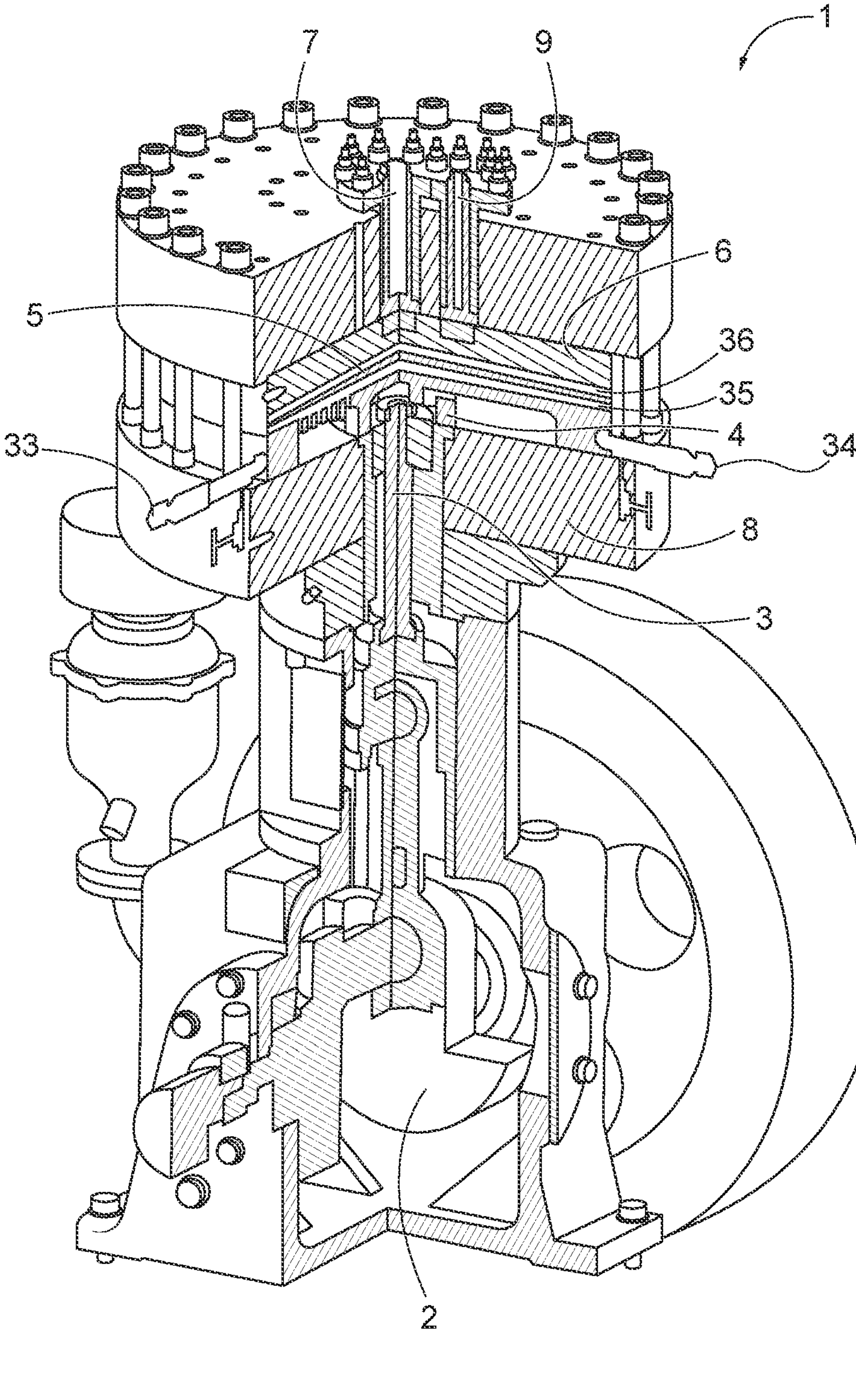


FIG. 1

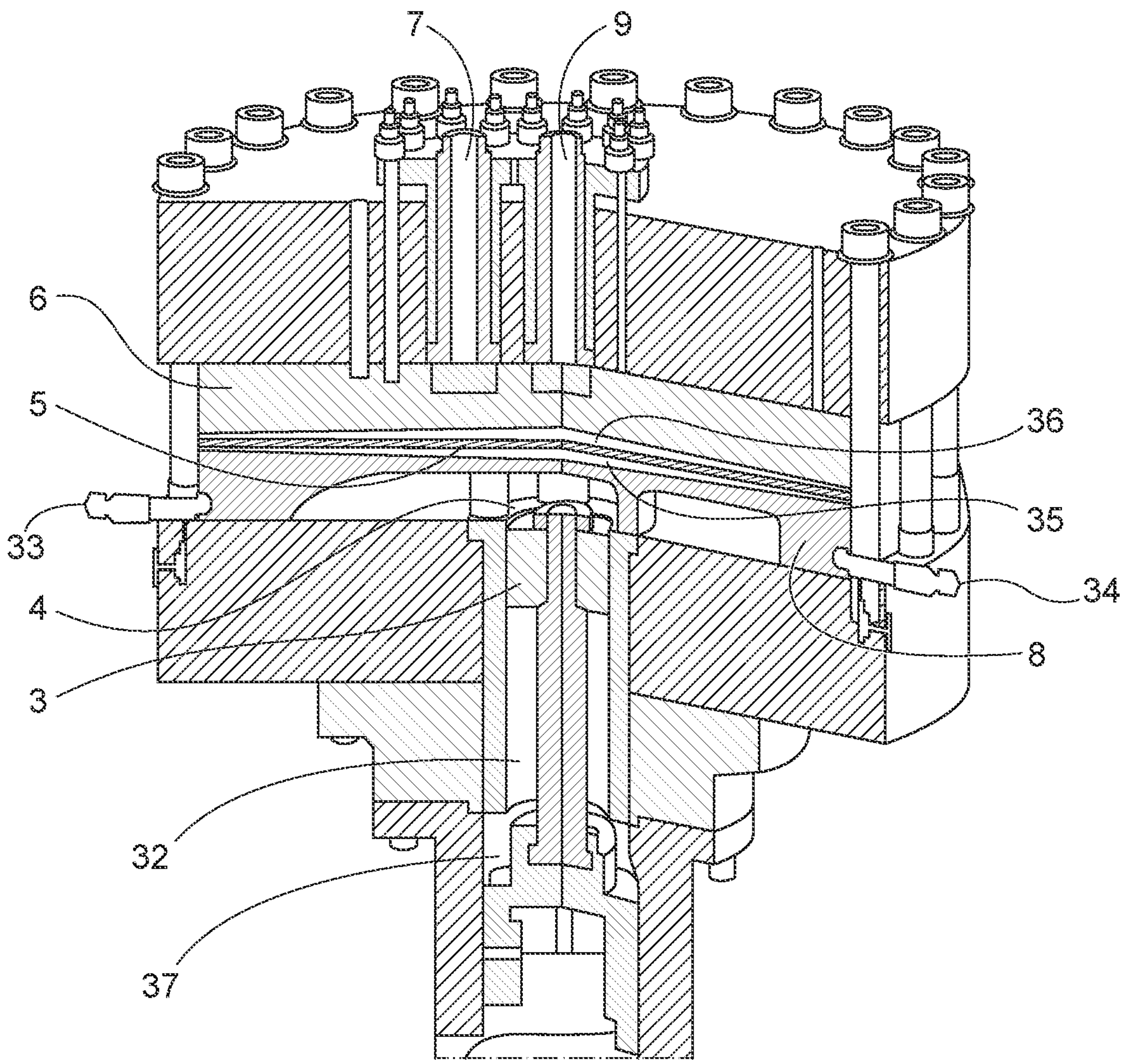


FIG. 2

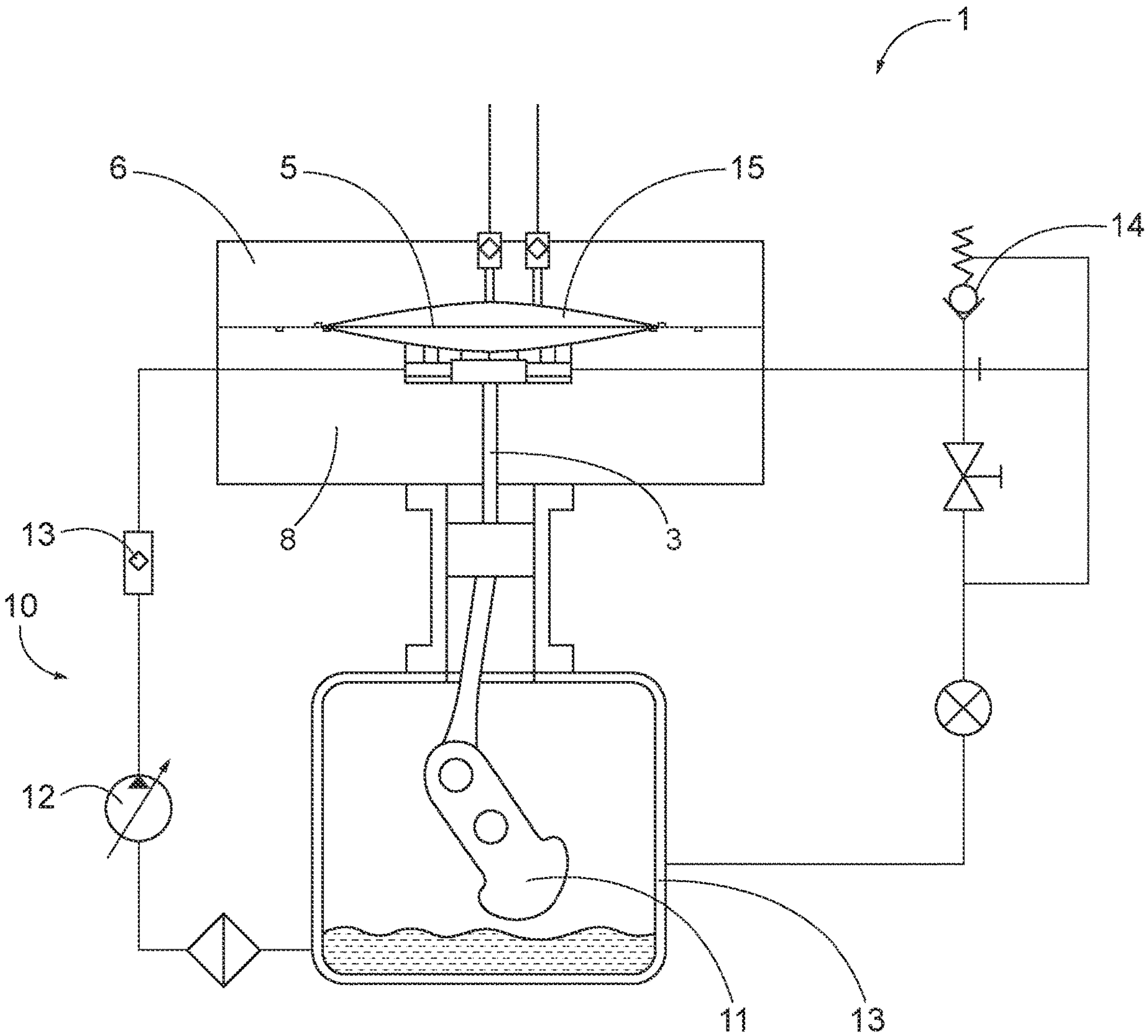
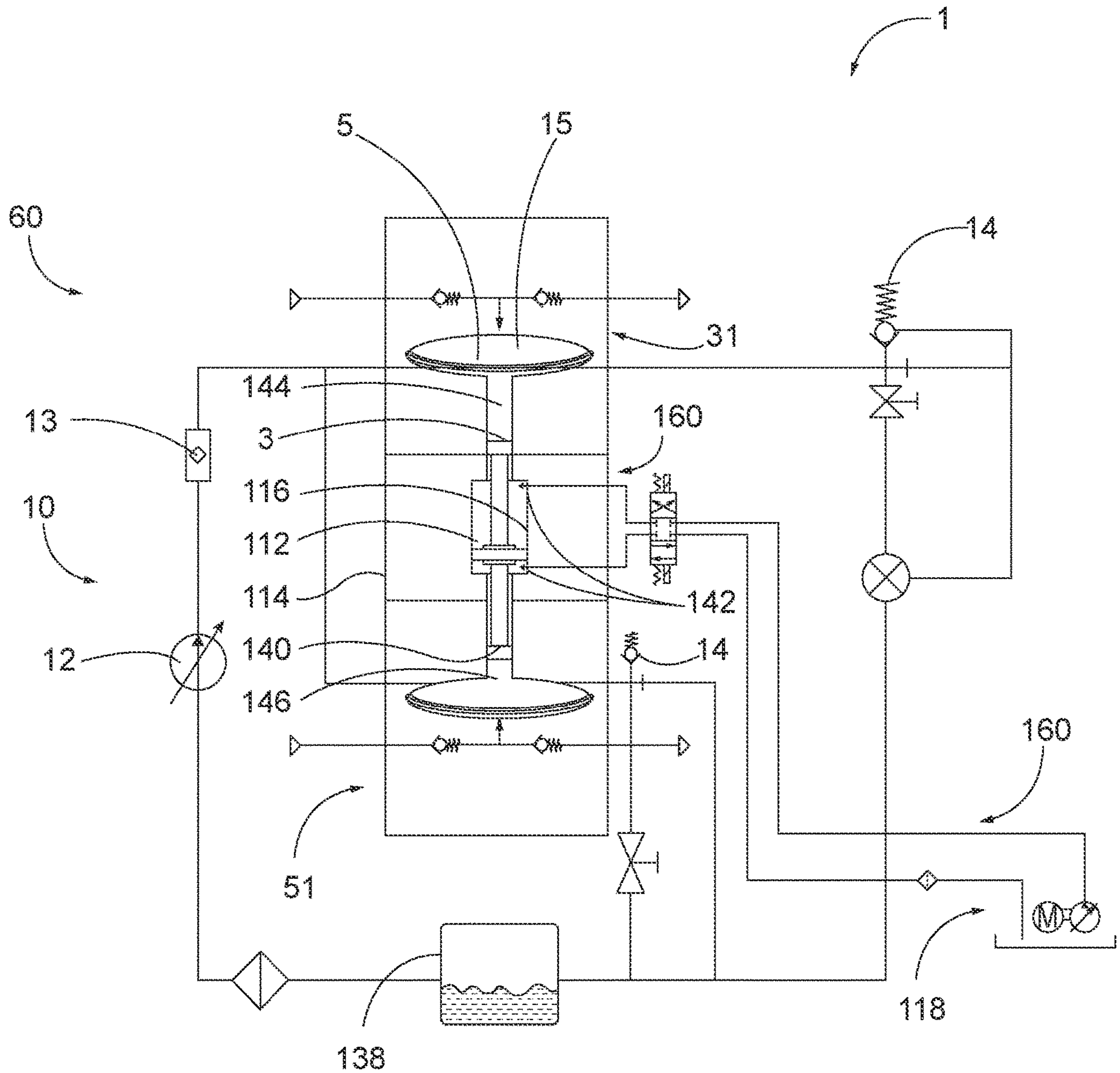


FIG. 3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5
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51
118
138

