



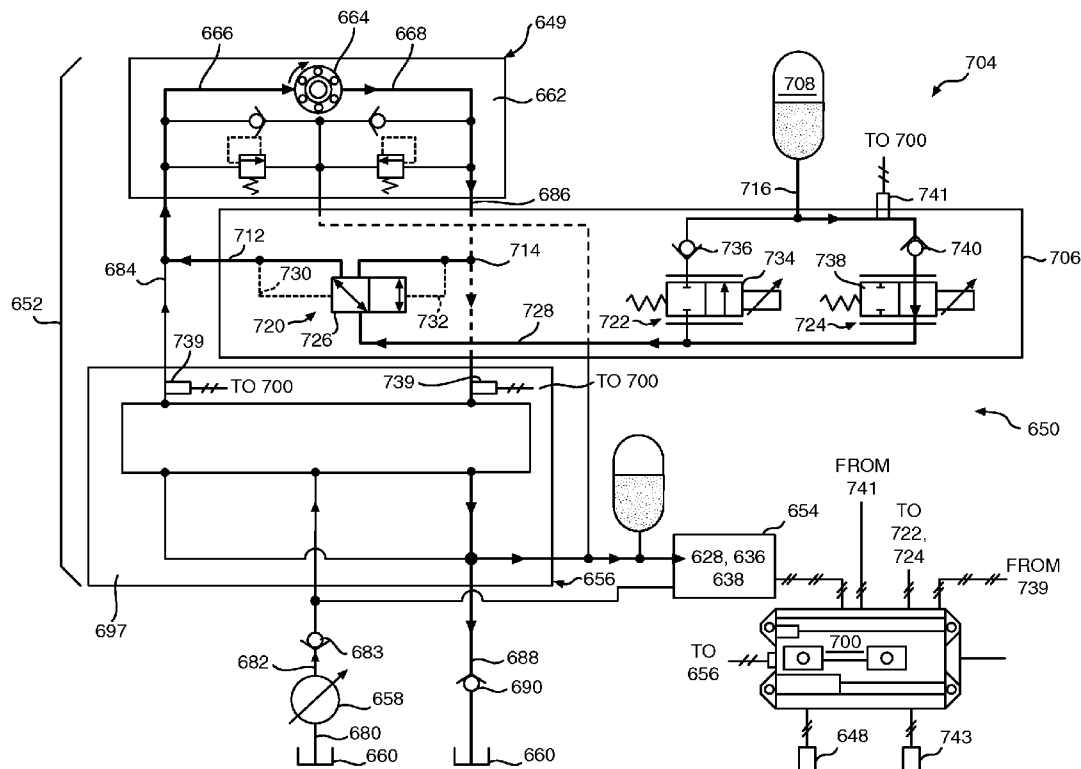
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(19) **United States**(12) **Patent Application Publication**
Ma et al.(10) **Pub. No.: US 2014/0060030 A1**(43) **Pub. Date: Mar. 6, 2014**(54) **HYDRAULIC ACCUMULATOR HEALTH MONITOR**(71) Applicant: **Caterpillar Inc.**, Peoria, IL (US)(72) Inventors: **Pengfei Ma**, Naperville, IL (US); **Dayao Chen**, Bolingbrook, IL (US); **Randal Peterson**, Peoria, IL (US)(21) Appl. No.: **13/908,012**(22) Filed: **Jun. 3, 2013****Related U.S. Application Data**

(60) Provisional application No. 61/695,344, filed on Aug. 31, 2012.

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E02F 9/12 (2006.01)(52) **U.S. Cl.**CPC **E02F 9/123** (2013.01)USPC **60/413**(57) **ABSTRACT**

A system and method to diagnose the operational health of a hydraulic accumulator are provided. The system can include a hydraulic accumulator selectively coupled to a hydraulic actuator, such as a swing motor. The accumulator can be charged by movement of the actuator. A pressure sensor can be associated with the accumulator to determine an accumulator pressure. A controller can be connected to the pressure sensor. The controller can determine a charge curve based on a relationship between an actuator operational parameter associated with the actuator movement and the accumulator pressure. The controller can compare the charge curve to a previously defined charge curve or range to determine an error between the charge curve and the previously defined charge curve or range. The degree of the error can be associated with the operational health of the accumulator, and if too large, the operator may be notified of the status.