FIG. 4

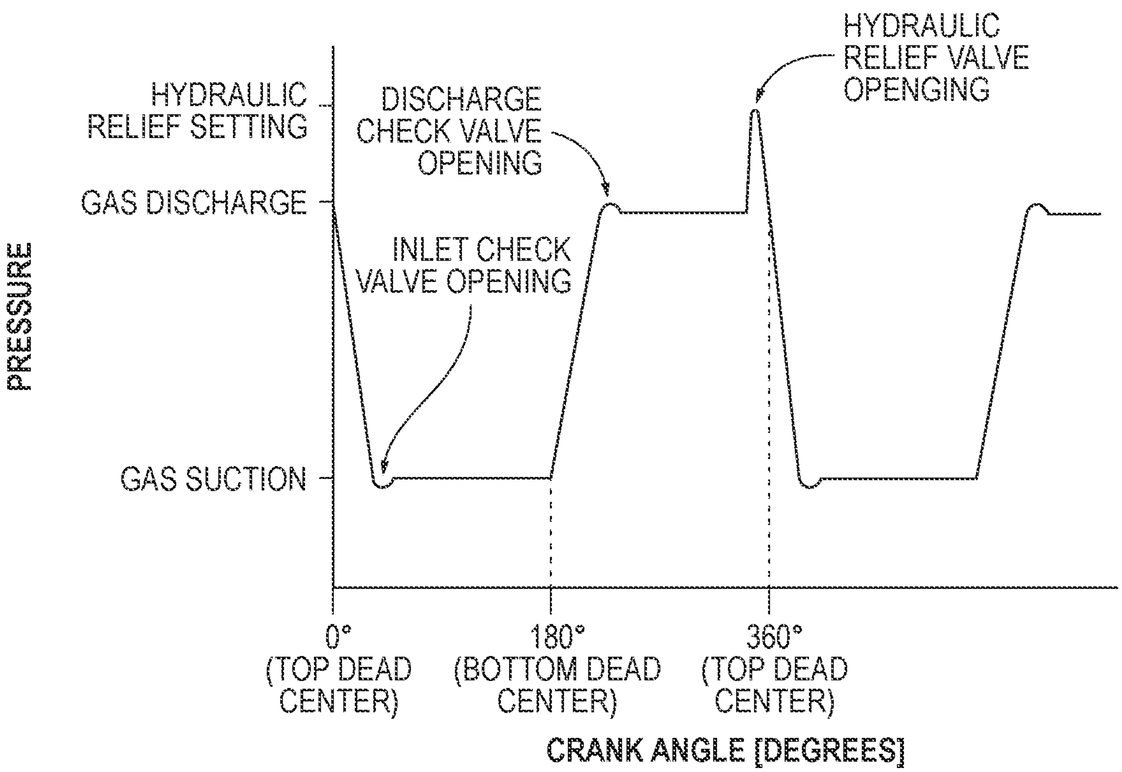
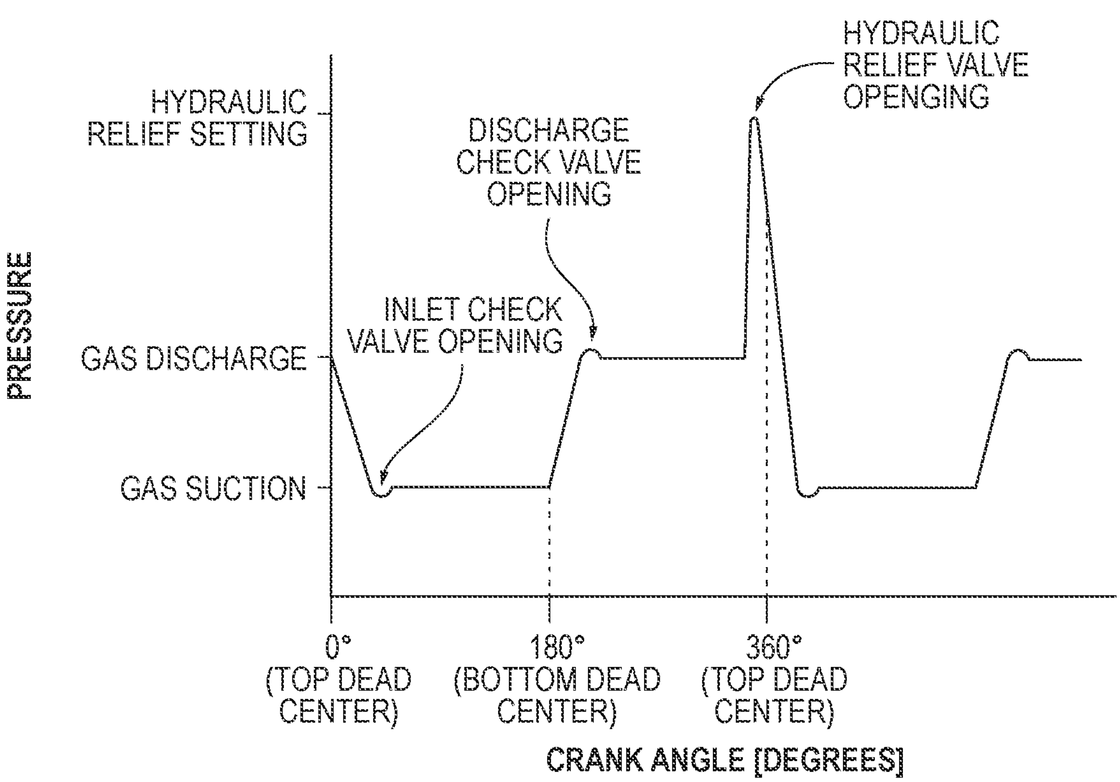

HYDRAULIC
RELIEF VALVE
OPENGING
HYDRAULIC
RELIEF SETTING
DISCHARGE
CHECK VALVE
OPENING
GAS DISCHARGE
INLET CHECK
VALVE OPENING
PRESSURE
GAS SUCTION
0°
(TOP DEAD
CENTER)
180°
(BOTTOM DEAD
CENTER)
360°
(TOP DEAD
CENTER)
CRANK ANGLE [DEGREES]

FIG. 5A


HYDRAULIC
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OPENGING
HYDRAULIC
RELIEF SETTING
DISCHARGE
CHECK VALVE
OPENING
PRESSURE
INLET CHECK
VALVE OPENING
GAS DISCHARGE
GAS SUCTION
0°
(TOP DEAD
CENTER)
180°
(BOTTOM DEAD
CENTER)
360°
(TOP DEAD
CENTER)
CRANK ANGLE [DEGREES]

FIG. 5B

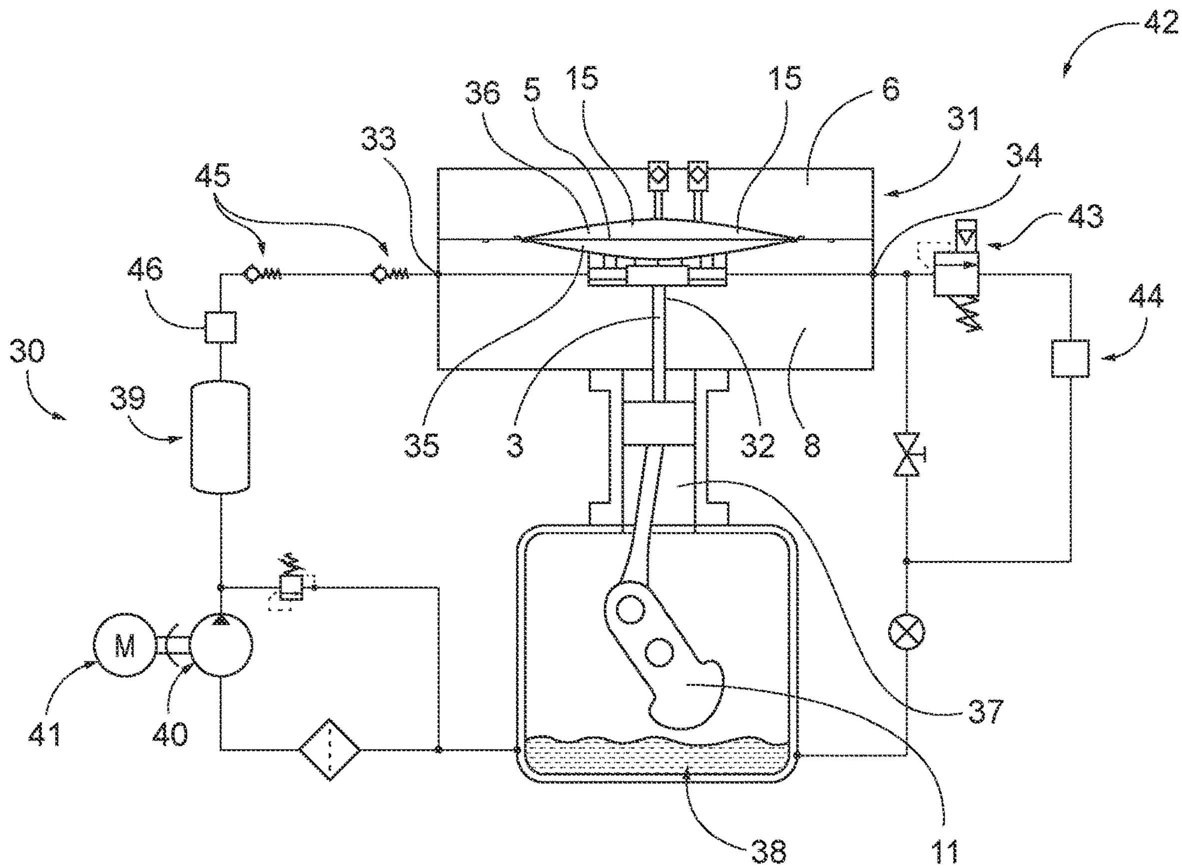


FIG. 6

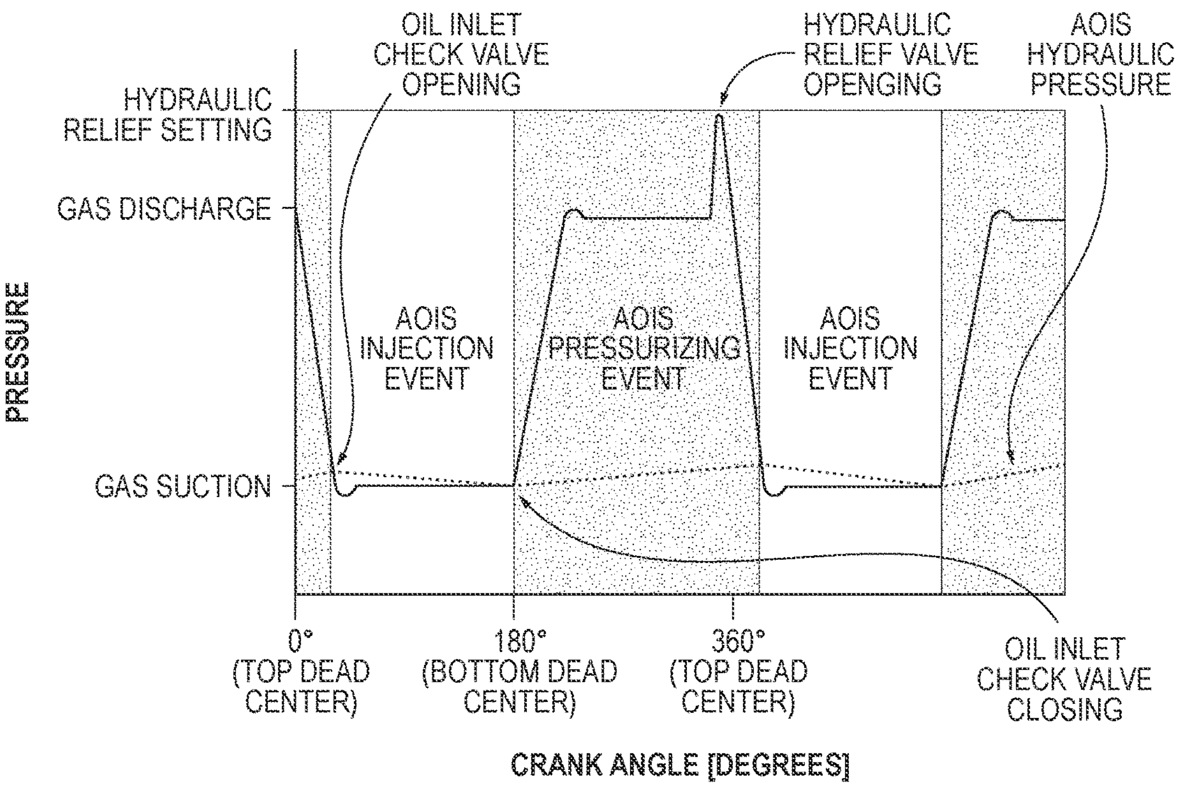

OIL INLET
CHECK VALVE
OPENING
HYDRAULIC
RELIEF VALVE
OPENGING
AOIS
HYDRAULIC
PRESSURE
HYDRAULIC
RELIEF SETTING
GAS DISCHARGE
PRESSURE
AOIS
INJECTION
EVENT
AOIS
PRESSURIZING
EVENT
AOIS
INJECTION
EVENT
GAS SUCTION
0°
(TOP DEAD
CENTER)
180°
(BOTTOM DEAD
CENTER)
360°
(TOP DEAD
CENTER)
OIL INLET
CHECK VALVE
CLOSING
CRANK ANGLE [DEGREES]

FIG. 7

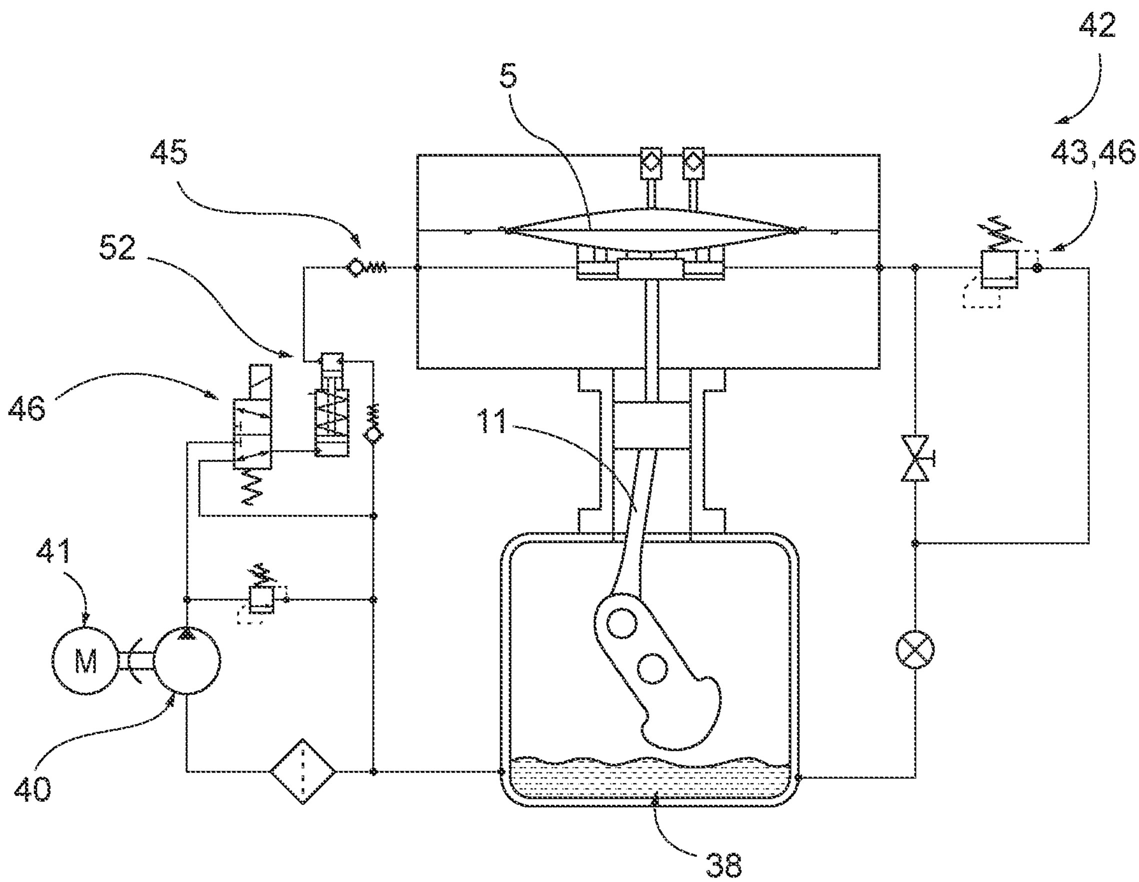


FIG. 8

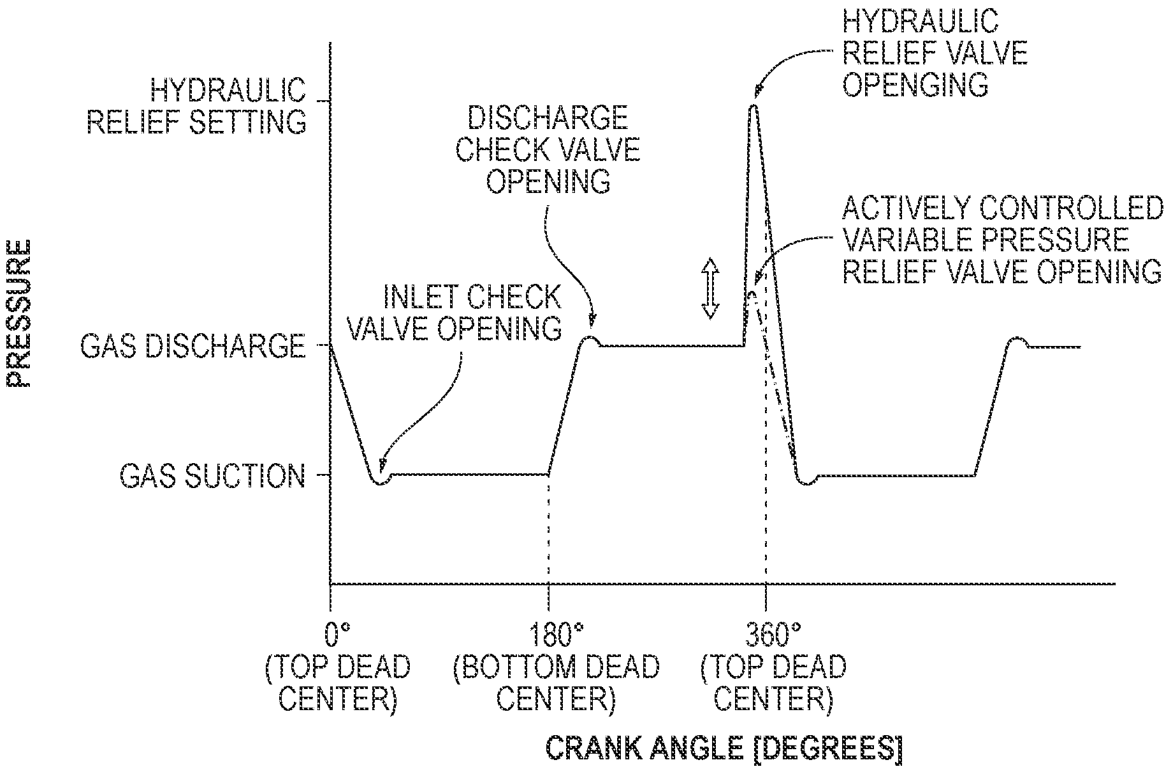

HYDRAULIC RELIEF SETTING
GAS DISCHARGE
GAS SUCTION
PRESSURE
DISCHARGE CHECK VALVE OPENING
INLET CHECK VALVE OPENING
HYDRAULIC RELIEF VALVE OPENGING
ACTIVELY CONTROLLED, VARIABLE PRESSURE RELIEF VALVE OPENING
0° (TOP DEAD CENTER)
180° (BOTTOM DEAD CENTER)
360° (TOP DEAD CENTER)
CRANK ANGLE [DEGREES]

FIG. 9

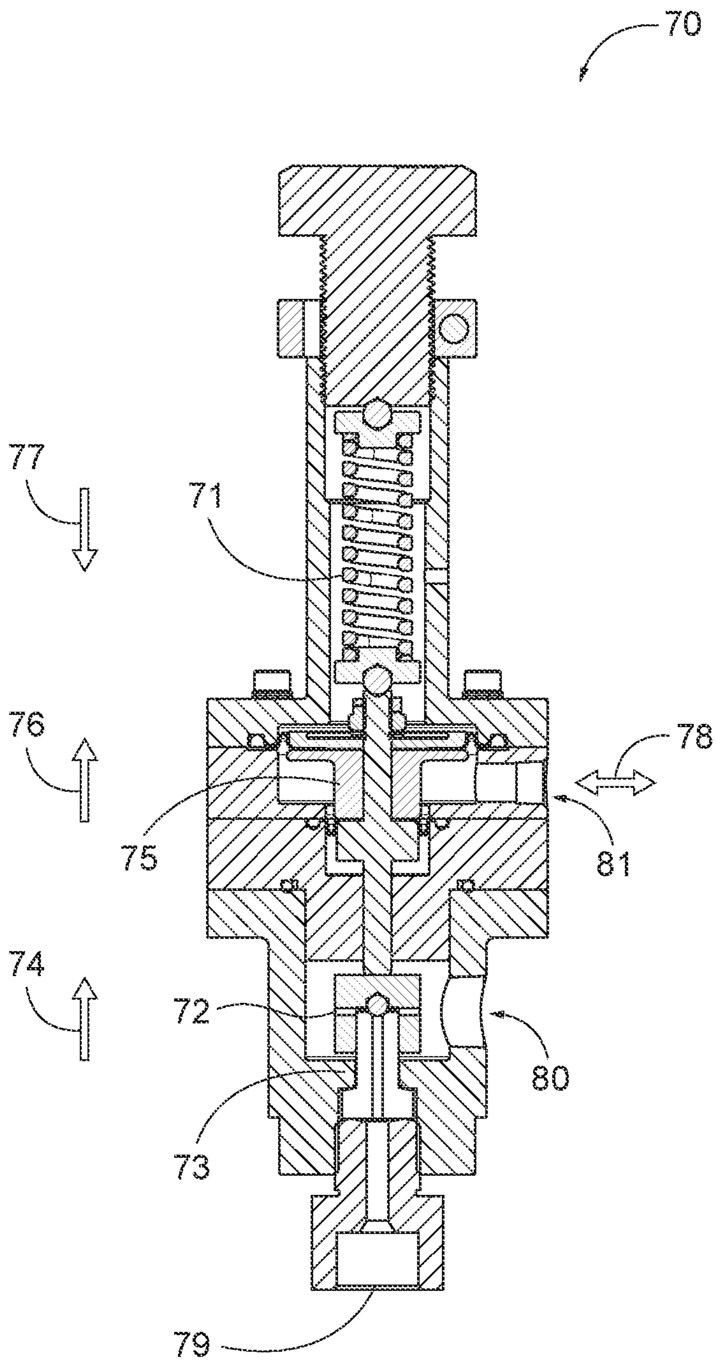
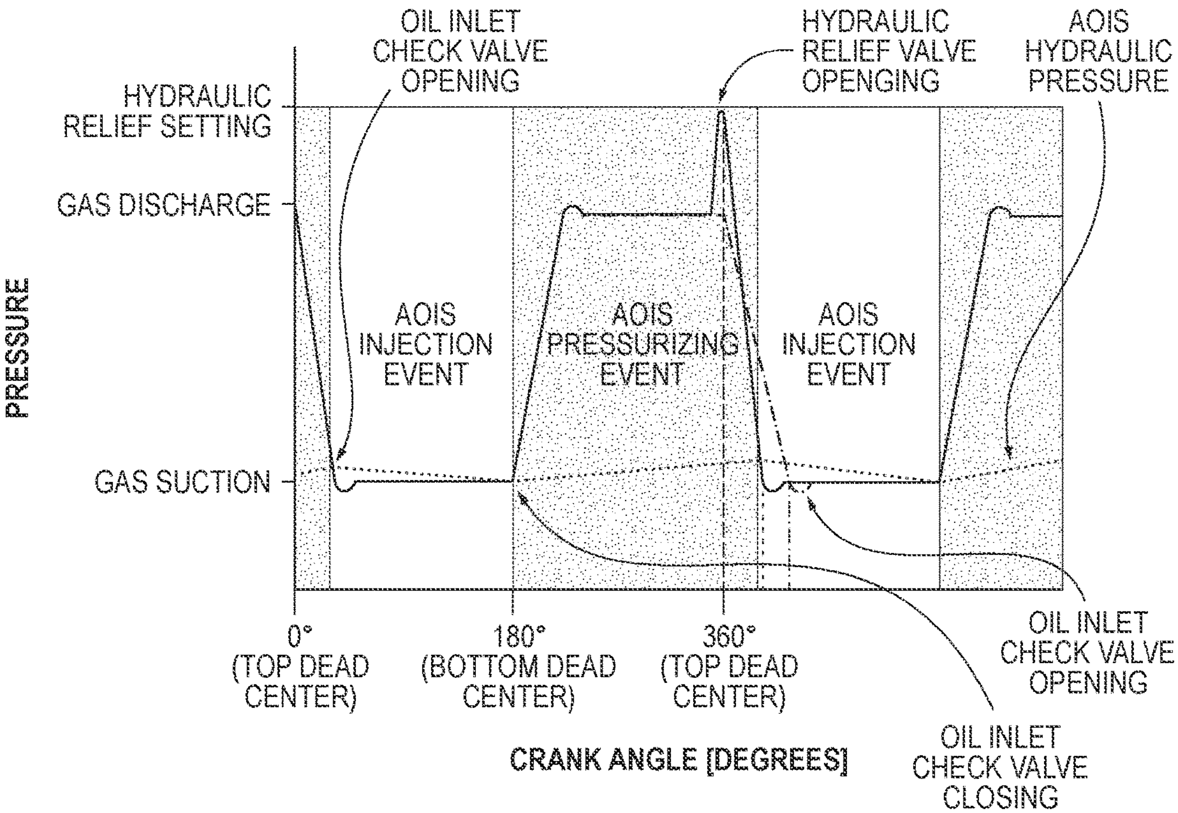


FIG. 10



OIL INLET CHECK VALVE OPENING
HYDRAULIC RELIEF VALVE OPENGING
AOIS HYDRAULIC PRESSURE
HYDRAULIC RELIEF SETTING
GAS DISCHARGE
PRESSURE
AOIS INJECTION EVENT
AOIS PRESSURIZING EVENT
AOIS INJECTION EVENT
GAS SUCTION
0° (TOP DEAD CENTER)
180° (BOTTOM DEAD CENTER)
360° (TOP DEAD CENTER)
OIL INLET CHECK VALVE OPENING
CRANK ANGLE [DEGREES]
OIL INLET CHECK VALVE CLOSING

FIG. 11

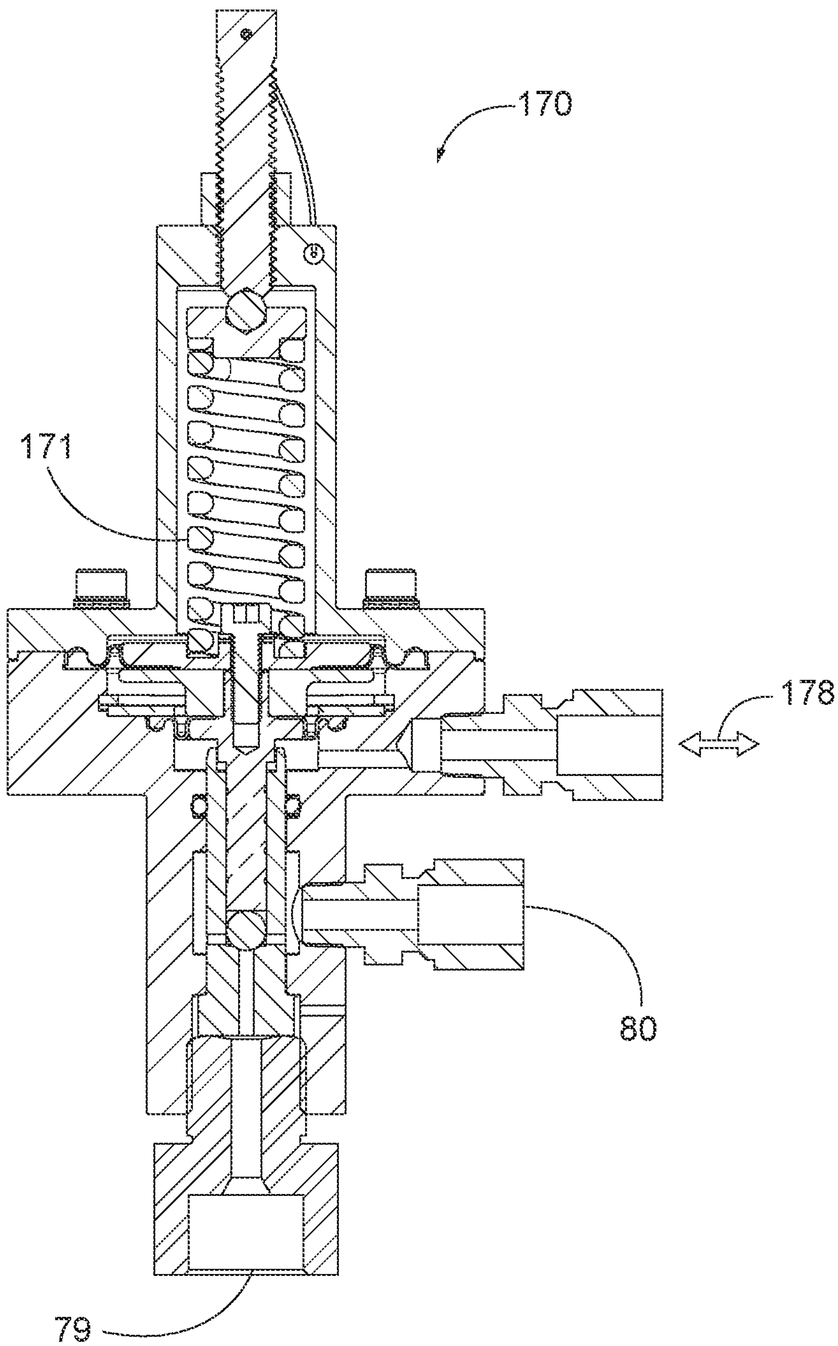


FIG. 12

ACTIVE OIL INJECTION SYSTEM FOR A DIAPHRAGM COMPRESSOR

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit under 35 U.S.C. § 119(e) of the earlier filing date of U.S. Provisional Patent Applications No. 63/111,356 filed on Nov. 9, 2020 and No. 63/277,125 filed on Nov. 8, 2021, the disclosures of which are incorporated herein by reference in their entirety.

This application is related to co-pending and co-owned U.S. patent application Ser. No. 17/522,896 entitled "Hydraulic drive for diaphragm compressor", filed on Nov. 9, 2021, which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

The present invention is directed to diaphragm compressors.

BACKGROUND OF THE INVENTION

A diaphragm compressor comprises a diaphragm that is actuated to pressurize a process gas for various purposes.

SUMMARY

A feature and benefit of embodiments is an active oil injection system in a diaphragm compressor comprising a diaphragm compressor, a hydraulic circuit, and a feedback mechanism. The diaphragm compressor comprises a compressor head. The compressor head comprises a work oil head support plate, a process gas head support plate, and a metallic diaphragm. The work oil head support plate and the process gas head support plate define a diaphragm cavity therebetween. The work oil head support plate comprises a piston cavity, an inlet, and an outlet. The diaphragm compressor further comprises a drive. The metallic diaphragm is mounted between the work oil head support plate and the process gas head support plate, dividing the diaphragm cavity into a work oil region and a process gas region. The work oil region is in separate communication with each of the piston cavity, the inlet, and the outlet. The metallic diaphragm is configured to actuate from a first position proximate the work oil head support plate to a second position proximate the process gas head support plate to pressurize process gas in the process gas region to a process gas discharge pressure. The drive is configured to intensify and supply primary work oil to the compressor head. The drive comprises a drive cavity, a piston, and an actuator. The drive cavity extends from the compressor head and is in communication with the work oil region via the piston cavity. The piston is mounted in the drive cavity and defines the volume of the work oil region. The actuator is configured to power the piston. During a discharge cycle, the drive is configured to power the piston to move toward the compressor head to intensify primary work oil in the work oil region from a first pressure to an intensified pressure and thereby actuate the diaphragm to the second position. The hydraulic circuit connects the outlet of the work oil head support plate to the inlet of the work oil head support plate. The hydraulic circuit comprises an oil reservoir, a hydraulic accumulator, and an injector pump. The oil reservoir is configured to collect overpumped work oil from the work oil region via the outlet of the work oil head support plate. The hydraulic accumulator is configured to provide a supply of supplemental work oil to the inlet of the work oil head support plate. The injector pump is in communication with the hydraulic accumulator and is configured to produce a variable volumetric displacement of the supplemental work oil from the oil reservoir to the hydraulic accumulator. The injector pump comprises a pump and a motor. The pump is operatively coupled to the hydraulic accumulator. The motor is configured to power the pump independently from the drive. The pressure relief mechanism is operatively coupled to the work oil region of the diaphragm cavity. The pressure relief mechanism comprises a pressure relief valve and a control valve. The pressure relief valve is in communication with the outlet of the work oil head support plate and configured to relieve the pressurized work oil from the work oil region. The pressure relief valve comprises a hydraulic relief setting corresponding to a target pressure condition of the pressurized work oil relative to the process gas discharge pressure. The control valve is configured to actively adjust the hydraulic relief setting of the pressure relief valve to correspond to a current condition of the process gas. The feedback mechanism is configured to control the injector pump. The feedback mechanism comprises a first measurement device. The first measurement device is operatively coupled to one or more of the outlet and the pressure relief valve. The measurement device is configured to detect a current condition of the pressurized work oil flowing through the pressure relief valve from the work oil region. The feedback mechanism is configured to adjust the volumetric displacement of the injector pump to the hydraulic accumulator in response to the detected current condition.