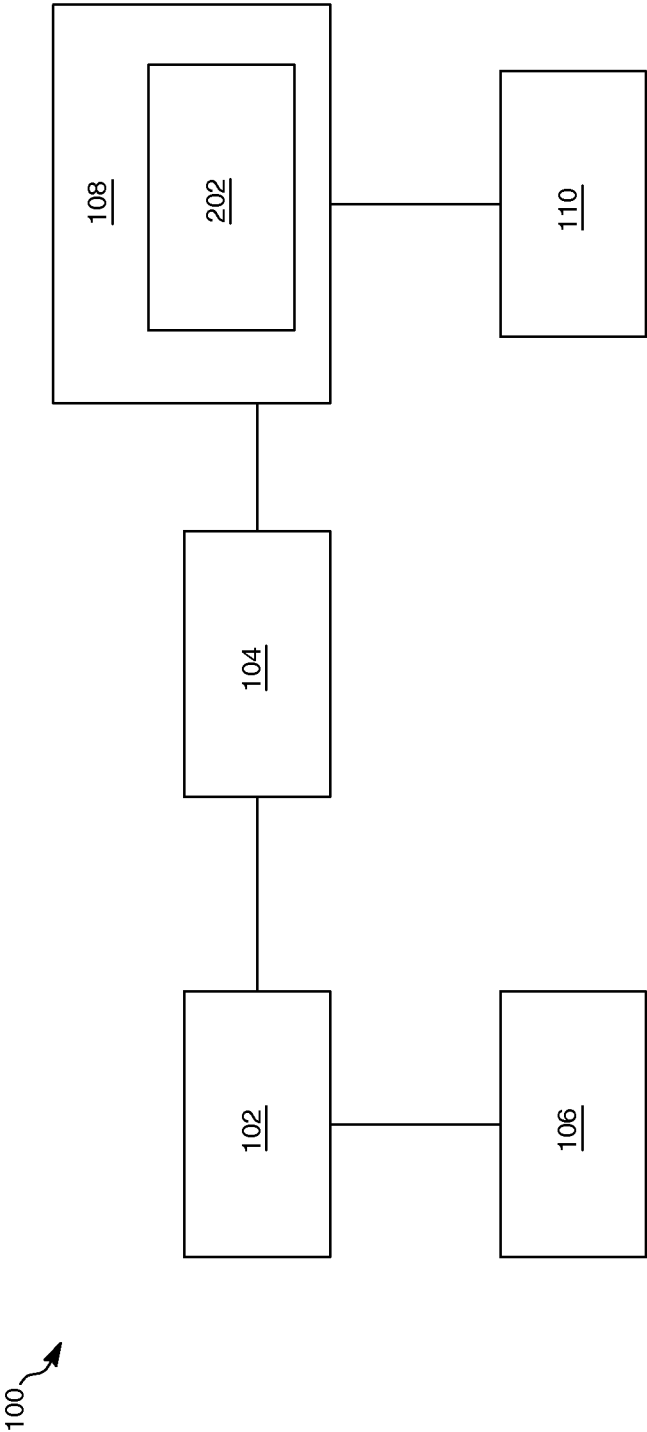


FIG. 1

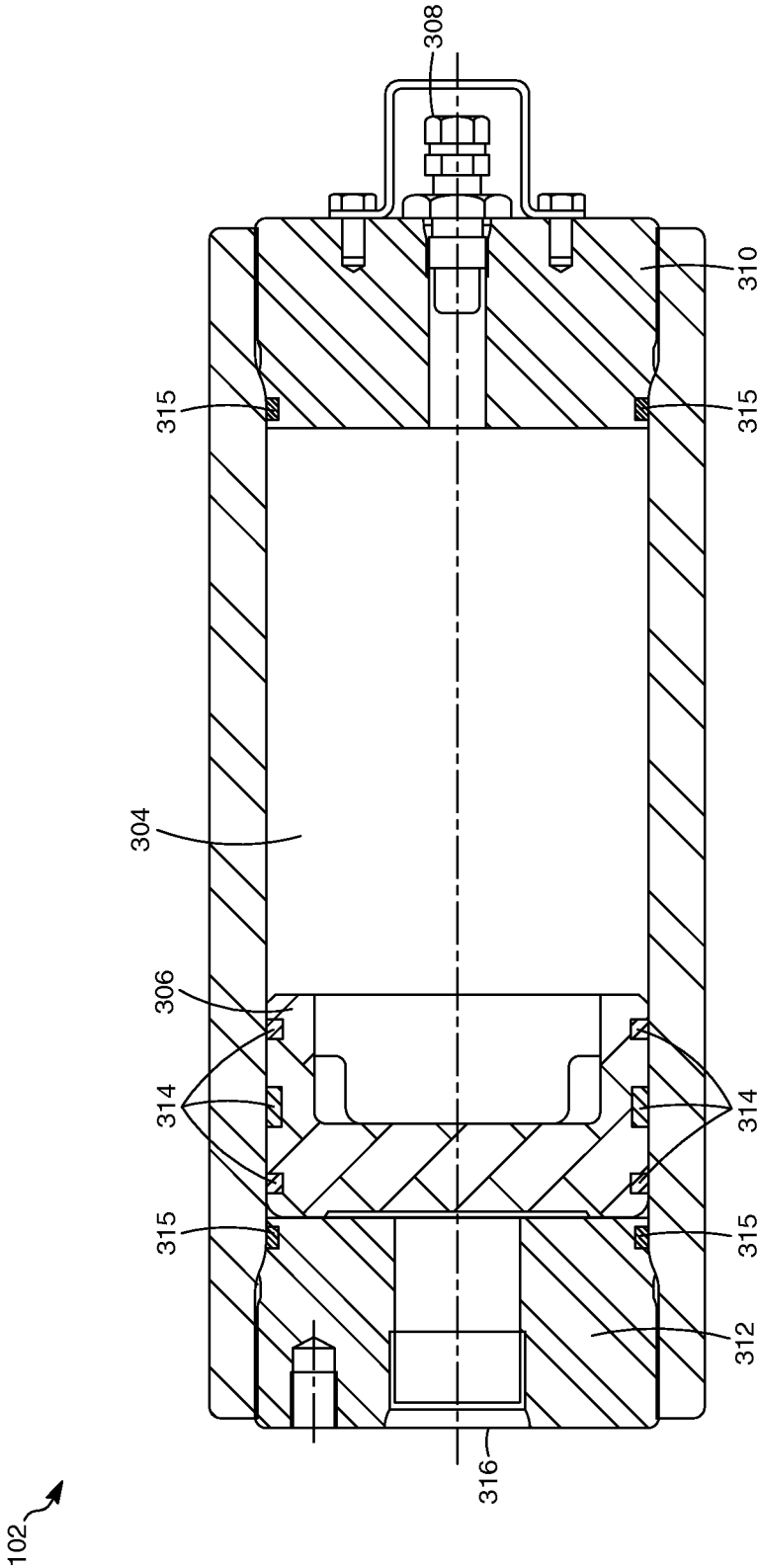


FIG. 2

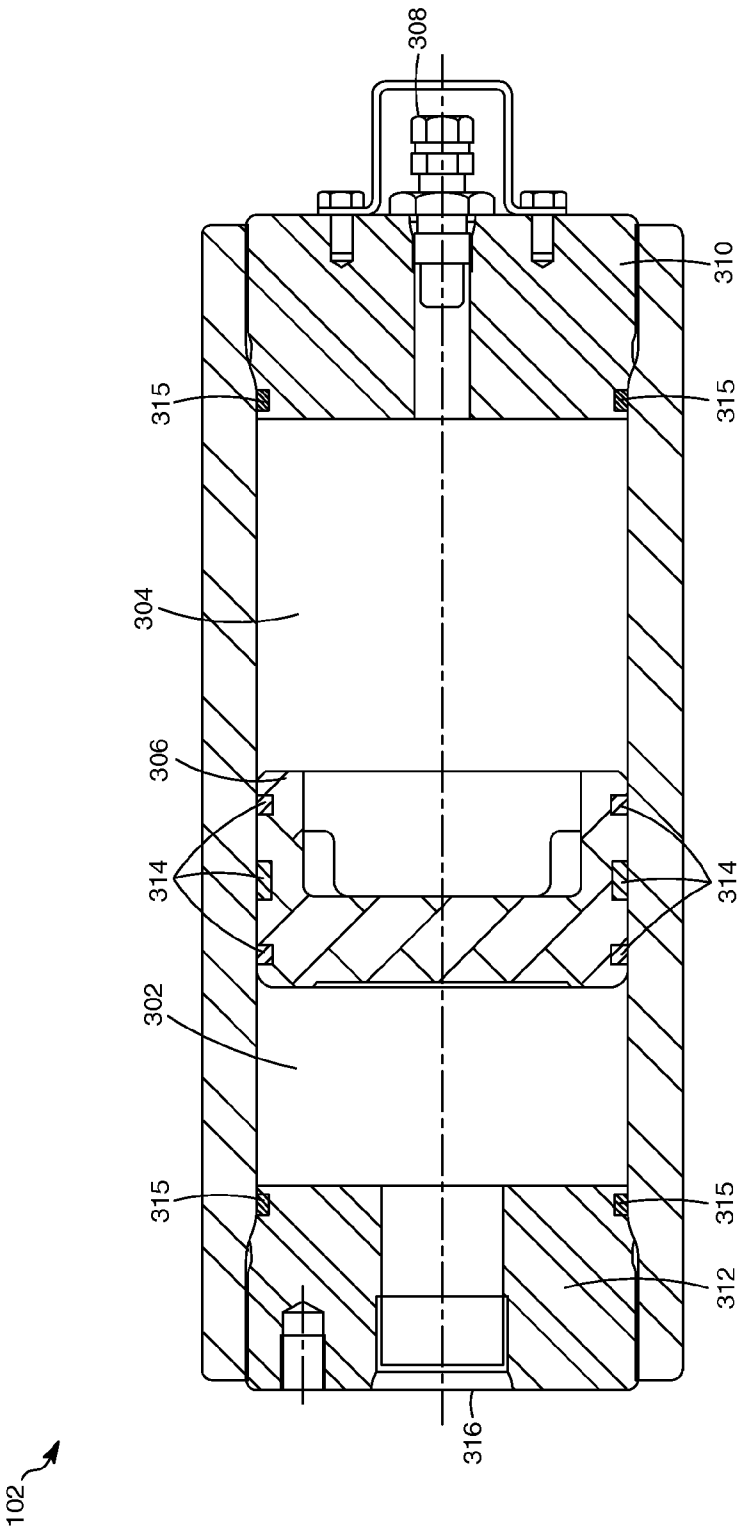


FIG. 3

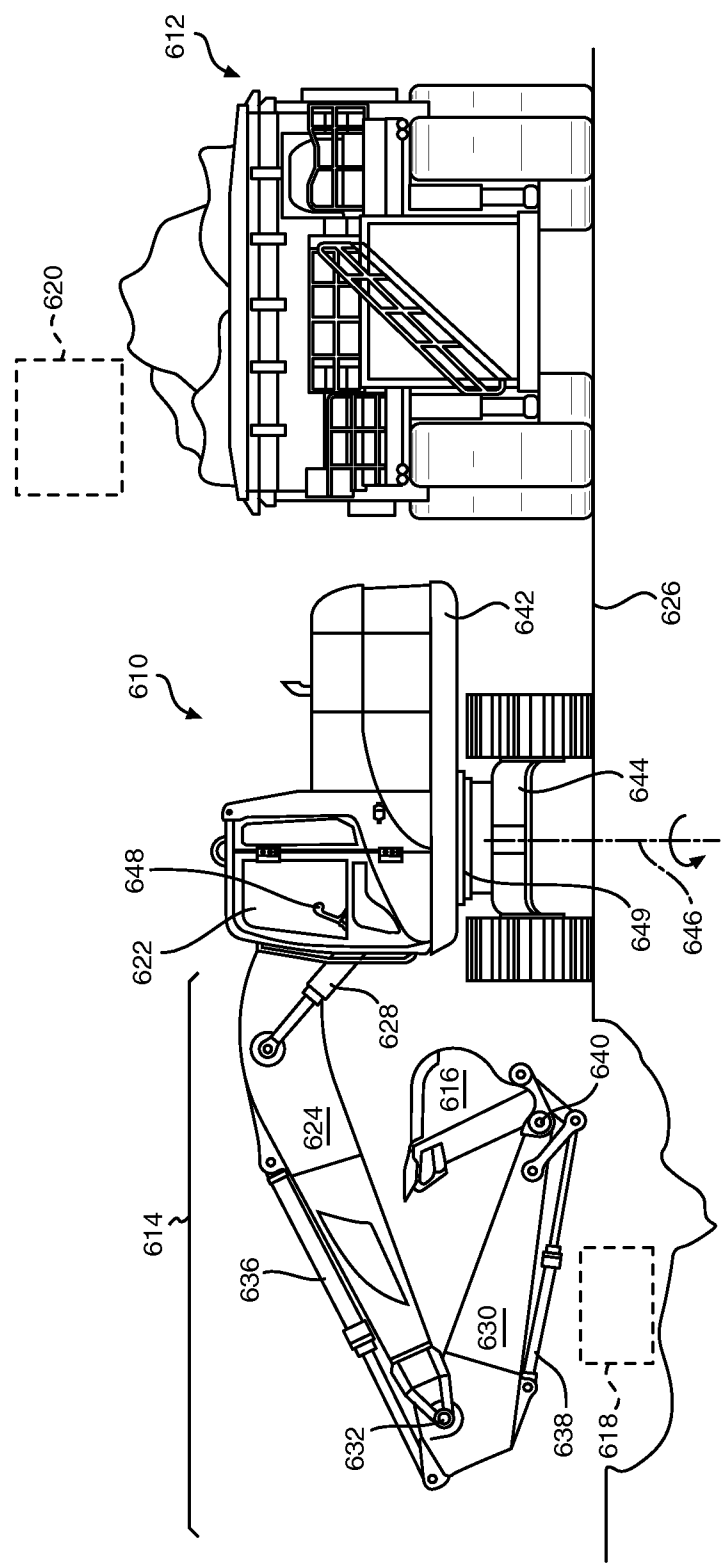


FIG. 4

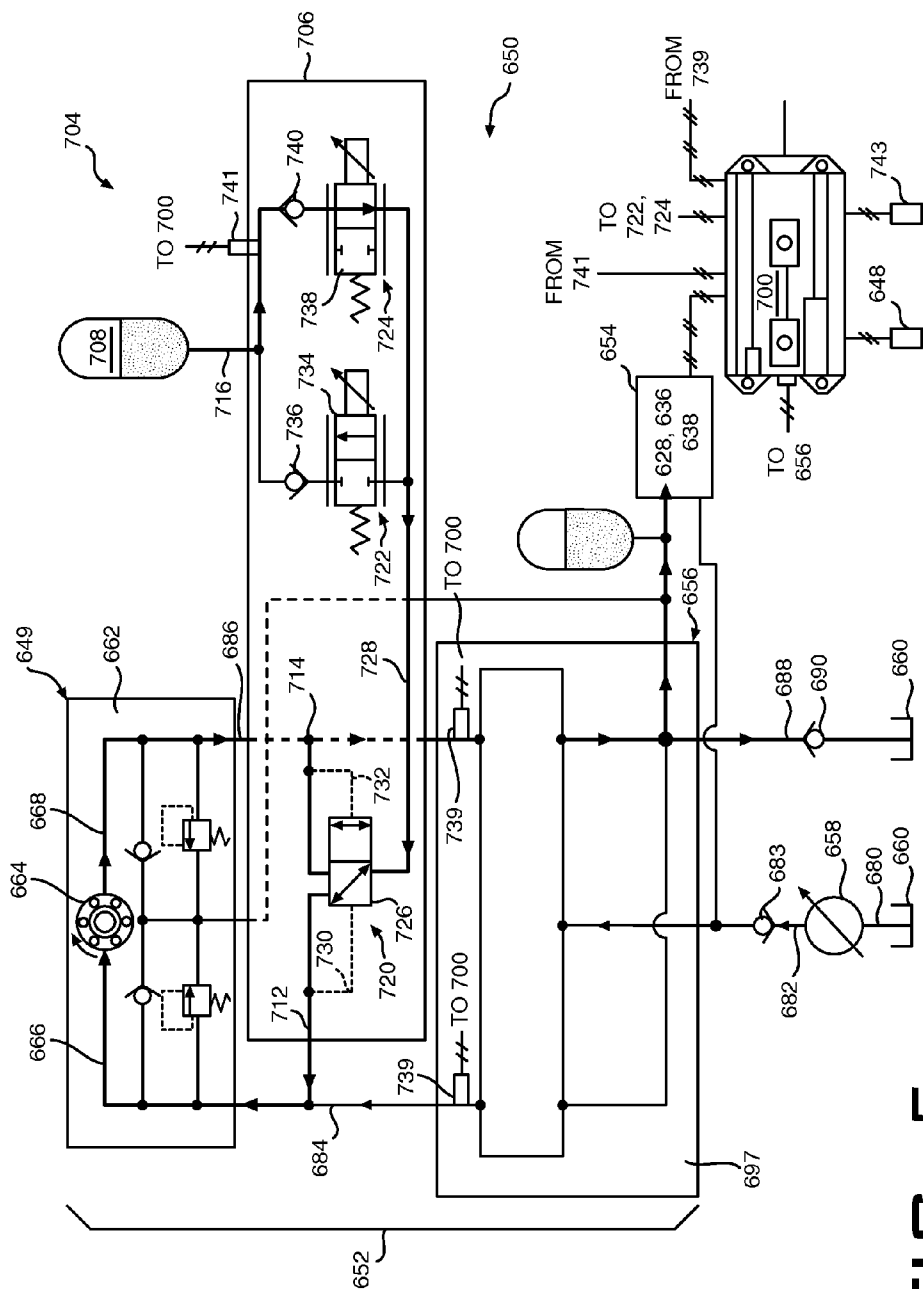


FIG. 5

FIG. 6

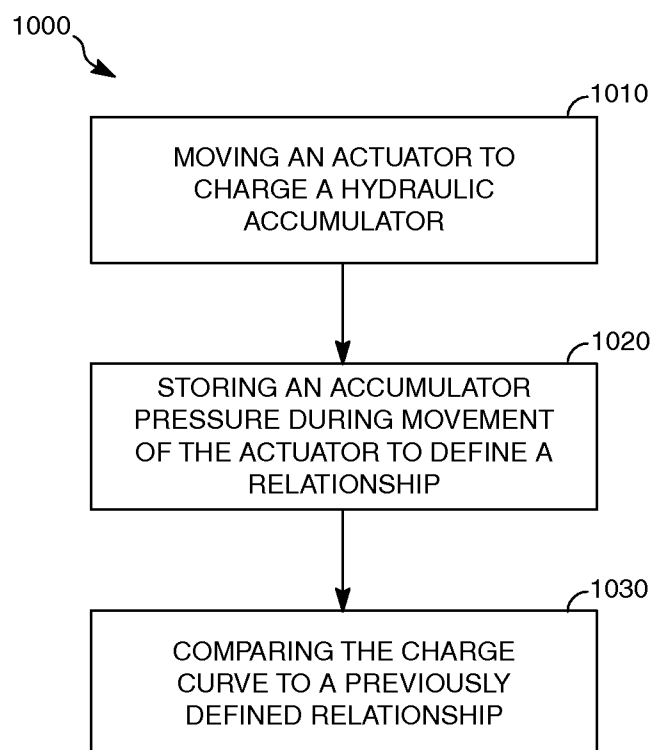
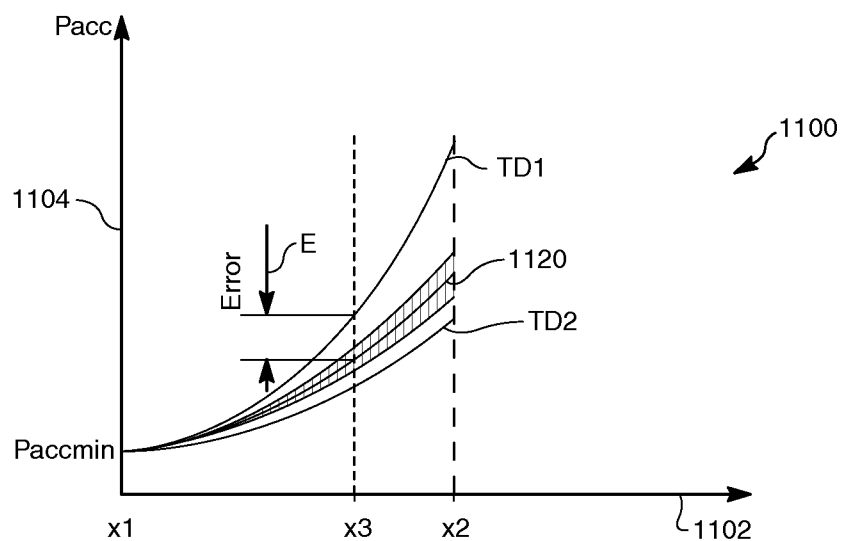


FIG. 7



HYDRAULIC ACCUMULATOR HEALTH MONITOR

RELATED APPLICATIONS

[0001] This application is based upon and claims the benefit of priority from U.S. Provisional Application No. 61/695,344 by Pengfei Ma et al., filed Aug. 31, 2013, the contents of which are expressly incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure relates to hydraulic accumulators and more particularly to monitoring and determining the health of the hydraulic accumulator.

BACKGROUND

[0003] Pre-charge pressure of a hydraulic accumulator needs to be periodically checked after installation in a hydraulic system to ensure operational health of the accumulator. Typical solutions for detecting the accumulator health involve connecting a gas pressure gauge and/or a modular kit to a gas valve of the hydraulic accumulator, when the machine is stopped and the fluid in the hydraulic accumulator is not pressurized. The gas pressure gauge provides a reading of the pre-charge pressure. Depending on such readings, the hydraulic accumulator is either re-charged or completely overhauled or replaced. Hence, typical solutions required physically connecting the hydraulic accumulator to the pressure gauge. However, the accumulator can be located on a machine such that it is difficult to access and couple the gas pressure gauge.

[0004] In one example, German Patent Number DE102005052640 relates to a method involving determination of a difference in accumulator volume using a flow regulator with constant adjustable flow rate and an actuating valve with preset response time. The method also involves determination of pressure values before and after the fluid withdrawal from a hydraulic accumulator using a pressure sensor based on its recalled calculated accumulator volume at an empty state.