In certain embodiments, the hydraulic relief setting is a pressure of at least 1-20% above a measured process gas discharge pressure.

In certain embodiments, the oil reservoir is in fluid communication with the drive of the diaphragm compressor.

In certain embodiments, the actuator of the diaphragm compressor comprises a crank-slider mechanism. The oil reservoir comprises a crankcase of the crank-slider mechanism.

In certain embodiments, the hydraulic circuit further comprises an inlet check valve and an outlet check valve. The inlet check valve is operatively coupled to the inlet of the work oil head support plate. The inlet check valve is configured to prevent backflow from the work oil region to the hydraulic accumulator. The outlet check valve is operatively coupled to the outlet of the work oil head support plate. The outlet check valve is configured to prevent backflow from the hydraulic circuit to the work oil region.

In certain embodiments, during a suction cycle of the diaphragm compressor at the compressor head, the drive of the diaphragm compressor is configured to move the piston away from the compressor head to depressurize the work oil region and thereby pull the diaphragm to the first position. During the suction cycle, the hydraulic accumulator is configured to supply an injection volume of the supplemental work oil to the inlet of the work oil head support plate.

In certain embodiments, the injection volume from the hydraulic accumulator corresponds to the volume of over-pump flow of pressurized work oil through the pressure relief valve.

In certain embodiments, during the discharge cycle of the diaphragm compressor, the injector pump is configured to charge the hydraulic accumulator.

In certain embodiments, the injector pump is configured to charge the hydraulic accumulator during both the discharge and suction cycles of the diaphragm compressor.

In certain embodiments, the pump and motor of the injector pump comprise a pump and motor selected from one of: of a variable speed motor with a fixed displacement hydraulic pump, a fixed speed motor with a variable displacement hydraulic pump, and a variable speed motor with a variable displacement hydraulic pump.

In certain embodiments, the hydraulic circuit further comprises a metering actuator operatively coupled to the inlet. The metering actuator is configured to inject the supplemental work oil selectively during each of a suction cycle and the discharge cycle of the diaphragm compressor.

In certain embodiments, the pressure relief valve comprises a valve spring and an adjustable pneumatic pressure bias, the control valve is configured to actively adjust the hydraulic relief setting by adjusting the pneumatic pressure bias.

In certain embodiments, the first measurement device of the feedback mechanism comprises one or more of: a flow meter downstream of the outlet, a position sensor in the pressure relief valve, and a pressure transducer with a temperature transducer each located downstream of the pressure relief valve.

In certain embodiments, the active oil injection system further comprises a hydraulic power unit driving the actuator of the diaphragm compressor.

In certain embodiments, the hydraulic power unit comprises a second hydraulic circuit of oil that is separate from the work oil of the hydraulic circuit of the active oil injection system.

In certain embodiments, the oil reservoir is a hydraulic tank operatively coupled with the hydraulic power unit. The injector pump comprises an active control valve configured to selectively isolate the injector pump from the hydraulic power unit of the diaphragm compressor.

In certain embodiments, the drive of the diaphragm compressor comprises a hydraulic drive supplied by a plurality of pressure rails configured to supply work oil to power the piston. The plurality of pressure rails comprises a low-pressure rail, a medium-pressure rail, and a high pressure-rail. The low-pressure rail supplies low-pressure work oil via a passive first valve. The medium-pressure rail supplies medium-pressure work oil via an active three-stage second valve. The high-pressure rail supplies high-pressure work oil via an active three-stage third valve.

In certain embodiments, the drive of the diaphragm compressor further comprises a hydraulic power unit providing the supply of work oil to the medium-pressure rail and the high-pressure rail. The hydraulic power unit comprising a hydraulic pump and motor.

A feature and benefit of embodiments is an active oil injection system in a diaphragm compressor comprising a diaphragm compressor, a hydraulic circuit, and a feedback mechanism. The diaphragm compressor comprises a first compressor head, a second compressor head, and a drive. The first compressor head comprises an inlet, an outlet, a first head cavity, and a first diaphragm. The first diaphragm divides the first head cavity into a first work oil region and a process gas region. The first diaphragm is configured to actuate to pressurize process gas in the process gas region. The second compressor head comprises an inlet, an outlet, a second cavity, and a second diaphragm. The second diaphragm divides the second head cavity into a second work oil region and a process gas region. The second diaphragm is configured to actuate to pressurize process gas in the process gas region. The drive is configured to intensify work oil and alternatingly provide intensified work oil to the first and second compressor heads. The hydraulic drive comprises a first diaphragm piston, a second diaphragm piston, and an actuator. The first diaphragm piston is configured to intensify work oil against the first diaphragm. The second diaphragm piston is configured to intensify work oil against the second diaphragm. The actuator is configured to power the first and second diaphragm pistons. The first diaphragm piston and the second diaphragm piston are configured to alternatingly intensify the work oil in the respective first or second diaphragm. The hydraulic circuit connects the outlet of the first compressor head to the inlet of the first compressor head and connects the outlet of the second compressor head to the inlet of the second compressor head. The hydraulic circuit comprises an oil reservoir, a hydraulic accumulator, and an injector pump. The oil reservoir is configured to collect overpumped work oil via the outlets of the first and second compressor heads. The hydraulic accumulator is configured to provide a supplemental supply of work oil to the inlets of the first and second compressor heads. The injector pump is in communication with the hydraulic accumulator. The injector pump is configured to produce a variable volumetric displacement of supplemental work oil from the oil reservoir to the hydraulic accumulator. The injector pump comprises a pump and a motor. The pump is operatively coupled to the hydraulic accumulator. The motor is configured to power the pump independently from the drive. The pressure relief mechanism comprises a first pressure relief valve, a first control valve, a second pressure relief valve, and a second control valve. The first pressure relief valve is in communication with the outlet of the first compressor head and is configured to relief an overpump of the pressurized work oil from the work oil region. The first pressure relief valve comprises a hydraulic relief setting corresponding to a first target pressure condition of the pressurized work oil relative to the process gas discharge pressure. The first control valve is configured to actively adjust the hydraulic relief setting of the first pressure relief valve to correspond to a current condition of the discharged process gas. The second pressure relief valve is in communication with the outlet of the second compressor head and is configured to relieve the pressurized work oil from the work oil region. The pressure relief valve comprises a hydraulic relief setting corresponding to a second target pressure condition of the pressurized work oil relative to the process gas discharge pressure. The second control valve is configured to actively adjust the hydraulic relief setting of the second pressure relief valve to correspond to the current condition. The feedback mechanism is configured to control the injector pump to maintain the first and second overpump target conditions. The feedback mechanism comprises one or more measurement devices configured to sense or measure the current condition. The feedback mechanism is configured to adjust the volumetric displacement of the injector pump in response to the current condition.

In certain embodiments, the hydraulic relief setting of the pressure relief valve is a fixed value corresponding to about 10-20% above a predetermined process gas discharge pressure.

In certain embodiments, the pressure relief valve is variable, the pressure relief mechanism further comprising a control valve configured to actively adjust the hydraulic relief setting of the pressure relief valve to correspond to the current condition. The hydraulic relief setting is a pressure of 10-20% above a process gas discharge pressure.

In certain embodiments, the drive is a hydraulic drive comprising a hydraulic actuator. The hydraulic drive comprises an actuator housing. The actuator housing comprising a drive cavity extending between the first and second compressor heads. The drive cavity comprises one or more inlets for work oil at one or more drive pressures. The first diaphragm piston defines a first variable volume region between the first diaphragm piston and the diaphragm of the first compressor head. The second diaphragm piston defines a second variable volume region between the second diaphragm piston and the diaphragm of the second compressor head.

A feature and benefit of embodiments is an active oil injection system in a hydraulically powered diaphragm compressor comprising a hydraulically powered diaphragm compressor, a hydraulic circuit, and a feedback mechanism. The hydraulically powered diaphragm compressor comprises a first compressor head, a second compressor head, and a hydraulic drive. The first compressor head comprises an inlet, an outlet, a first head cavity, and a first diaphragm. The first diaphragm divides the first head cavity into a first work oil region and a process gas region. The first diaphragm is configured to actuate to pressurize process gas in the process gas region. The second compressor head comprises an inlet, an outlet, a second head cavity, and a second diaphragm. The second diaphragm divides the second head cavity into a second work oil region and a process gas region. The second diaphragm is configured to actuate to pressurize process gas in the process gas region. The hydraulic drive is configured to intensify work oil and alternatingly provide intensified work oil to the first and second compressor heads. The hydraulic drive comprises a first diaphragm piston, a second diaphragm piston, and a hydraulic actuator. The first diaphragm piston configured to intensify work oil against the first diaphragm. The second diaphragm piston is configured to intensify work oil against the second diaphragm. The hydraulic actuator is configured to power the first and second diaphragm pistons. The first diaphragm piston and the second diaphragm piston are configured to alternatingly intensify the work oil in the respective first or second work oil region to an intensified pressure and thereby actuate the respective first or second diaphragm. The hydraulic circuit connects the outlet of the first compressor head and connects the outlet of the second compressor head to the inlet of the second compressor head. The hydraulic circuit comprises an oil reservoir, a hydraulic accumulator, and an injector pump. The oil reservoir is configured to collect overpumped work oil via the outlets of the first and second compressor heads. The hydraulic accumulator is configured to provide a supplemental supply of work oil to the inlets of the first and second compressor heads. The injector pump is in communication with the hydraulic accumulator. The injector pump is configured to produce a variable volumetric displacement of supplemental work oil from the oil reservoir to the hydraulic accumulator. The injector pump comprises a pump and a motor. The pump is operatively coupled to the hydraulic accumulator. The motor is configured to power the pump independently from the drive. The pressure relief mechanism comprises a first pressure relief valve and a second pressure relief valve. The first pressure relief valve is in communication with the outlet of the first compressor head and is configured to relief the pressurized work oil from the work oil region. The first pressure relief valve comprises a hydraulic relief setting corresponding to a first target pressure condition of the pressurized work oil relative to the process gas discharge pressure. The second pressure relief valve is in communication with the outlet of the second compressor head and is configured to relieve the pressurized work oil from the work oil region, the pressure relief valve comprises a hydraulic relief setting corresponding to a second target pressure condition of the pressurized work oil relative to the process gas discharge pressure. The feedback mechanism is configured to control the injector pump. The feedback mechanism comprises one or more measurement devices configured to sense or measure a current condition of the intensified work oil flowing out one or more of the first compressor head and the second compressor head. The feedback mechanism is configured to adjust the volumetric displacement of the injector pump in response to the current condition. The above summary of the various representative embodiments of the invention is not intended to describe each illustrated embodiment or every implementation of the invention. Rather, the embodiments are chosen and described so that others skilled in the art can appreciate and understand the principles and practices of the invention. The Figures in the detailed description that follow more particularly exemplify these embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention can be completely understood in consideration of the following detailed description of various embodiments of the invention in connection with the accompanying drawings, in which:

FIG. **1** is front perspective and sectional view of a crank-driven diaphragm compressor in accord with embodiments of the present disclosure.

FIG. **2** is a side cross-sectional view of a compressor head of the compressor of FIG. **1**.

FIG. **3** is a schematic view of the compressor of FIG. **1** with an injection pump system in accord with embodiments of the present disclosure.

FIG. **4** is a schematic view of a hydraulically-driven diaphragm compressor with an injection pump system in accord with embodiments of the present disclosure.

FIG. **5**A is a pressure graph for a crank-driven diaphragm compressor.

FIG. **5**B is a pressure graph for a crank-driven diaphragm compressor.

FIG. **6** is a schematic view of a crank-driven compressor with an embodiment of an active oil injection system (AOIS) in accord with embodiments of the present disclosure.

FIG. **7** is a pressure graph for the compressor of FIG. **6**.

FIG. **8** is a schematic view of a crank-driven compressor with an embodiment of an active oil injection system (AOIS) in accord with embodiments of the present disclosure.

FIG. **9** is a pressure graph for the compressor of FIG. **8**.

FIG. **10** is a side cross-sectional view of a valve according to embodiments of the present disclosure.

FIG. **11** is a pressure graph.

FIG. **12** is a side cross-sectional view of a valve according to embodiments of the present disclosure.

While the invention is amenable to various modifications and alternative forms, specifics thereof have been depicted by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the invention to the particular embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION

In some embodiments such as the one shown in FIG. **1**, a diaphragm compressor **1** employs a crank **2** to drive a high pressure oil piston **3** that moves a column of hydraulic fluid **4** through the compressor **1** suction and discharge cycles. Process gas compression occurs as the volume of hydraulic fluid **4** is pushed upward to fill the lower plate **8** cavity, exerting a uniform force against the bottom of the diaphragm **5**. This deflects the diaphragm **5** into the upper cavity in the gas plate **6** that is filled with the process gas. The deflection of the diaphragm **5** against the upper gas plate **6** cavity first compresses the gas and then expels it through the discharge check valve **7**. As the oil piston **3** reverses to begin the suction cycle, the diaphragm **5** is drawn downward to hug the lower cavity of the oil plate **8** while the inlet check valve **9** opens and fills the upper cavity with a fresh charge of gas. The oil piston **3** passes through bottom dead center and begins its upward stroke, and the compression cycle is repeated.

In certain embodiments, the diaphragm **5** may be metallic, a composite material, or may be formed of any material with suitable flexibility and strength to meet compressor demands. In embodiments, the diaphragm **5** is a diaphragm set comprises a plurality of diaphragm plates sandwiched together and acting in unison, for example two, three, four, or more diaphragm plates may comprise a diaphragm set. The diaphragm plates of such a set may be formed from the same or different materials.

In some embodiments, the diaphragm compressor **1** employs a cam driven hydraulic injection pump system **10** that is driven off the primary crankshaft **11** of the compressor **1**. The hydraulic injection pump system **10** consists of a crank driven radial piston pump **12**, at least one oil check valves **13** and a fixed setting oil relief valve **14** as illustrated in FIG. **3**. The injection pump system's **10** primary function is to maintain the required oil volume between the high-pressure oil piston **3** and diaphragm **5**. During the compressor's **1** suction stroke, a fixed volume of hydraulic fluid is injected into the compressor **1** by the radial piston pump's **12** plunger driven by a cam connected to the compressor's **1** crankshaft **11**. This mechanical linkage ensures a fixed volume of oil is injected during each suction stroke to ensure the oil volume is maintained for proper compressor **1** performance.

In certain embodiments the oil volume between the high-pressure oil piston **3** and diaphragm **5** is impacted by two modes of oil loss. The first mode of oil loss is annular leakage past the high-pressure oil piston **3** back to the ambient pressure crankcase **13**. This annular leakage is most significant on high pressure compressors **1** operating above 5,000 psi due to the use of match fit high pressure oil pistons **3** and bores. At pressures above 5,000 psi, dynamic sealing technologies with the required life expectancy are limited, so the use of a match fit piston and bore provides a robust solution without seals. However, this architecture is prone to more significant annular leakage during compressor **1** operation due to the small clearances between the piston and the bore. Leakage past the high-pressure oil piston **3** is a function of oil temperature, oil pressure, fluid viscosity and manufacturing tolerances, among other factors. During the compressor's **1** operation, parameters such as hydraulic oil temperature and pressure vary significantly so the actual annular leakage past the high-pressure oil piston **3** varies significantly during operation.

The second mode of oil loss is defined as "overpump," which is hydraulic flow over the oil relief valve **14** back to the crankcase **13** which occurs every cycle during normal compressor **1** operation. The injector pump system **10** is designed and operated to maintain an "overpump" condition of work oil flow through the oil relief valve **14** in each discharge cycle ensuring the diaphragms **5** are sweeping the entire compressor cavity **15** thereby maximizing volumetric efficiency of the compressor **1**.

Crank-based injection pump systems **10** are mechanically adjustable by a user to vary the radial piston pump's **12** volumetric flow rate into the compressor **1**. However, this requires manual observations and adjustment. An incorrect volumetric displacement setting of the radial piston pump **12** can lead to various machine failures and loss of process.

In certain embodiments, the oil relief valve **14** has a manually adjustable relief setting. The oil relief valve **14** is set to a fixed oil relief pressure setting that is at least 10-20% higher than the maximum process gas pressure. The maximum process gas pressure is the maximum expected pressure of the process gas for any particular use case. This elevated relief setting allows the diaphragm **5** to contact the top of the gas plate **6** cavity **15** firmly before any hydraulic fluid flows over the relief valve **14**, thus, assuring a complete sweep of the entire cavity **15** volume at the highest expected pressure of the process gas. When the diaphragm **5** contacts the top of the cavity **15**, the oil piston **3** still has a few degrees of crank **2** angle left before it reaches top dead center ("TDC"). During this period, the oil compresses further and the hydraulic pressure rises above the compressor **1** gas discharge pressure until it reaches the setting of the oil relief valve **14**. At this point, the oil relief valve **14** opens and oil, in the amount of the injection pump displacement per revolution less the annular leakage in the hydraulic injection pump system **10**, is displaced over the oil relief valve **14**. This oil flow out of the relief valve **14** is defined as overpump. FIG. **5**A illustrates a compression cycle for a diaphragm compressor **1** operating at maximum process gas pressure.

A manually adjustable oil relief valve **14** is typically set to a fixed hydraulic relief setting. This design assumes and requires that the hydraulic pressure within the cavity **15** reaches this relief set point each cycle during normal compressor operation. FIG. **5**B shows a compression cycle for a compressor **1** with an oil relief valve **14** set for maximum process gas pressure, but where the actual process gas pressure is much lower, for example, at the beginning of filling a large storage tank with process gas. This additional difference between process gas pressure and fixed hydraulic relief setting generates a large alternating stress within the compressor which can decrease fatigue resistance as a result of higher amplitude equivalent stresses experienced by the compressor each cycle.

Certain embodiments of the present invention include an active oil injection system **30** ("AOIS") in a diaphragm compressor **1**. In those embodiments, the diaphragm compressor **1** includes a compressor head **31** including a work oil head support plate **8** and a process gas head support plate **6** defining a diaphragm cavity **15** therebetween. In those embodiments, the work oil head support plate **8** comprises a piston bore **32**, which operates as a cylinder for the oil piston **3**. In certain embodiments, the work oil head support plate **8** also includes an inlet **33**, and an outlet **34**, which allow work oil to enter the work oil head support plate **8** through the inlet **33**, and exit through the outlet **34**. The compressor head **31** may also include a metallic diaphragm **5** mounted between the work oil head support plate **8** and the process gas plate **6**. In those embodiments, the diaphragm **5** divides the diaphragm cavity **15** into a work oil region **35** and a process gas region **36**. In some embodiments, the work oil region **35** is in separate communication with each of the piston bore **32**, the inlet **33**, and the outlet **34**. In other words, the work oil region **35** is in fluid communication with each of the piston bore **32**, where work oil can enter and leave the work oil region **35**, the inlet **33**, where work oil can enter the work oil region **35**, and the outlet **34**, where work oil can exit work oil region **35**.

In some embodiments, the diaphragm **5** is configured to actuate from a first position proximate the work oil head support plate **8** to a second position proximate the process gas plate **6** to pressurize process gas in the process gas region **36** to a process gas discharge pressure.

Certain embodiments include an actuator configured to power the oil piston **3**, wherein, during a discharge cycle, the drive is configured to power the oil piston **3** to move toward the compressor head **31** to intensify primary work oil in the work oil region **35** from a first pressure to an intensified pressure and thereby actuate the diaphragm **5** to the second position.

In certain embodiments, the intensified pressure is at least 5,000 psi. In other embodiments, the intensified pressure is at least 7,500 psi, at least 10,000 psi, or at least 15,000 psi. In still other embodiments, the intensified pressure is from about 5,000 psi to about 15,000 psi.

In certain embodiments, a drive is a mechanical drive such as a crank-slider system comprising the crankshaft **11** and is configured to intensify and supply primary work oil to the compressor head **31**, the drive including a drive cavity **37** extending from the compressor head **31** and in communication with the work oil region **35** via the piston bore **32**, and an oil piston **3** mounted in the drive cavity **37**. The oil piston **3** defines the volume of the work oil region **35** between a top face of the oil piston **3**, and a bottom face of the diaphragm **5**, and because the oil piston **3** and diaphragm **5** are dynamic, the volume of the work oil region **35** is variable. In certain embodiments, the drive can be a mechanical drive such as a crankshaft **11**, and in other embodiments, the drive can be a hydraulic actuator **110**. In some embodiments, the drive of the diaphragm compressor **1** is a crank-slider mechanism such as the crank drive **2** described above, and the oil reservoir **38** is a crankcase of the crank-slider mechanism. In other embodiments, the drive includes a hydraulic power unit **118** driving the actuator of the diaphragm compressor **1**. In some embodiments, the hydraulic power unit **118** includes a second hydraulic circuit **160** of oil that is separate from the work oil of the hydraulic circuit of the AOIS system **30**. In further embodiments, the oil reservoir **38** includes a hydraulic tank operatively coupled with the hydraulic power unit **118**, and the injector pump **40** includes a control valve **46**. In embodiments, the control valve **46** may be configured to selectively isolate the injector pump **40** from the hydraulic power unit **118** of the diaphragm compressor **1**. In other embodiments, the control valve **46** comprises one or more valves that can selectively connect the injector pump **40** to one or more compressor heads (e.g., first and second compressor heads **31**, **51**). In further embodiments, the control valve **46** comprises one or more valves configured to selectively connect the injector pump **40** to one or more compressors (e.g., compressor **1** and another diaphragm compressor not shown). In this manner, the AOIS system **30** and the hydraulic circuit **60** are configured to supply supplementary work oil to one or more compressors and/or supply supplementary work oil to one or more compressor heads.

In some embodiments, the drive of the diaphragm compressor **1** comprises a hydraulic drive **110** supplied by a plurality of pressure rails (not shown) configured to supply work oil to power the oil piston **3**. In some embodiments, the plurality of pressure rails includes a low-pressure rail supplying low-pressure work oil (e.g., work oil slightly above ambient pressure or at a pressure of about 500 psi, or less than 500 psi) via a passive first valve, a medium-pressure rail supplying medium-pressure work oil via an active second valve, and a high-pressure rail supplying high-pressure work oil via an active third valve. In some embodiments, the drive of the diaphragm compressor **1** further includes a hydraulic power unit **118** providing the supply of work oil to the medium-pressure rail and the high-pressure rail, the hydraulic power unit **118** comprises a hydraulic pump and motor dedicated to the hydraulic drive **110**.

In certain embodiments, the compressor **1** forms a hydraulic circuit **60** connecting the outlet **34** of the work oil head support plate **8** to the inlet **33** of the work oil head support plate **8**. In those embodiments, the hydraulic circuit may also include an oil reservoir **38** configured to collect overpumped work oil from the work oil region **35** via the outlet **34** of the work oil head support plate **8**. By forming a hydraulic circuit, oil is circulated from the oil reservoir **38**, through the inlet **33** and into the work oil region **35**, and then overpumped out the outlet **34** and back into the oil reservoir **38**. In other embodiments, the oil reservoir **38** is in fluid communication with the drive of the diaphragm compressor **1**.

In other embodiments shown in FIG. **6**, the hydraulic circuit **60** also comprises the AOIS **30** including a hydraulic accumulator **39** configured to provide a supply of supplemental work oil to the inlet **33** of the work oil head support plate **8**. In certain embodiments, the hydraulic accumulator **39** may be a hydraulic volume or any style of hydraulic accumulator **39** such as a bladder, piston, or diaphragm gas over fluid style hydraulic accumulator. In still further embodiments, the AOIS includes an injector pump **40**, the injector pump **40** configured to produce a variable volumetric displacement of the supplemental work oil from the oil reservoir **38** or **138** to the hydraulic accumulator **39** or directly to the inlet **33** without an accumulator. As used herein, variable volumetric displacement means that the AOIS system **30** can provide a variable volumetric flow, i.e. variable injection quantities of work oil, to the work oil region **35** depending on the particular process conditions of the compressor head **31**. This allows for variable injection quantities during the compressor's **1** operation to maintain the compressor's **1** oil volume most efficiently within the compressor **1**, and particularly the work oil region **35**. In certain embodiments, this allows the AOIS system to actively adjust the amount of supplemental work oil being supplied to the hydraulic accumulator **39** or directly to the inlet **33** during operation of compressor head **31** in direct response to conditions work oil region **35**. In certain embodiments, the AOIS system **30** comprises an injector pump **40** operatively coupled to the hydraulic accumulator **39**, and a motor **41** configured to power the injector pump **40** independently from the drive. In other words, the speed and control of the motor **41** is completely independent from, and not mechanically linked to or dependent upon, the mechanical or hydraulic drive that powers the oil piston **3**.

In certain embodiments, the hydraulic circuit **60** further includes at least one inlet check valve **45** operatively coupled to the inlet **33** of the work oil head support plate **8**, the inlet check valve **45** configured to prevent backflow from the work oil region **35** to the hydraulic accumulator **39**. In further embodiments, the hydraulic circuit further includes an outlet check valve operatively coupled to the outlet **34** of the work oil head support plate **8**, the outlet check valve configured to prevent backflow from the hydraulic circuit to the work oil region **35**.

In some embodiments, the hydraulic circuit **60** further includes a metering actuator **52** (FIG. **8**) operatively coupled to the inlet **33**, the metering actuator configured to inject the supplemental work oil selectively during each of a suction cycle and the discharge cycle of the diaphragm compressor **1**.

In certain embodiments, during a suction cycle of the diaphragm compressor **1** at the compressor head **31**, the drive of the diaphragm compressor **1** is configured to move the oil piston **3** away from the compressor head **31** to depressurize the work oil region **35** and thereby pull the diaphragm **5** to the first position. In other embodiments, during the suction cycle, the hydraulic accumulator **39** is configured to supply an injection volume of the supplemental work oil to the work oil region **35** via the inlet **33** of the work oil head support plate **8**. In other embodiments, the injection volume from the hydraulic accumulator **39** corresponds to the outlet volume of pressurized work oil through the pressure relief valve **43**, and a volume of annular leakage. In further embodiments, during the discharge cycle of the diaphragm compressor **1**, the injector pump **40** is configured to charge the hydraulic accumulator **39**. In still further embodiments, the injector pump **40** is configured to charge the hydraulic accumulator **39** during both the discharge and suction cycles of the diaphragm compressor **1**.

In certain embodiments, the AOIS utilizes the existing pressure dynamics within the compressor **1** to satisfy the hydraulic flow requirements into the compressor **1**, and particularly into the work oil region **35**. As the compressor **1** transitions through its suction and discharge cycles, the AOIS pump **40** charges and discharges the hydraulic accumulator **39**. During the compressor's **1** suction stroke, this lower pressure condition within the compressor **1**, including the work oil region **35**, creates a positive pressure differential between the hydraulic accumulator **39** and the oil within the compressor head **31**, and particularly in the work oil region **35**. During this suction condition, hydraulic flow goes through the oil inlet check valves **45** and through inlet **33** into the work oil region **35** satisfying the injection event. During this time, the injector pump **40** may be continuously pumping into the hydraulic accumulator **39**. During this discharge stroke, the hydraulic pressure within work oil region **35** is greater than the pressure in the hydraulic accumulator **39** therefore there is no flow from the hydraulic accumulator **39** into the compressor **1**. At least one inlet check valve **45**, and in some embodiments at least two inlet check valves **45**, prevent backflow from the work oil region **35** into the hydraulic accumulator **39** and beyond. During this this condition, the hydraulic flow from the AOIS pump **40** pressurizes the hydraulic accumulator **39** in preparation for the next injection event. This series of injection and pressurizing events as they relate to the compressor's **1** suction and discharge cycles is illustrated in FIG. **7**.

In certain embodiments, the injector pump **40** is configured to produce a variable volumetric displacement of the supplemental work oil from the oil reservoir **38** to the hydraulic accumulator **39**. In some embodiments, the motor **41** includes a variable speed motor **41** and the injector pump **40** includes a fixed displacement hydraulic injector pump **40**. The motor **41** speed is actively controlled and adjusted to control volumetric displacement of the fixed displacement pump **40** into the hydraulic accumulator **39**. The active control of the volumetric displacement results in a certain change in pressure within the hydraulic accumulator **39** to satisfy the AOIS injection events. In certain embodiments, the variable speed motor **41** could be servo, AC induction, among others and driven by a common controller or variable frequency drive (VFD), among others.

In other embodiments, the motor **41** includes a fixed speed motor and the injector pump **40** includes a variable displacement hydraulic injector pump **40**. The motor **41** speed would remain constant during operation and the variable displacement pump **40** would be controlled to produce enough flow to attain the desired pressure in hydraulic accumulator **39** to satisfy the AOIS injection events.

In still further embodiments, the motor **41** includes a variable speed motor **41** and the injector pump **40** includes a variable displacement hydraulic injector pump **40**. The combination of variable speed motor **41** and variable speed injector pump **40** allows for variable hydraulic delivery and maintain maximum system efficiency as the variable displacement pump **40** can be operated in its maximum efficiency ranges. The active control of the volumetric displacement would result in a certain change in pressure within the hydraulic accumulator **39** to satisfy the AOIS injection events.

In other embodiments, the AOIS system **30** includes a control valve **46** added to any of the mentioned injector pump **40** embodiments. The addition of a control valve **46** allows the injector pump **40** to be isolated from the compressor **1** for failure mode prevention and independent cycle to cycle injection control, among others. In certain embodiments, the control valve **46** could be a solenoid valve or a proportional valve, among others.

In still other embodiments, the AOIS system **30** includes a metering actuator that can be actuated to displace a fixed or variable hydraulic volume into the compressor **1**, as shown in FIG. **8**. The independent control of the actuator allows for injection events to occur during the compressor's **1** suction and discharge cycles, if desired.

Further embodiments include a variable pressure relieve valve (VPRV), which includes a pressure relief mechanism **42** operatively coupled to the work oil region **35** of the diaphragm cavity **15**, the pressure relief mechanism **42** including a pressure relief valve **43** in communication with the outlet **34** of the work oil head support plate **8** and configured to relieve an outlet volume of the pressurized work oil from the work oil region **35**. In these embodiments, the pressure relief valve **43** includes a hydraulic relief setting corresponding to an target pressure condition of the pressurized work oil relative to the process gas discharge pressure. In some embodiments, the target pressure condition corresponds to a maximum process gas discharge pressure. In other words, the target pressure condition corresponds to a maximum process gas discharge pressure that the compressor head **31** is configured to operate at for a particular mode of operation, so that the process gas region **36** is configured to be completely evacuated by the diaphragm **5** at maximum gas discharge pressure.

In certain embodiments, during an oil relief event during the discharge cycle, the relief valve **43** opens and oil, in the amount of the injection volume per revolution less the annular leakage in the system, is displaced over the oil relief valve **434**, defined as overpump. During this time, the hydraulic flow from the injector pump **40** pressurizes the hydraulic accumulator **39** in preparation for the next injection event during the next suction cycle.

However, in certain embodiments, the pressure relief valve **43** is configured to actively adjust the hydraulic relief setting of the pressure relief valve **43** to correspond to a current condition of the process gas. In other words, the pressure relief valve **43** is configured to adjust the hydraulic relief setting up or down corresponding to a relative increase or decrease in process gas discharge pressure. The current condition corresponds to the measured process gas discharge pressure being experienced at the compressor head **31** in real time or as otherwise measured by the system. In certain embodiments, the hydraulic relief setting corresponds to pressure 10-20% above a measured process gas discharge pressure. In other embodiments, the hydraulic relief setting corresponds to pressure 1-10% above a measured process gas discharge pressure. In still further embodiments, the hydraulic relief setting corresponds to pressure one of 1-20%, and 1-5% above a measured process gas discharge pressure. The "current" and "real time" discussed throughout the present disclosure can include measurements that are recent or immediately preceding a given time, and moreover can include a calculation or estimation of the current condition based on related data or previous measurements.