SUMMARY OF THE DISCLOSURE

[0005] In one embodiment, a system to diagnose the operational health of a hydraulic accumulator is provided. The system can include a hydraulic actuator and a hydraulic accumulator selectively coupled to the hydraulic actuator. The hydraulic accumulator can be charged as a result of movement of the actuator. A pressure sensor can be associated with the hydraulic accumulator to determine an accumulator pressure. A controller can be in communication with the pressure sensor. The controller can determine a relationship between an actuator operational parameter associated with the movement of the actuator and the accumulator pressure. The controller can compare the relationship to a previously defined relationship (or range) to determine an error, if any, between the relationship and the previously defined relationship.

[0006] In another embodiment, a method of diagnosing an operational health of a hydraulic accumulator is provided. Another step may include moving an actuator to charge a hydraulic accumulator selectively coupled to the actuator. Another step may include storing an accumulator pressure during the movement of the actuator to define a relationship between an actuator operational parameter associated with the movement of the actuator and the accumulator pressure.

Another step may include comparing the relationship to a previously defined relationship to determine an error, if any, between the relationship and the previously defined relationship.

[0007] In another embodiment, a machine is provided having a pump, a hydraulic actuator selectively moved by fluid provided by the pump, and a hydraulic accumulator fluidly coupled to the hydraulic actuator. The hydraulic accumulator is configured to be charged with pressurized fluid resulting from movement of the actuator. A pressure sensor is associated with the hydraulic accumulator to determine an accumulator pressure. A controller is in communication with the pressure sensor. The controller is configured to determine a relationship between an actuator operational parameter associated with the movement of the actuator and the accumulator pressure, and compare the relationship to a previously defined relationship to determine an error, if any, between the determined relationship and the previously defined relationship. The degree of error may be associated with the operational health of the hydraulic accumulator.

[0008] Other features and aspects of this disclosure will be apparent from the following description and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 is a block diagram of an exemplary system having a hydraulic accumulator and a controller, according to one embodiment of the disclosure;

[0010] FIG. 2 is a diagrammatic view of the hydraulic accumulator in an initial state;

[0011] FIG. 3 is a diagrammatic view of the hydraulic accumulator at an intermediate state;

[0012] FIG. 4 is a diagrammatic illustration of an exemplary disclosed machine operating at a worksite with a haul vehicle;

[0013] FIG. 5 is a schematic illustration of an exemplary disclosed hydraulic control system that may be used with the machine of FIG. 4;

[0014] FIG. 6 is a diagram of a process of determining the health of an accumulator; and

[0015] FIG. 7 is a graphical view of change in accumulator pressure with respect to position of a machine during charging.

DETAILED DESCRIPTION

[0016] FIG. 1 illustrates an exemplary system **100** including a hydraulic accumulator **102**, a pressure sensor **104**, a fluid source **106** and a controller **108**, according to one embodiment of the present disclosure. The system **100** may be embodied in any machine such as excavators, wheel loaders, tractors and other machinery. The hydraulic accumulator **102** may be a piston-based accumulator, a bladder-based accumulator, membrane/spring-biased accumulator, or other kind of pressurized fluid storage device that can be selectively charged and discharged. One or more valves (not shown) may be associated with the system **100** to selectively control charging and discharging of the accumulator. For example, one or more valves may be open to permit charging and/or discharging of the accumulator, whereas one or more valves (same or different) may be closed to permit charging and/or discharging.

[0017] Hydraulic accumulator **102** may embody pressure vessels filled with a compressible gas that are configured to

store pressurized fluid for future use by the hydraulic system. The compressible gas may include, for example, nitrogen, argon, helium, or another appropriate compressible gas. As fluid in communication with the accumulator exceeds a predetermined pressure of the accumulator, the fluid may flow into accumulator to charge. Because the gas therein is compressible, it may act like a spring and compress as the fluid flows into the accumulator. When the pressure of the fluid drops below the predetermined pressure of the accumulator, the compressed gas may expand and urge the fluid from within the accumulator to exit or discharge.

[0018] As shown in FIGS. 2-3, one example of hydraulic accumulator 102 may include a first chamber 302 (FIG. 3), such as a working fluid or oil chamber, a second chamber 304, such as a compressible fluid or gas chamber, and a separator 306 disposed between the chambers 302, 304. The first chamber 302 may be configured to be filled with a first fluid. In one embodiment, the first fluid may include oil, lubricating fluid, or any other fluid associated with hydraulic machinery. The second chamber 304 of the hydraulic accumulator 102 may be filled with a gas or any other compressible fluid via a gas valve 308. In one embodiment, the gas may be nitrogen. The separator 306 of the hydraulic accumulator 102 may be configured to separate the first fluid and second chambers 302, 304 to keep the fluid contained therein substantially isolated from one another.

[0019] The hydraulic accumulator 102 may include a first end cap 310 associated with the second chamber 304 and a second end cap 312 associated with the first chamber 302. The separator 306 may be a piston having one or more seals 314 to reduce the risk of fluid from one chamber entering into the other chamber. The separator 306 is movable within the hydraulic accumulator 102 to reduce or increase the volume of the respective chambers. Additional seals 315 may be provided in the first end cap 310 and the second end cap 312 of the hydraulic accumulator 102. Similarly, in case of a bladder-based accumulator, the separator 306 may be flexible membrane or an expandable separator being movable between an expanded configuration and a compressible configuration. The hydraulic accumulator 102 is sized to have a pre-charge pressure capacity to pressurize accumulated fluid within the first chamber 302, e.g., for energy recovery, which is sequentially released from the first chamber 302 at the pressure associated with the charged pressure of the second chamber 304. The pre-charge pressure can be determined by the pressure capacity and difference between the first and second chambers 302, 304.

[0020] To determine the pressure associated with the hydraulic accumulator 102, the pressure sensor 104 may be connected upstream or downstream of the first chamber 302 of the hydraulic accumulator 102. The pressure sensor 104 may be configured to monitor and provide to the controller 108 pressure readings of the fluid in the first chamber 302 during charging and discharging of the hydraulic accumulator 102. In one embodiment, the pressure readings may either be provided continuously or after pre-determined intervals of time. In one example, the pressure sensor 104 can be a fluid or oil pressure sensor.

[0021] The first chamber 302 of the hydraulic accumulator 102 can be connected to the fluid source 106, such as a fixed or variable displacement hydraulic pump, or a hydraulic actuator as later described. The first chamber 302 of the hydraulic accumulator 102 is configured to receive and deliver fluid at a flow rate during accumulator charging and

discharging modes, respectively. Parameters related to the pump such as flow rate, flow direction, and the like may vary. It should be understood that any other device which may regulate a flow of the fluid may also be utilized. One or more valves may be associated with the first chamber 302 such that after discharging of the hydraulic accumulator 102, the valve is configured to prevent charging at specified periods, such as later described.