The use of a fixed setting pressure relief valve **43** that corresponds to the maximum process gas discharge pressure leads to higher cyclic stresses within the compressor **1** than otherwise necessary, potentially reducing overall compressor life expectancy. The large alternating stress is driven by the gap between lower process gas discharge pressures (e.g., pressure of discharges that occur at the beginning of filling a tank) compared to the maximum process gas discharge pressure, while the fixed target pressure condition corresponds to the maximum process gas discharge pressure condition. This gap causes higher than necessary work oil pressures that force the diaphragm **5** against the upper gas head **6** with more force and/or for a longer duration than necessary. If work oil pressure is reduced to match the current gas discharge pressure more closely, the life expectancy and fatigue resistance of the compressor **1**, and particularly of diaphragm **5**, may be increased as a result of lower amplitude equivalent stresses during the compressor's **1** discharge and suction cycles, as is illustrated in FIG. **9**. For example, since the fixed relief valve **43** is fixed at a setting of 10-20% above the maximum process gas pressure regardless of the actual current process gas conditions, then the oil pressure within the compressor **1** reaches this maximum pressure condition each cycle to satisfy the overpump requirements during normal operation. In certain embodiments, when the relief setting is adjusted based on the current process gas conditions, the magnitude of the cyclic stress imparted on the compressors **1** may be reduced, and may extend machine life. Moreover, the compressor **1** will expend less energy pressurizing the work oil during current process gas conditions that are less than a target (maximum) process gas condition. Similarly, the compressor's **1** rod load is proportional to the work oil pressure set by the relief valve **43**. If the oil relief setting on the relief valve **43** is actively adjusted, the maximum rod load experienced by the compressor **1** would adjust proportionally to the current process gas conditions and may therefore improve energy efficiency of the compressor **1**. In certain embodiments, the process gas pressure conditions are measured via a pressure transducer. In these embodiments, the discharge gas pressure measurement may provide the feedback to control the relief valve's **43** pressure set point although other feedback methods may be used. In various embodiments, the relief setting is set to a pressure above the process gas condition by at least 1%, at least 2%, at least 5%, at least 10%, at least 25%, at least 50%, and at least 100%. In some embodiments, the relief setting is set to a pressure above the gas condition by about 1-5%, 1-10%, 1-20%, 5-10%, 5-20%, 5-30%, 5-50%, 10-20%, 10-30%, 10-50%. In other embodiments, the relief setting is set to a pressure above the process gas condition by at least 1 psi, at least 10 psi, about 1-10 psi, about 1-50 psi, about 1-100 psi, about 10-50 psi, about 10-100 psi, about 100-1,000 psi, about 1,000-1,500 psi, about 1,000-2,000 psi, and about 1,000-2,500 psi.

In certain embodiments, VPRV includes an actively controlled pneumatic pressure bias **78** to either aid or counteract an existing spring force **77** within the relief valve. FIG. **10** includes one embodiment of this force bias relief valve **70** that relieves high pressure work oil from valve inlet **79** to lower pressure storage, e.g. the crankcase of a crank-driven diaphragm compressor **1**, via the valve outlet **80**. During force bias relief valve **70** assembly, the force bias relief valve **70** spring **71** is compressed which forces the valve poppet **72** and valve seat **73** together resulting in a force balance within the force bias relief valve **70** between the spring force **77** and the seat force **74**. This seat force **74** in combination with the valve's **70** seat **73** area (effective area) sets the hydraulic relief pressure of the force bias relief valve **70**. The embodiment shown in FIG. **10** includes an internal piston **75** that allows for a bias force **76** to be applied within the force bias relief valve **70**. In certain embodiments, when either hydraulic or pneumatic bias pressure **78** is applied to the internal piston **75** via the bias pressure inlet **81**, the force from the internal piston **75** pushes against the spring force **77** which results in a lower seating force and thus a reduced pressure relief setting. In certain embodiments, by adjusting the bias force/pressure **76** within the force bias relief valve **70**, the seating force **74** can be actively controlled allowing for a controlled pressure relief setting. In certain embodiments, the pressure bias **78** may be applied by the use of an I/P (current to pressure) transducer, for example. In other embodiments, multiple bias combinations that can be achieved with a spring **71** and internal piston **75** combination. In certain embodiments, the internal piston **75** could be oriented to either increase or decrease the force bias relief valve's **70** seating force **74** thus either increasing or decreasing the pressure relief setting as a bias pressure/force **78** is applied within the force bias relief valve **70**.

In certain embodiments, the pressure relief valve **70** includes a valve spring **71** and an adjustable pneumatic pressure bias **78**, the control valve **46** configured to actively adjust the hydraulic relief setting by adjusting the pneumatic pressure bias **78**. One embodiment of the force bias relief valve **70** uses the process gas as an energy source for the bias force **76** via the bias pressure **78**. In certain embodiments, the process gas is plumbed to a port on the VPRV such as bias pressure inlet **81** such that this gas pressure acts on the internal piston **75** to adjust the pressure relief setting. In other embodiments, hydraulic pressure from a hydraulic pressure source may be used as an energy source for the bias force **76** via the bias pressure **78**. In still further embodiments, an electric actuator may be used as an energy source for the bias force **76** via the bias pressure **78**. The actuator could be moved to adjust the pre load on the relief valve's **70** spring **71** thus changing the seating force **74** and pressure relief setting.

FIG. **12** illustrates another embodiment of a pressure relief valve **170** that may function similarly to the pressure relief valve **170**. In certain embodiments, the pressure relief valve **170** includes a valve spring **171** and an adjustable pneumatic pressure bias **178**, and the control valve **46** is configured to actively adjust the hydraulic relief setting by adjusting the pneumatic pressure bias **178**.

Certain embodiments of the AOIS include an injector pump **40** and hydraulic accumulator **39** without a VPRV, while other embodiments include both systems.

In certain embodiments, during the compressor's **1** normal operation, a certain amount of overpump is required over the oil relief valve **14** to ensure the diaphragm **5** is making a complete sweep of the compressor volume **15** during each discharge cycle to maximize volumetric efficiency of the compressor **1**. Certain embodiments include a feedback mechanism for measuring or inferring the amount of overpump out of the relief valve **43** during compressor **1** operation in order to control the injector pump **40** and motor **41** to produce the correct amount of flow into the compressor **1**. In certain embodiments, the feedback mechanism includes primary feedback, i.e. a direct measurement of overpump. In other embodiments, primary feedback is enhanced by, or replaced with, indirect feedback, i.e. a measurement of some other parameter of the compressor **1** to indirectly infer a measurement of overpump.

As shown in FIG. **4**, certain embodiments of the diaphragm compressor **1** include a first compressor head **31** and second compressor head **51**, and a drive configured to intensify work oil and alternatingly provide intensified work oil to the first and second compressor heads **31**, **51**. In the embodiment of FIG. **4**, the drive is a hydraulic drive **110**. In some embodiments, the hydraulic drive **110** includes a first diaphragm oil piston **3** configured to intensify work oil against the first diaphragm **5**, a second diaphragm oil piston **140** configured to intensify work oil against the second diaphragm **5** of the second compressor head **51**, and an actuator **112** configured to power the first and second diaphragm oil pistons **3**, wherein the first diaphragm oil piston **3** and the second diaphragm oil piston **3** are configured to alternatingly intensify the work oil in the respective first or second work oil region to an intensified pressure and thereby actuate the respective first or second diaphragm **5**.

In certain embodiments, the compressor **1** also includes a hydraulic circuit **60** connecting the outlet **34** of the first compressor head **31** to the inlet **33** of the first compressor head **31** and connecting the outlet **34** of the second compressor head **51** to the inlet **33** of the second compressor head **31**. In some embodiments, the hydraulic circuit **60** includes an oil reservoir **138** configured to collect overpumped work oil via the outlets **34** of the first and second compressor heads **31**, **51**. In other embodiments, the compressor **1** includes at least one hydraulic accumulator **39** (FIG. **6**) configured to provide a supplemental supply of work oil to the inlets **33** of the first and second compressor heads **31**, **51**. In certain embodiments, each of the first and second compressor heads **31**, **51** include a hydraulic accumulator **39**. In some embodiments, the compressor **1** includes a pressure relief mechanism including a first pressure relief valve **43** in communication with the outlet **34** of the first compressor head **31** and configured to relieve the pressurized work oil from the first work oil region **35**, the first pressure relief valve **43** comprising a first hydraulic relief setting corresponding to a first target condition of the pressurized work oil relative to the process gas discharge pressure in first compressor head **31**, the first pressure relief valve **43** configured to actively adjust the hydraulic relief setting to correspond to a first current condition of the process gas in first compressor head **31**. These embodiments may also include a second pressure relief valve **43** in communication with the outlet **34** of the second compressor head **51** and configured to relieve the pressurized work oil from the second work oil region, the second pressure relief valve **43** comprising a second hydraulic relief setting corresponding to a second target condition of the pressurized work oil relative to the process gas discharge pressure in second compressor head **51**, the second pressure relief valve **43** configured to actively adjust the second pressure relief valve **43** to correspond to a second current condition of the process gas in second compressor head **51**. In some embodiments, the first target condition and the second target condition may be different, corresponding to different conditions in the first head and the second head, and in other embodiments, they may be the same. In further embodiments, the first current condition and the second current condition may be different, corresponding to different conditions in the first head and the second head, and in other embodiments, they may be the same.

In some embodiments, the compressor **1** includes a feedback mechanism configured to control an injector pump **40** to maintain the first and second target conditions, or first and second current conditions, the feedback mechanism including one or more measurement devices **44** configured to sense or measure a current condition of the intensified work oil flowing out one or more of the first compressor head **31** and the second compressor head **51**, and wherein the feedback mechanism is configured to adjust the volumetric displacement of the injector pump **40** in response to both the first current condition and the second current condition.

In some embodiments, the hydraulic relief setting of the first pressure relief valve **43** and second pressure relief valve **43** is a fixed value corresponding to the first target condition and second target condition being above a predetermined process gas discharge pressure as discussed herein. In other embodiments, the first pressure relief valve **43** and second pressure relief valve **43** are variable, the pressure relief mechanism **42** further including a first control valve **46** configured to actively adjust the hydraulic relief setting of the first pressure relief valve **43** to correspond to the first current condition, and a second control valve **46** configured to actively adjust the hydraulic relief setting of the second pressure relief valve **43** to correspond to the second current condition, wherein the first current condition and the second current condition are above a process gas discharge pressure as discussed herein.

In some embodiments such as FIG. **4**, the compressor **1** includes a hydraulic drive **110** comprising a hydraulic actuator, the hydraulic drive including an actuator housing **114** comprising a drive cavity **116** extending between the first and second compressor heads **31**, **51**. In some embodiments, the drive cavity **116** includes one or more inlets **142** for work oil at one or more drive pressures. In other embodiments, the first diaphragm oil piston **3** defines a first variable volume region **144** between the first diaphragm oil piston **3** and the diaphragm **5** of the first compressor head **31**, and the second diaphragm oil piston **3** defines a second variable volume region **146** between the second diaphragm oil piston **3** and the diaphragm **5** of the second compressor head **51**.

In certain embodiments, the AOIS includes a feedback mechanism configured to control the injector pump **40** to maintain the target condition or the current condition of the work oil region **35**. The feedback mechanism includes a measurement device **44** that provides feedback to verify the current condition is being met to control the injector pump system **30**. In certain embodiments, the feedback mechanism includes a first measurement device **44** operatively coupled to the diaphragm compressor **1**, the measurement device **44** configured to detect and/or measure the overpump current condition of the volumetric flow of intensified work oil flowing out of the outlet **34** from the work oil region **35**. In other embodiments, the measurement device **44** is operatively coupled to another section of the hydraulic circuit **60**, the discharged process gas, or the drive, such embodiments providing indirect feedback whereby a controller can infer the overpump current condition based on the measurement device. In any embodiment, the measurement device **44** may comprise a plurality of measurement devices at one or more locations. In certain embodiments, the feedback mechanism is configured to adjust the volumetric displacement of the injector pump **40** to the hydraulic accumulator **39** in response to the overpump current condition. In some embodiments, the first measurement device **44** of the feedback mechanism includes one or more of: a flow meter downstream of the outlet **34**, a position sensor in the pressure relief valve **43**, and a pressure transducer with a temperature transducer each located downstream of the pressure relief valve **43**.

In one embodiment, the feedback mechanism includes a direct feedback mechanism including a flowmeter downstream of the relief valve outlet **80**, and between a hydraulic tank, oil reservoir **38** or **138**, or crankcase. In certain embodiments, the flow meter may include a positive displacement flow meter, turbine flow meter, ultrasonic flow meter, a sensor measuring change in pressure over an orifice plate, or Coriolis flow meter.

In some embodiments, a flowmeter may include a pulse-output. In certain of these embodiments, flow may be calculated based on a moving average based on time. In this method, a new moving average may be calculated at a constant time interval—a flowrate may be updated periodically, but large flowrate changes may be detected more slowly than other options. In further embodiments, the flow may be calculated by a moving average based on number of pulses—this method may calculate a new moving average after a specific number of pulses have been read from the flowmeter. This method may work well in high flowrate and increasing flowrate conditions, because the moving average will be updated more often due to the flowmeter reporting more pulses. However, in low flowrate and decreasing flowrate conditions, this method may not update as fast, or at all if the flowmeter stops reporting pulses. This could potentially delay the controller's response to a decreasing flowrate. In still further embodiments, the flow may be calculated by a hybrid method of time and pulses—with this method, a new moving average may be computed based on either time or flowrate or both, and whichever condition is satisfied first will trigger a new flowmeter average. This method may allow for a pulse-based method to be used at higher flowrates and a time-based method to be used at lower flowrates.

In other embodiments, the feedback mechanism includes an indirect feedback mechanism including an oil relief valve **43** that includes position feedback of e.g. the valve seat **73** to monitor the valve's trajectory, i.e. the position and/or duration of the opening of the valve seat **73**, during a relief event. Monitoring valve trajectory may enable a control system to indirectly measure the amount of fluid that was relieved during a relief event. This measurement of valve trajectory could include a direct analog or digital position measurement or an electrical continuity measurement between the valve poppet **72** and valve seat **73**, among other options. In certain embodiments, the sensor may include a hall effect, LVDT, magnetoresistive, or optical sensor, to monitor the valve's trajectory.

In certain embodiments, a sensor measuring a continuous position measurement of the oil relief valve **14** position may include at least one of an analog hall effect sensor, an ultrasonic displacement sensor, an optical sensor (for example, laser doppler vibrometer, or other), a linear variable differential transformer (LVDT), a capacitive displacement sensor, and an eddy-current sensor. In other embodiments, a sensor measuring two valve positions of the oil relief valve **14** (i.e. open vs. closed) may include at least one of an optical proximity sensor, a contact switch, and a digital hall effect sensor.

In another embodiment, the feedback mechanism includes an indirect feedback mechanism including monitoring the pressure dynamics downstream of the relief valve **43**. In some embodiments, the pressure and temperature of the hydraulic fluid may be monitored to measure pressure spikes that occur during each relief event to infer flow rate though the relief valve **43**.

In certain embodiments, the feedback mechanism may include an I/P pneumatic pressure transducer on the pneumatic line between the I/P transducer and VPRV, which may be used to measure the bias pressure applied to the VPRV.

In still further embodiments, the feedback mechanism includes an indirect feedback mechanism including monitoring the pressure within the compressor **1**. In these embodiments, if the hydraulic pressure within the compressor **1** does not reach the oil relief valve **43** setting, there may not be enough oil in the compressor **1** and the overpump condition may not be satisfied.

In a further embodiment, the feedback mechanism includes an indirect feedback mechanism including monitoring the pressure in the hydraulic accumulator **39**. In certain of these embodiments, the pressure is measured by a pressure transducer or inferred from a compressor **1** motor **41** torque measurement (based on a model or look-up tables), or a pressure transducer in the hydraulic volume. In these embodiments, if the pressure within the hydraulic accumulator **39** is significantly lower than the pressure within the work oil region **35**, this could be an indication the AOIS is not injecting fluid into the compressor **1**. In other embodiments, if the diaphragm **5** begins to contact the process gas head support plate **8**, cavitation and voiding may occur within the compressor **1**. Any cavitation or voiding events within the compressor **1** may significantly reduce the pressure within hydraulic accumulator **39**. In some embodiments, during normal operation, the hydraulic pressure at inlet **33** may be very close to the process gas suction pressure. If the hydraulic pressure in hydraulic accumulator **39** drops significantly, it may be inferred the diaphragm **5** has hit the work oil head support plate **8** and the AOIS system **30** needs to provide more flow until the AOIS pressure is regained. Additionally, if the oil relief setting of the oil relief valve **14** is not reached during a discharge cycle, this may impact when the hydraulic accumulator **39** volume begins to flow into the compressor **1** as illustrated in FIG. **11**. In some embodiments, these conditions could be measured to monitor if the overpump condition is being satisfied or if cavitation is occurring within the compressor **1** on a cycle to cycle basis.

In a further embodiment, the feedback mechanism includes an indirect feedback mechanism including measuring process gas temperature and pressure to infer the amount of annular leakage that is occurring during operation. In some embodiments, based on these measurements, a model based adaptive controller may be implemented to control the AOIS injector pump **40** to satisfy the overpump requirements. In these embodiments, process gas pressure may be measured by one of suction, interstage, and outlet pressure, and the gas pressure within the cavity **15**. In certain embodiments, these measurements may be raw or filtered. In other embodiments, annular leakage may be measured directly by a flowmeter of the type discussed herein, or the catch and weigh method.

In a further embodiment, the feedback mechanism includes a direct feedback mechanism including physically capturing the overpump through the relief valve **43** and measuring the amount of oil that has been captured. In some embodiments, this measurement could be monitored on a time-based scale, among others, to calculate flow rates through the relief valve.

In a further embodiment, the feedback mechanism includes an indirect feedback mechanism including monitoring motor current of an electric motor of the compressor **1**. In these embodiments, if the hydraulic oil relief setting produces additional torque requirements from the motor each cycle, the motor current could be monitored to ensure these pressure spikes are occurring each cycle and the overpump condition is being satisfied.

In still other embodiments, a sensor may monitor the AOIS system **30** injector pump **40** motor **41** torque and speed, including by at least one of motor **41** current measurement, reported torque from motor drive (variable frequency drive or other), and the motor **41** speed may be measured by at least one of a rotary encoder and reported speed from motor **41** drive (variable frequency drive or other).

In further embodiments, the flowrate of hydraulic fluid through the injector pump **40** including a method of at least one of determining from motor **41** speed and displacement, and a flowmeter (positive displacement, turbine, or other).

In certain embodiments, a sensor may monitor the state of process gas valves by at least one of measuring feedback from valves, process gas pressure, and a signal from process gas control subsystem.

In further embodiments, a sensor may measure the temperature of the hydraulic fluid at any point in the AOIS, including at least the use of a thermocouple, thermistor, and resistance temperature detector (RTD).

Turndown ratio refers to the width of the operational range of a device, and is defined as the ratio of the maximum capacity to minimum capacity. In certain embodiments of the active oil injection system, the oil injection system is configured to provide a turndown ratio relative to the primary work oil in the work oil region **35**. In other embodiments, the maximum capacity can satisfy the target condition, and the minimum capacity is zero volumetric flow. By separating the functions of the drive and the injector pump **40**, a large turndown ratio can be achieved allowing for adjustability of injection quantity when compared to the previous non-adjustable crank driven injection pump system **10**. When the injector pump **40** is mechanically linked to the drive, e.g. in a crank-driven compressor **1**, the compressor's **1** RPM is constant during normal operation, which does not allow for volumetric displacement adjustability. However, the large turn down ratio of an independent AOIS allows for a highly variable injection quantity to tightly control the amount of overpump through the relief valve **43** over a wide range of operating conditions, from zero volumetric flow, to flow corresponding to a current condition, to flow corresponding to a target or maximum condition.

Certain embodiments herein may include control system variants for the AOIS. In some embodiments, feedback may be used to control the flowrate from the hydraulic accumulator **39**. Under this control strategy, the overpump of work oil out of the compressor head **31** and through the VPRV **70** will be measured or derived from other sensor inputs. Some form of a PID controller may be used to adjust the injector pump **40** and/or motor **41** speed based on the measured flowrate. In some embodiments, the desired overpump may be derived from a model, from a look-up table, or from operator input. In some embodiments, the flowrate measurement may be raw or filtered. In certain embodiments, during start-up operation of the compressor **1**, normal flow rates are not expected as the hydraulic accumulator **39** and compressor head **31** are primed with work oil. As a result, the flowrate measurement may not be used for feedback until a specified time has elapsed or until consistent flowrate measurements are obtained.

Other embodiments may use feedforward control from annular leakage model. In these embodiments, the process gas outlet pressure and oil temperature may be used to predict an annular leakage rate. The injector pump **40** and/or motor **41** speed may be adjusted such that the injector pump **40** output is equal to the sum of the predicted annular leakage and desired overpump out of the compressor head **31**. In these embodiments, the annular leakage rate may be determined from a model, a look-up table, or from operator input, and the desired over injector pump **40** may be derived from a model, from a look-up table, or from operator input. In these embodiments, there are some variables that may not be accounted for in the annular leakage model and may not be able to be measured by sensors, such as eccentricity of the oil piston **3**. As a result, the predicted annular leakage may have an error associated with it, which may be difficult to account for without an additional form of feedback. Therefore, in some embodiments this variant could be used in conjunction with the flowrate measurement discussed herein as a bias for the feedback controller.

Certain embodiments may employ model-reference adaptive control, wherein the annular leakage model would be used to predict the annular leakage across the oil piston **3**. In these embodiments, process gas outlet pressure and hydraulic fluid temperature may be measured to predict the annular leakage. In these embodiments, the overpump flowrate would be used to provide feedback of the overpump of work oil out of the compressor head **31**. The flowrate may be compared to the expected overpump predicted by the model and adjustments to the model may be made to account for this error. In these embodiments, the flowrate measurement may be raw or filtered. In some embodiments, parameters in the annular leakage model may be adjusted such that the predicted overpump from the model matches the measured flowrate.

Other embodiments may employ feedback control of I/P transducer, where a pressure transducer may be used to measure the pneumatic pressure output of the I/P transducer, which may converts an analog electrical signal into a pneumatic pressure output used as the bias pressure for the VPRV. In these embodiments, the pressure measurement may be raw or filtered. In some embodiments, the pressure output of the I/P transducer may be compared to the desired pressure output of the I/P transducer. In these embodiments, the I/P transducer command may be adjusted to reduce the error between the actual and desired pneumatic pressure output of the I/P transducer. In further embodiments, the desired pressure output of the I/P transducer may be derived from a model, from a look-up table, or from operator input.

Certain embodiments may employ feedback from process gas control subsystem, where for the AOIS, feedback from the process gas control subsystem can be used during gas loading and unloading processes. In these embodiments, during gas loading, the process gas interstage and outlet pressures may increase rapidly. If feedback control of the injection pump motor **41** uses flowmeter feedback, the time delay between the decreased actual flowrate across the flowmeter and decreased measured flowrate across the flowmeter may be too great for the injection pump motor **41** to be able to catch up and provide enough flowrate to account for annular leakage and the desired overpump. In these embodiments, if the process gas control subsystem actuates a valve as part of the gas loading process, the state of this valve can be monitored and reacted to accordingly. In one example, if the valve is actuated as part of a gas loading process, the AOIS control system can transition from a steady-state control state to a gas loading state. In this gas loading state, the injection pump motor **41** speed may be commanded to its maximum speed to account for the increased in annular leakage. In these embodiments, the process gas pressure transducers and flowmeter measurements may be used to determine when the gas loading process is completed and the AOIS control system will transition back to a steady-state control state. In some embodiments, during gas loading, the VPRV may also need to be adjusted quickly to prevent hydraulic fluid in the compressor cavity **15** being pumped out over the relief valve **43**. When the AOIS control system is in a gas loading state, the VPRV bias pressure **78** can be reduced based on the incoming process gas pressure. In still further embodiments, during gas unloading, the process gas suction and outlet pressure may decrease rapidly. If the process gas control subsystem actuates a valve as part of the gas unloading process, the state of this valve can be monitored and reacted to accordingly. When the valve is actuated to start a gas unloading process, the AOIS control system may transition from a steady-state control state to a gas unloading control state. During the gas unloading state, the injection pump motor **41** speed may be decreased to decrease the amount of hydraulic fluid overpump over the relief valve **43**. When the gas unloading process is complete, e.g. determined by pressure or flowrate measurements, the AOIS control system may return to a steady-state control state.

Certain embodiments may employ feedback from a work oil region **35** pressure transducer. In these embodiments, the AOIS injector pump **40** pumps fluid into a hydraulic accumulator **39**, which may be connected to the inlet **33** of the compressor head **31**. Under normal operating conditions, the pressure of this hydraulic accumulator **39** may be similar to the process gas inlet pressure and it will increase during a compressor **1** exhaust stroke (when the inlet check valve **9** to the compressor head **31** is closed). In these embodiments, if the pressure of the hydraulic accumulator **39** drops below a threshold pressure, the hydraulic accumulator **39** is not receiving enough fluid from the injector pump **40** and the compressor diaphragm **5** is at risk of hitting the hydraulic head **8** of the compressor **1**. In this scenario, the AOIS injector pump **40** speed may be increased to prevent the diaphragm **5** from hitting the hydraulic head **8**. In some embodiments, the threshold pressure may be derived from a model, a look-up table, or operator input. In other embodiments, the pressure measurement may be filtered or it may be raw.

Some embodiments may employ feedback from relief valve **43** position, where the overpump of work oil out of the compressor head **31** and through the VPRV **70** will be measured. In these embodiments, some form of a PID controller may be used to adjust the variable volumetric flow of work oil based on the measured flowrate. In these embodiments, the desired over pump may be derived from a model, from a look-up table, or from operator input. In these embodiments, the flowrate measurement may be raw or filtered. In some embodiments, during start-up operation of the compressor **1**, normal flow rates are not expected as the hydraulic accumulator **39** and compressor head **31** are primed with work oil. As a result, the flowrate measurement may not be used for feedback until a specified time has elapsed or until consistent flowrate measurements are obtained.

Still further embodiments may employ feedback from a relief valve **43** open/close switch. In some embodiments, the timing of the relief valve **43** opening will be compared to a desired timing of the relief valve **43** opening. If the actual open/close time does not match the desired timing, adjustments to the system, such as the AOIS injector pump **40** speed, may be made. In these embodiments, the desired timing may be derived from a model, a look-up table, or from operator input.

Other embodiments may include other prognostic or diagnostic functions of the AOIS. Some embodiments may employ pressure measurement of I/P transducer output, and may include measuring the pneumatic pressure output of the I/P transducer, which may allow for any failure in the I/P transducer to be detected. In some embodiments, in the case that the I/P transducer pressure output is higher than commanded, the VPRV **70** cracking pressure will be lower than desired, and the work oil in the work oil region **35** is at risk of draining out of the work oil region **35** quickly. In this scenario, the I/P transducer may be disabled, which may cause the pressure output to be 0 psi and the VPRV cracking pressure will return to its baseline setting since no bias pressure **78** is applied. In some embodiments, the higher than commanded I/P pressure output is indicative of a malfunction of the I/P transducer and may alert the operator. In some embodiments, in the case that the I/P pressure output is lower than commanded, the VPRV cracking pressure may be higher than desired, which may decrease the efficiency of the system and may increase the magnitude of the cyclic stress on compressor **1** components. The lower than commanded I/P pressure output may be indicative of a malfunction of the I/P transducer and may alert the operator.

Certain embodiments may monitor the flowrate of overpump, where in addition to the flow measurement feedback that the flowmeter provides to the control system, it can also be used to monitor the system's overall health and functionality. In these embodiments, during a start-up condition when the compressor **1** is not fully primed, the flow meter can be used to provide feedback that hydraulic fluid is flowing out of the compressor cavity **15**. After a specified duration of consistent flow measurements, the priming process may be flagged as complete and the compressor **1** can continue with normal operation. In other embodiments, during normal operating conditions, the flow measurement may be used to set both warning and fault flags if the flow measurement is lower than expected. For example, a flow measurement that is lower than expected for a short duration may be caused by an insufficient control strategy and may only warrant a warning to the operator. In a more severe case where the flow measurement is below a lower threshold or if a low flow measurement is recorded for an extended duration, then a fault flag may be set and the compressor **1** system may be shut down.

Some embodiments may monitor for excessive annular leakage, where the annular leakage model may be used to predict the leakage of hydraulic fluid over the oil piston **3**. If the measured overpump from the flowmeter is less than the predicted overpump and the adjustable parameters, such as radial clearance and eccentricity, in the annular leakage model are at their limits, then the control system may alert the operator with a warning. This warning may be indicative of excessive compressor **1** wear or other mechanical wear/failure that may be addressed.

Certain embodiments may monitor for motor **41** torque levels being out of bounds, where excessive motor **41** torque may be indicative of a blocked hydraulic line and may alert the operator with a warning or fault depending on the deviation of motor **41** torque from expected. In some embodiments, motor **41** torque below a certain threshold may be indicative of a leak or ruptured hydraulic line and may alert the operator with a warning or fault depending on the deviation of motor **41** torque from expected.

Some embodiments may monitor the hydraulic pressure in hydraulic accumulator **39**, where in addition to using the hydraulic pressure as a potential control method, it can also be monitored for diagnostics. If the pressure in the hydraulic accumulator **39** drops below a threshold value, the injector pump **40** is not supplying enough work oil. In these embodiments, the threshold value may be derived from a model, a look-up table, or from operator input.

All of the features disclosed, claimed, and incorporated by reference herein, and all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive. Each feature disclosed in this specification may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is an example only of a generic series of equivalent or similar features. Inventive aspects of this disclosure are not restricted to the details of the foregoing embodiments, but rather extend to any novel embodiment, or any novel combination of embodiments, of the features presented in this disclosure, and to any novel embodiment, or any novel combination of embodiments, of the steps of any method or process so disclosed.

Although specific examples have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement calculated to achieve the same purpose could be substituted for the specific examples disclosed. This application is intended to cover adaptations or variations of the present subject matter. Therefore, it is intended that the invention be defined by the attached claims and their legal equivalents, as well as the illustrative aspects. The above described embodiments are merely descriptive of its principles and are not to be considered limiting. Further modifications of the invention herein disclosed will occur to those skilled in the respective arts and all such modifications are deemed to be within the scope of the inventive aspects.

What is claimed is:

1. An active oil injection system in a diaphragm compressor, comprising:

a diaphragm compressor comprising:

a compressor head comprising:

a work oil head support plate and a process gas head support plate defining a diaphragm cavity therebetween, the work oil head support plate comprising a piston cavity, an inlet, and an outlet, and

a metallic diaphragm mounted between the work oil head support plate and the process gas head support plate, the metallic diaphragm dividing the diaphragm cavity into a work oil region and a process gas region, the work oil region being in separate communication with each of the piston cavity, the inlet, and the outlet, wherein the metallic diaphragm is configured to actuate from a first position proximate the work oil head support plate to a second position proximate the process gas head support plate to pressurize process gas in the process gas region to a process gas discharge pressure,

a drive configured to intensify and supply primary work oil to the compressor head, the drive comprising:

a drive cavity extending from the compressor head and in communication with the work oil region via the piston cavity,

a piston mounted in the drive cavity and defining the volume of the work oil region, and

an actuator configured to power the piston,

wherein, during a discharge cycle, the drive is configured to power the piston to move toward the compressor head to intensify primary work oil in the work oil region from a first pressure to an intensified pressure and thereby actuate the metallic diaphragm to the second position;

a hydraulic circuit connecting the outlet of the work oil head support plate to the inlet of the work oil head support plate, the hydraulic circuit comprising:

an oil reservoir configured to collect overpumped work oil from the work oil region via the outlet of the work oil head support plate,

a hydraulic accumulator configured to provide a supply of supplemental work oil to the inlet of the work oil head support plate,

an injector pump in communication with the hydraulic accumulator, the injector pump configured to produce a variable volumetric displacement of the supplemental work oil from the oil reservoir to the hydraulic accumulator, the injector pump comprising:

a pump operatively coupled to the hydraulic accumulator, and

a pressure relief mechanism operatively coupled to the work oil region of the diaphragm cavity, the pressure relief mechanism comprising:

a pressure relief valve in communication with the outlet of the work oil head support plate and configured to relieve the pressurized work oil from the work oil region, the pressure relief valve comprising a hydraulic relief setting corresponding to a target pressure condition of the pressurized work oil relative to the process gas discharge pressure, and

a control valve configured to actively adjust the hydraulic relief setting of the pressure relief valve based on a current condition of the process gas; and

a feedback mechanism configured to control the injector pump, the feedback mechanism comprising:

a first measurement device operatively coupled to one or more of the outlet and the pressure relief valve, the first measurement device configured to detect a current condition of the pressurized work oil flowing through the pressure relief valve from the work oil region, the first measurement device of the feedback mechanism comprising one or more of a flow meter downstream of the outlet, a position sensor in the pressure relief valve, and a pressure transducer located downstream of the pressure relief valve, and wherein the feedback mechanism is configured to adjust the volumetric displacement of the injector pump to the hydraulic accumulator in response to the detected current condition.