[0022] As shown in FIG. 1, the controller 108 may be connected to the pressure sensor 104. The controller 108 may be configured to receive and process the pressure readings taken by the pressure sensor 104. Moreover, the controller 108 may determine an approximate pre-charge pressure of the hydraulic accumulator 102. Also, the controller 108 may be configured to determine or estimate frictional forces associated with the separator 306 of the hydraulic accumulator 102. For example, determination of such frictional forces may be useful to determine the effectiveness of the seals 314 of a piston-based accumulator.

[0023] In one embodiment, the controller 108 may include a comparator 202 to diagnose a health of the hydraulic accumulator 102. The comparator 202 may compare at least one of the pre-charge pressure, the frictional forces with a pre-defined threshold range of pre-charge pressure and the frictional forces associated with the hydraulic accumulator 102 to diagnose the health of the hydraulic accumulator 102. In another embodiment, the comparator 202 may be an independent or separate module connected to the controller 108 by known methods.

[0024] The controller 108 and/or comparator 202 may include a processor unit, input and output ports, an electronic storage medium for executable programs and threshold values, random access memory, a data bus, and the like. The functionality of the controller 108 and/or comparator 202 may further include other activities not described herein. The controller 108 may include a memory, a secondary storage device, a clock, and one or more processors that cooperate to accomplish a task consistent with the present disclosure. Numerous commercially available microprocessors can be configured to perform the functions of the controller 108. It should be appreciated that controller 108 could readily embody a general machine controller capable of controlling numerous other functions of a machine. Various known circuits may be associated with controller 108, including signal-conditioning circuitry, communication circuitry, and other appropriate circuitry. It should also be appreciated that controller 108 may include one or more of an application-specific integrated circuit (ASIC), a field-programmable gate array (FPGA), a computer system, and a logic circuit configured to allow controller 108 to function in accordance with the present disclosure.

[0025] Also, the controller 108 and/or the comparator 202 may retrieve or store the pressure readings in a database 110. The database 110 may store historical data values related to the threshold range of pre-charge pressure and frictional forces of the hydraulic accumulator 102. The database 110 may utilize data structures, index files, or any other data storage and retrieval technique, without any limitation. It should be understood that the exemplary system 100 may include other components not described herein.

[0026] In one example, a process for determining the pre-charge pressure of the hydraulic accumulator 102. Initially, the first chamber 302 of the hydraulic accumulator 102 is connected to the fluid source 106 (such as, e.g., a pump or a

hydraulic actuator). Fluid pressure may be driven to a minimum working pressure or zero such as, e.g., by withdrawing the fluid from the first chamber 302 (that is, discharging fluid from the first chamber 302) such that the hydraulic accumulator 102 is in an minimum volume state as shown in FIG. 2. In the piston-based accumulator, at the minimum working pressure, the separator 306 of the hydraulic accumulator 102 may be in contact with walls of the first chamber 302. Hence, the first chamber 302 may be reduced to a minimum or zero volume state, while the second chamber 304 may be at a maximum volume state, resulting in a minimum working pressure. Here, the pressure readings of the fluid pressure of the first chamber 302 at a minimum or zero volume may be monitored by the pressure sensor 104.

[0027] In one example, the pre-charge pressure of the hydraulic accumulator 102 is defined as the pressure of the inert gas or compressible fluid filled in the second chamber 304 when the hydraulic accumulator 102 is in the minimum volume state. The fluid pressure recorded by the pressure sensor 104 at the minimum volume state is at a minimum working pressure or zero.

[0028] Subsequently, the hydraulic accumulator 102 may be charged by providing the fluid to the first chamber 302. FIG. 3 illustrates an intermediate state of the hydraulic accumulator 102 during the charging or discharging cycle. During charging, the fluid is provided to the first chamber 302 by the fluid source 106, at the pre-determined flow rate via a port 316 located near the first chamber 302. In one embodiment, the pump may be driven to minimum or low flow such as, e.g., about 30 lpm or less. Substantially faster rates can be more difficult to measure and control due to temperature increase and other factors. The pressure readings of the fluid pressure may be simultaneously monitored by the pressure sensor 104.

[0029] As the fluid is filled in the first chamber 302, the separator 306 is pushed towards the second chamber 304 of the hydraulic accumulator 102. For a certain interval of time, the pressure of the fluid may continue to remain zero or minimal until the frictional forces associated with the separator 306 are overcome and the separator 306 begins to move away from the second end cap 312.

[0030] When the separator 306 starts moving, the volume associated with the first chamber 302 increases as the fluid fills into the first chamber 302, causing a corresponding decrease in the volume associated with the compressible fluid filled in the second chamber 304. At this time, the pressure of the fluid may change at a first rate and then transition to a second rate. It may be observed that the first rate of change in the fluid pressure with time is greater than the second rate of change in the fluid pressure with time, as a rapid change to the first rate and subsequent gradual transitioning to the second rate.

[0031] Subsequently, the controller 108 may determine an approximate pre-charge pressure of the hydraulic accumulator 102 based on the monitored transition pressure. In one embodiment, the determination may be based on the second transition pressure. In another embodiment, the determination of the approximate pre-charge pressure of the hydraulic accumulator 102 may be based on a correlation of the first and second transition pressures. The correlation may include any mathematical function of the first and second transition pressure readings or the derivation of the approximate pre-charge pressure based on statistical analysis of the first and second transition pressure readings. In one embodiment, the controller 108 may calculate an average of the first and second

transition pressures to determine the approximate pre-charge pressure of the hydraulic accumulator 102.

[0032] It should be understood that the determined approximate pre-charge pressure may be substantially equivalent to the pressure of the hydraulic accumulator 102 at the minimum volume state. The rate of change of the gas pressure with time during charging and discharging of the hydraulic accumulator 102 may be proportional to the comparatively slower rate of change the fluid pressure with time recorded by the pressure sensor 104. The slower rates may be easier to read and control.

[0033] The controller 108 may also be adapted to notify an operator if at least one of the determined pre-charge pressure and the frictional forces is not within the predefined threshold range. It should be understood that the notification may be provided to indicate that the determined approximate pre-charge pressure and/or the frictional forces of the hydraulic accumulator 102 may either be lower or higher than acceptable performance. Moreover, the notification provided by the controller 108 may be a visual feedback like an alert message, an audio feedback like a warning alarm, or any other type of feedback. Based on the notification, one or more remedial actions such as re-charging of the hydraulic accumulator 102, overhauling of the hydraulic accumulator 102 or replacement of the seals 314 in case of the piston-based accumulator may be performed.