2. The active oil injection system of claim **1**, wherein the hydraulic relief setting is a pressure of at least 10-20% above a measured process gas discharge pressure.

3. The active oil injection system of claim **1**, wherein the oil reservoir is in fluid communication with the drive of the diaphragm compressor;

wherein the actuator of the diaphragm compressor is a crank-slider mechanism, and the oil reservoir is a crankcase of the crank-slider mechanism;

wherein the hydraulic circuit further comprises:

an inlet check valve operatively coupled to the inlet of the work oil head support plate, the inlet check valve configured to prevent backflow from the work oil region to the hydraulic accumulator, and

an outlet check valve operatively coupled to the outlet of the work oil head support plate, the outlet check valve configured to prevent backflow from the hydraulic circuit to the work oil region;

wherein, during a suction cycle of the diaphragm compressor at the compressor head, the drive of the diaphragm compressor is configured to move the piston away from the compressor head to depressurize the work oil region and thereby pull the metallic diaphragm to the first position, and

wherein, during the suction cycle, the hydraulic accumulator is configured to supply an injection volume of the supplemental work oil to the inlet of the work oil head support plate.

4. The active oil injection system of claim **3**, wherein the injection volume from the hydraulic accumulator corresponds to the volume of overpump flow of pressurized work oil through the pressure relief valve; wherein the injector pump is configured to charge the hydraulic accumulator during both the discharge and suction cycles of the diaphragm compressor.

5. The active oil injection system of claim **1**, the injector pump further comprising a motor configured to drive the pump independently from the drive, the pump and motor of the injector pump comprising a pump and motor selected from one of: a variable speed motor with a fixed displacement hydraulic pump, a fixed speed motor with a variable displacement hydraulic pump, and a variable speed motor with a variable displacement hydraulic pump.

6. The active oil injection system of claim **1**, the hydraulic circuit further comprising a metering actuator operatively coupled to the inlet, the metering actuator configured to inject the supplemental work oil selectively during each of a suction cycle and the discharge cycle of the diaphragm compressor.

7. The active oil injection system of claim **1**, the pressure relief valve comprising a valve spring and an adjustable pneumatic pressure bias, the control valve configured to actively adjust the hydraulic relief setting by adjusting the pneumatic pressure bias.

8. The active oil injection system of claim **1**, wherein the pressure transducer located downstream of the pressure relief valve comprises a pressure transducer with a temperature transducer each located downstream of the pressure relief valve.

9. The active oil injection system of claim **1**, further comprising a hydraulic power unit driving the actuator of the diaphragm compressor; wherein the hydraulic power unit comprises a second hydraulic circuit of oil that is separate from the work oil of the hydraulic circuit of the active oil injection system.

10. The active oil injection system of claim **9**, wherein the oil reservoir is a hydraulic tank operatively coupled with the hydraulic power unit,

the injector pump comprising an active control valve configured to selectively isolate the injector pump from the hydraulic power unit of the diaphragm compressor.

11. The active oil injection system of claim **1**, the drive of the diaphragm compressor comprising a hydraulic drive supplied by a plurality of pressure rails configured to supply work oil to power the piston, the plurality of pressure rails comprising:

a low-pressure rail supplying low-pressure work oil via a passive first valve,

a medium-pressure rail supplying medium-pressure work oil via an active second valve, and

a high-pressure rail supplying high-pressure work oil via an active third valve;

wherein the drive of the diaphragm compressor further comprising a hydraulic power unit providing the supply of work oil to the medium-pressure rail and the high-pressure rail, the hydraulic power unit comprising a hydraulic pump and motor.

12. An active oil injection system in a diaphragm compressor, comprising:

a diaphragm compressor comprising:

a first compressor head comprising:

an inlet, an outlet, a first head cavity, and

a first diaphragm dividing the first head cavity into a first work oil region and a process gas region, the first diaphragm configured to actuate to pressurize process gas in the process gas region,

a second compressor head comprising:

an inlet, an outlet, a second head cavity, and

a second diaphragm dividing the second head cavity into a second work oil region and a process gas region, the second diaphragm configured to actuate to pressurize process gas in the process gas region,

a drive configured to intensify work oil and alternatingly provide intensified work oil to the first and second compressor heads, the drive comprising:

a first diaphragm piston configured to intensify work oil against the first diaphragm,

a second diaphragm piston configured to intensify work oil against the second diaphragm, and

an actuator configured to power the first and second diaphragm pistons,

wherein the first diaphragm piston and the second diaphragm piston are configured to alternatingly intensify the work oil in the respective first or second work oil region to an intensified pressure and thereby actuate the respective first or second diaphragm;

a hydraulic circuit connecting the outlet of the first compressor head to the inlet of the first compressor head and connecting the outlet of the second compressor head to the inlet of the second compressor head, the hydraulic circuit comprising:

an oil reservoir configured to collect overpumped work oil via the outlets of the first and second compressor heads, a hydraulic accumulator configured to provide a supplemental supply of work oil to the inlets of the first and second compressor heads,

an injector pump in communication with the hydraulic accumulator, the injector pump configured to produce a variable volumetric displacement of supplemental work oil from the oil reservoir to the hydraulic accumulator, the injector pump comprising:

a pump operatively coupled to the hydraulic accumulator,

a pressure relief mechanism comprising:

a first pressure relief valve in communication with the outlet of the first compressor head and configured to relieve an overpump of the pressurized work oil from the work oil region, the first pressure relief valve comprising a hydraulic relief setting corresponding to a first target pressure condition of the pressurized work oil relative to the process gas discharge pressure,

a first control valve configured to actively adjust the hydraulic relief setting of the first pressure relief valve based on the current condition of the discharged process gas,

a second pressure relief valve in communication with the outlet of the second compressor head and configured to relieve an overpump of the pressurized work oil from the work oil region, the second pressure relief valve comprising a hydraulic relief setting corresponding to a second target pressure condition of the pressurized work oil relative to the process gas discharge pressure,

a second control valve configured to actively adjust the hydraulic relief setting of the second pressure relief valve based on the current condition of the discharged process gas; and

a feedback mechanism configured to control the injector pump, the feedback mechanism comprising:

one or more measurement devices configured to measure the current condition of the pressurized work oil flowing through one or more of the first and second pressure relief valves from the one or more first work oil region and the second work oil region, the one or more measurement devices of the feedback mechanism comprising one or more of a flow meter downstream of the outlet of one or more of the first compressor head and the second compressor head, a position sensor in the pressure relief valve, and a pressure transducer located downstream of the pressure relief valve, and

wherein the feedback mechanism is configured to adjust the volumetric displacement of the injector pump in response to the current condition of the pressurized work oil flowing through the pressure relief valve from the first work oil region and the second work oil region.

13. An active oil injection system in a hydraulically powered diaphragm compressor, comprising:

a hydraulically powered diaphragm compressor comprising:

a first compressor head comprising:

an inlet, an outlet, a first head cavity, and

a first diaphragm dividing the first head cavity into a first work oil region and a process gas region, the first diaphragm configured to actuate to pressurize process gas in the process gas region,

a second compressor head comprising:

an inlet, an outlet, a second head cavity, and

a second diaphragm dividing the second head cavity into a second work oil region and a process gas region, the second diaphragm configured to actuate to pressurize process gas in the process gas region,

a hydraulic drive configured to intensify work oil and alternatingly provide intensified work oil to the first and second compressor heads, the hydraulic drive comprising:

a first diaphragm piston configured to intensify work oil against the first diaphragm,

a second diaphragm piston configured to intensify work oil against the second diaphragm, and

a hydraulic actuator configured to power the first and second diaphragm pistons,

wherein the first diaphragm piston and the second diaphragm piston are configured to alternatingly intensify the work oil in the respective first or second work oil region to an intensified pressure and thereby actuate the respective first or second diaphragm;

a hydraulic circuit connecting the outlet of the first compressor head to the inlet of the first compressor head and connecting the outlet of the second compressor head to the inlet of the second compressor head, the hydraulic circuit comprising:

an oil reservoir configured to collect overpumped work oil via the outlets of the first and second compressor heads,

a hydraulic accumulator configured to provide a supplemental supply of work oil to the inlets of the first and second compressor heads,

an injector pump in communication with the hydraulic accumulator, the injector pump configured to produce a variable volumetric displacement of supplemental work oil from the oil reservoir to the hydraulic accumulator, the injector pump comprising:

a pump operatively coupled to the hydraulic accumulator,

a pressure relief mechanism comprising:

a first pressure relief valve in communication with the outlet of the first compressor head and configured to relieve the pressurized work oil from the work oil region, the first pressure relief valve comprising a hydraulic relief setting corresponding to a first target pressure condition of the pressurized work oil relative to the process gas discharge pressure, and

a second pressure relief valve in communication with the outlet of the second compressor head and configured to relieve the pressurized work oil from the work oil region, the pressure relief valve comprising a hydraulic relief setting corresponding to a second target pressure condition of the pressurized work oil relative to the process gas discharge pressure; and

a feedback mechanism configured to control the injector pump, the feedback mechanism comprising:

one or more measurement devices configured to sense or measure a current condition of the intensified work oil flowing out one or more of the first compressor head and the second compressor head, the one or more measurement devices of the feedback mechanism comprising one or more of a flow meter downstream of the outlet of one or more of the first compressor head and the second compressor head, a position sensor in the pressure relief valve, and a pressure transducer located downstream of the pressure relief valve, and

wherein the feedback mechanism is configured to adjust the volumetric displacement of the injector pump in response to the current condition.

14. An active oil injection system in a diaphragm compressor, comprising:

a diaphragm compressor comprising:

a compressor head comprising:

a work oil head support plate and a process gas head support plate defining a diaphragm cavity therebetween, the work oil head support plate comprising a piston cavity, an inlet, and an outlet, and

a metallic diaphragm mounted between the work oil head support plate and the process gas head support plate, the metallic diaphragm dividing the diaphragm cavity into a work oil region and a process gas region, the work oil region being in separate communication with each of the piston cavity, the inlet, and the outlet, wherein the metallic diaphragm is configured to actuate from a first position proximate the work oil head support plate to a second position proximate the process gas head support plate to pressurize process gas in the process gas region to a process gas discharge pressure,

a drive configured to intensify and supply primary work oil to the compressor head, the drive comprising:

a drive cavity extending from the compressor head and in communication with the work oil region via the piston cavity,

a piston mounted in the drive cavity and defining the volume of the work oil region, and

an actuator configured to power the piston,

wherein, during a discharge cycle, the drive is configured to power the piston to move toward the compressor head to intensify primary work oil in the work oil region from a first pressure to an intensified pressure and thereby actuate the metallic diaphragm to the second position;

a hydraulic circuit connecting the outlet of the work oil head support plate to the inlet of the work oil head support plate, the hydraulic circuit comprising:

an oil reservoir configured to collect overpumped work oil from the work oil region via the outlet of the work oil head support plate,

an injector pump in communication with the oil reservoir, the injector pump configured to produce supplemental work oil from the oil reservoir to the inlet of the work oil head support plate; and

a pressure relief mechanism operatively coupled to the work oil region of the diaphragm cavity, the pressure relief mechanism comprising:

a pressure relief valve in communication with the outlet of the work oil head support plate and configured to relieve the pressurized work oil from the work oil region, the pressure relief valve comprising a hydraulic relief setting corresponding to a target pressure condition of the pressurized work oil relative to the process gas discharge pressure, and

a control valve configured to actively adjust the hydraulic relief setting of the pressure relief valve based on a current condition of the process gas; and

a feedback mechanism configured to control the injector pump, the feedback mechanism comprising:

a first measurement device operatively coupled to one or more of the outlet and the pressure relief valve, the first measurement device configured to detect a current condition of the pressurized work oil flowing through the pressure relief valve from the work oil region, the first measurement device of the feedback mechanism comprising one or more of a flow meter downstream of the outlet, a position sensor in the pressure relief valve, and a pressure transducer located downstream of the pressure relief valve.

15. The active oil injection system of claim **14**, wherein the hydraulic relief setting is a pressure of is at least 10-20% above a measured process gas discharge pressure.

16. The active oil injection system of claim **14**, the hydraulic circuit further comprising a hydraulic accumulator configured to provide a supply of supplemental work oil to the inlet of the work oil head support plate, wherein the injector pump is in communication with the hydraulic accumulator, the injector pump configured to produce a variable volumetric displacement of the supplemental work oil from the oil reservoir to the hydraulic accumulator;

wherein the oil reservoir is in fluid communication with the drive of the diaphragm compressor;

wherein the actuator of the diaphragm compressor is a crank-slider mechanism, and the oil reservoir is a crankcase of the crank-slider mechanism;

wherein the hydraulic circuit further comprises:

an inlet check valve operatively coupled to the inlet of the work oil head support plate, the inlet check valve configured to prevent backflow from the work oil region to the hydraulic accumulator, and

an outlet check valve operatively coupled to the outlet of the work oil head support plate, the outlet check valve configured to prevent backflow from the hydraulic circuit to the work oil region;

wherein, during a suction cycle of the diaphragm compressor at the compressor head, the drive of the diaphragm compressor is configured to move the piston away from the compressor head to depressurize the work oil region and thereby pull the metallic diaphragm to the first position, and

wherein, during the suction cycle, the hydraulic accumulator is configured to supply an injection volume of the supplemental work oil to the inlet of the work oil head support plate.

17. The active oil injection system of claim **16**, wherein the feedback mechanism is configured to adjust the volumetric displacement of the injector pump to the hydraulic accumulator in response to the detected current condition; and

wherein the injection volume from the hydraulic accumulator corresponds to the volume of overpump flow of pressurized work oil through the pressure relief valve; wherein the injector pump is configured to charge the hydraulic accumulator during both the discharge and suction cycles of the diaphragm compressor.

18. The active oil injection system of claim **14**, the injector pump further comprising a motor configured to drive the pump, the pump and motor of the injector pump comprising a pump and motor selected from one of: a variable speed motor with a fixed displacement hydraulic pump, a fixed speed motor with a variable displacement hydraulic pump, and a variable speed motor with a variable displacement hydraulic pump.

19. The active oil injection system of claim **14**, the hydraulic circuit further comprising a metering actuator operatively coupled to the inlet, the metering actuator configured to inject the supplemental work oil selectively during each of a suction cycle and the discharge cycle of the diaphragm compressor.

20. The active oil injection system of claim **14**, the pressure relief valve comprising a valve spring and an adjustable pneumatic pressure bias, the control valve configured to actively adjust the hydraulic relief setting by adjusting the pneumatic pressure bias.

21. The active oil injection system of claim **14**, wherein the pressure transducer located downstream of the pressure relief valve comprises a pressure transducer with a temperature transducer each located downstream of the pressure relief valve.

22. The active oil injection system of claim **14**, further comprising a hydraulic power unit driving the actuator of the diaphragm compressor; wherein the hydraulic power unit comprises a second hydraulic circuit of oil that is separate from the work oil of the hydraulic circuit of the active oil injection system.

23. The active oil injection system of claim **22**, wherein the oil reservoir is a hydraulic tank operatively coupled with the hydraulic power unit,

the injector pump comprising an active control valve configured to selectively isolate the injector pump from the hydraulic power unit of the diaphragm compressor.

24. The active oil injection system of claim **14**, the drive of the diaphragm compressor comprising a hydraulic drive supplied by a plurality of pressure rails configured to supply work oil to power the piston, the plurality of pressure rails comprising:

a low-pressure rail supplying low-pressure work oil via a passive first valve,

a medium-pressure rail supplying medium-pressure work oil via an active second valve, and

a high-pressure rail supplying high-pressure work oil via an active third valve;

wherein the drive of the diaphragm compressor further comprising a hydraulic power unit providing the supply of work oil to the medium-pressure rail and the high-pressure rail, the hydraulic power unit comprising a hydraulic pump and motor.

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