[0034] The accumulator 102 can be fluidly coupled to a hydraulic actuator circuit of a machine, such as, e.g., a swing circuit or a hydraulic cylinder circuit. FIG. 4 illustrates an exemplary machine 610 having multiple systems and components that cooperate to excavate and load earthen material onto a nearby haul vehicle 612. In the depicted example, machine 610 is a hydraulic excavator having a swing circuit with a swing motor. It is contemplated, however, that machine 610 could alternatively embody another swing-type excavation or material handling machine, such as a backhoe, a front shovel, a dragline excavator, or another similar machine. Alternatively, the machine could have a hydraulic cylinder circuit (boom, stick, and/or tool circuit) coupled to the accumulator, such as an excavator, a wheel loader, or another similar machine. In other words, a hydraulic actuator, such as a swing motor or a hydraulic cylinder, may be coupled to the accumulator. Machine 610 may include, among other things, an implement system 614 configured to move a work tool 616 between a dig location 618 within a trench or at a pile, and a dump location 620, for example over haul vehicle 612. Machine 610 may also include an operator station 622 for manual control of implement system 614. It is contemplated that machine 610 may perform operations other than truck loading, if desired, such as craning, trenching, and material handling.

[0035] Implement system 614 may include a linkage structure acted on by fluid actuators to move work tool 616. Specifically, implement system 614 may include a boom 624 that is vertically pivotal relative to a work surface 626 by one or more adjacent, double-acting, hydraulic cylinders 628 (only one shown in FIG. 6). Implement system 614 may also include a stick 630 that is vertically pivotal about a horizontal pivot axis 632 relative to boom 624 by a double-acting, hydraulic cylinder 636. Implement system 614 may further include a double-acting, hydraulic cylinder 638 that is operatively connected to work tool 616 to tilt work tool 616 vertically about a horizontal pivot axis 640 relative to stick 630. Boom 624 may be pivotally connected to a frame 642 of machine 610,

while frame 642 may be pivotally connected to an undercarriage member 644 and swung about a vertical axis 646 by a swing motor 649. Stick 630 may pivotally connect work tool 616 to boom 624 by way of pivot axes 632 and 640. It is contemplated that a greater or lesser number of fluid actuators may be included within implement system 614 and connected in a manner other than described above, if desired.

[0036] Numerous different work tools 616 may be attachable to a single machine 610 and controllable via operator station 622. Work tool 616 may include any device used to perform a particular task such as, for example, a bucket, a fork arrangement, a blade, a shovel, or any other task-performing device known in the art. Although connected in the embodiment of FIG. 4 to lift, swing, and tilt relative to machine 610, work tool 616 may alternatively or additionally rotate, slide, extend, open and close, or move in another manner known in the art.

[0037] Operator station 622 may be configured to receive input from a machine operator indicative of a desired work tool movement. Specifically, operator station 622 may include one or more input devices 648 embodied, for example, as single or multi-axis joysticks located proximal an operator seat (not shown). Input devices 648 may be proportional-type controllers configured to position and/or orient work tool 616 by producing a work tool position signal that is indicative of a desired work tool speed and/or force in a particular direction. The position signal may be used to actuate any one or more of hydraulic cylinders 628, 636, 638 and/or swing motor 649. It is contemplated that different input devices may alternatively or additionally be included within operator station 622 such as, for example, wheels, knobs, push-pull devices, switches, pedals, and other operator input devices known in the art.

[0038] As illustrated in FIG. 5, machine 610 may include a hydraulic control system 650 having a plurality of fluid components that cooperate to move implement system 614 (referring to FIG. 4). In particular, hydraulic control system 650 may include a first circuit 652 associated with swing motor 649, and at least a second circuit 654 associated with hydraulic cylinders 628, 636, and 638. First circuit 652 may include, among other things, a swing control valve 656 connected to regulate a flow of pressurized fluid from a pump 658 to swing motor 649 and from swing motor 649 to a low-pressure tank 660 to cause a swinging movement of work tool 616 about axis 646 (referring to FIG. 4) in accordance with an operator request received via input device 648. Second circuit 654 may include similar control valves, for example a boom control valve (not shown), a stick control valve (not shown), a tool control valve (not shown), a travel control valve (not shown), and/or an auxiliary control valve connected in parallel to receive pressurized fluid from pump 658 and to discharge waste fluid to tank 660, thereby regulating the corresponding actuators (e.g., hydraulic cylinders 628, 636, and 638).

[0039] Swing motor 649 may include a housing 662 at least partially forming a first and a second chamber (not shown) located to either side of an impeller 664. When the first chamber is connected to an output of pump 658 (e.g., via a first chamber passage 666 formed within housing 662) and the second chamber is connected to tank 660 (e.g., via a second chamber passage 668 formed within housing 662), impeller 664 may be driven to rotate in a first direction (shown in FIG. 5). Conversely, when the first chamber is connected to tank 660 via first chamber passage 666 and the second chamber is connected to pump 658 via second chamber passage

668, impeller 664 may be driven to rotate in an opposite direction (not shown). The flow rate of fluid through impeller 664 may relate to a rotational speed of swing motor 649, while a pressure differential across impeller 664 may relate to an output torque thereof.

[0040] Pump 658 may be configured to draw fluid from tank 660 via an inlet passage 680, pressurize the fluid to a desired level, and discharge the fluid to first and second circuits 652, 654 via a discharge passage 682. A check valve 683 may be disposed within discharge passage 682, if desired, to provide for a unidirectional flow of pressurized fluid from pump 658 into first and second circuits 652, 654. Pump 658 may embody, for example, a variable displacement pump (shown in FIG. 5), a fixed displacement pump, or another source known in the art. Pump 658 may be drivably connected to a power source (not shown) of machine 610 by, for example, a countershaft (not shown), a belt (not shown), an electrical circuit (not shown), or in another suitable manner. Alternatively, pump 658 may be indirectly connected to the power source of machine 610 via a torque converter, a reduction gear box, an electrical circuit, or in any other suitable manner. Pump 658 may produce a stream of pressurized fluid having a pressure level and/or a flow rate determined, at least in part, by demands of the actuators within first and second circuits 652, 654 that correspond with operator requested movements. Discharge passage 682 may be connected within first circuit 652 to first and second chamber passages 666, 668 via swing control valve 656 and first and second chamber conduits 684, 686, respectively, which extend between swing control valve 656 and swing motor 649.

[0041] Tank 660 may constitute a reservoir configured to hold a low-pressure supply of fluid. The fluid may include, for example, a dedicated hydraulic oil, an engine lubrication oil, a transmission lubrication oil, or any other fluid known in the art. One or more hydraulic systems within machine 610 may draw fluid from and return fluid to tank 660. It is contemplated that hydraulic control system 650 may be connected to multiple separate fluid tanks or to a single tank, as desired. Tank 660 may be fluidly connected to swing control valve 656 via a drain passage 688, and to first and second chamber passages 666, 668 via swing control valve 656 and first and second chamber conduits 684, 686, respectively. Tank 660 may also be connected to low-pressure passage 688. A check valve 690 may be disposed within drain passage 688, if desired, to promote a unidirectional flow of fluid into tank 660.

[0042] Swing control valve 656 may have one or more elements that are movable to control the rotation of swing motor 649 and corresponding swinging motion of implement system 614. Swing control valve 656 may include an element configured as spool, or independent metering valve (IMV) configuration.

[0043] To drive swing motor 649 to rotate in a first direction (shown in FIG. 5), swing control valve 656 can have a first configuration to allow pressurized fluid from pump 658 to enter the first chamber of swing motor 649 via discharge passage 682 and first chamber conduit 684, and to allow fluid from the second chamber of swing motor 649 to drain to tank 660 via second chamber conduit 686 and drain passage 688. To drive swing motor 649 to rotate in the opposite direction, swing control valve 656 can have a second configuration to communicate the second chamber of swing motor 649 with pressurized fluid from pump 658, and to allow draining of fluid from the first chamber of swing motor 649 to tank 660. It is contemplated that both the supply and drain functions of

swing control valve 656 may alternatively be performed by a single valve element associated with the first chamber and a single valve element associated with the second chamber, or by a single valve element associated with both the first and second chambers, if desired.

[0044] Controller 700 (an example of previously referenced controller 108 in FIG. 1) may be in communication with the different components of hydraulic control system 650 to regulate operations of machine 610. For example, controller 700 may be in communication with the element(s) of swing control valve 656 in first circuit 652 and with the element(s) of control valves (not shown) associated with second circuit 654. Based on various operator input and monitored parameters, controller 700 may be configured to selectively activate the different control valves in a coordinated manner to efficiently carry out operator requested movements of implement system 614. Controller 700 may be connected to input device 648 such that current position of the input device is an input for the controller. Based on the current position of input device 648, the controller may determine and command the appropriate operation of the machine components for a desired task.

[0045] Hydraulic control system 650 may be fitted with an energy recovery arrangement 704 that is in communication with at least first circuit 652 and configured to selectively extract and recover energy from waste fluid that is discharged from swing motor 649. Energy recovery arrangement (ERA) 704 may include, among other things, a recovery valve block (RVB) 706 that is fluidly connectable between pump 658 and swing motor 649, an accumulator 708 (an example of previously referenced accumulator 102 in FIG. 1) configured to selectively communicate with swing motor 649 via RVB 706. In the disclosed embodiment, RVB 706 may be fixedly and mechanically connectable to one or both of swing control valve 656 and swing motor 649, for example directly to housing 662 and/or directly to housing 697. RVB 706 may include a first passage 712 fluidly connectable to first chamber conduit 684, and a second passage 714 fluidly connectable to second chamber conduit 686. Accumulator 708 may be fluidly connected to RVB 706 via a conduit 716.

[0046] RVB 706 may house a selector valve 720, a charge valve 722 associated with accumulator 708, and a discharge valve 724 associated with accumulator 708 and disposed in parallel with charge valve 722. Selector valve 720 may automatically fluidly communicate one of first and second passages 712, 714 with charge and discharge valves 722, 724 based on a pressure of first and second passages 712, 714. Charge and discharge valves 722, 724 may be selectively movable in response to commands from controller 700 to fluidly communicate accumulator 708 with selector valve 720 for fluid charging and discharging purposes.

[0047] Selector valve 720 may be a pilot-operated, 2-position, 3-way valve that is automatically movable in response to fluid pressures in first and second passages 712, 714 (i.e., in response to a fluid pressures within the first and second chambers of swing motor 649). In particular, selector valve 720 may include a valve element 726 that is movable from a first position (shown in FIG. 5) at which first passage 712 is fluidly connected to charge and discharge valves 722, 724 via an internal passage 728, toward a second position (not shown) at which second passage 714 is fluid connected to charge and discharge valves 722, 724 via passage 728. When first passage 712 is fluidly connected to charge and discharge valves 722, 724 via passage 728, fluid flow through second passage

714 may be inhibited by selector valve 720 and vice versa. First and second pilot passages 730, 732 may communicate fluid from first and second passages 712, 714 to opposing ends of valve element 726 such that a higher-pressure one of first or second passages 712, 714 may cause valve element 726 to move and fluidly connect the corresponding passage with charge and discharge valves 722, 724 via passage 728.

[0048] Charge valve 722 and discharge valve 724 may be a solenoid-operated, variable position, 2-way valve that is movable in response to a command from controller 700 to allow fluid from passage 728 to enter or exit accumulator 708. In particular, each of the charge and discharge valves 722, 724 may include a valve element 734 or 738, respectively. For instance, the valve element 734 is movable between a first position (shown in FIG. 5) at which fluid flow from passage 728 into accumulator 708 is inhibited, and a second position (not shown) at which passage 728 is fluidly connected to accumulator 708. When valve element 734 is away from the first position (i.e., in the second position or in an intermediate position between the first and second positions) and a fluid pressure within passage 728 exceeds a fluid pressure within accumulator 708, fluid from passage 728 may fill (i.e., charge) accumulator 708. Valve element 734 may be spring-biased toward the first position and movable in response to a command from controller 700 to any position between the first and second positions to thereby vary a flow rate of fluid from passage 728 into accumulator 708. A check valve 736 may be disposed between charge valve 722 and accumulator 708 to provide for a unidirectional flow of fluid into accumulator 708 via charge valve 722.

[0049] Valve element 738 is movable between a first position (not shown) at which fluid flow from accumulator 708 into passage 728 is inhibited, and a second position (shown in FIG. 5) at which accumulator 708 is fluidly connected to passage 728. When valve element 738 is away from the first position (i.e., in the second position or in an intermediate position between the first and second positions) and a fluid pressure within accumulator 708 exceeds a fluid pressure within passage 728, fluid from accumulator 708 may flow into passage 728. Valve element 138 may be spring-biased toward the first position and movable in response to a command from controller 700 to any position between the first and second positions to thereby vary a flow rate of fluid from accumulator 708 into passage 728. A check valve 740 may be disposed between accumulator 708 and discharge valve 724 to provide for a unidirectional flow of fluid from accumulator 708 into passage 728 via discharge valve 724.

[0050] The operational parameters monitored by controller 700, in one embodiment, may include a pressure of fluid within first and/or second circuits 652, 654. For example, one or more pressure sensors 739 may be strategically located within first chamber and/or second chamber conduits 684, 686 to sense a pressure of the respective passages and generate a corresponding signal indicative of the pressure directed to controller 700. It is contemplated that any number of pressure sensors 739 may be placed in any location within first and/or second circuits 652, 654, as desired. It is further contemplated that other operational parameters such as, for example, speeds, temperatures, viscosities, densities, etc. may also or alternatively be monitored and used to regulate operation of hydraulic control system 650, if desired.

[0051] Moreover, operational parameters monitored by controller 700, in one embodiment, may include accumulator pressure. For example, an accumulator pressure sensor 741

may be associated with accumulator 708 and configured to generate signals indicative of a pressure of fluid within accumulator 708, if desired. The accumulator pressure sensor 741 may be disposed between accumulator 708 and discharge valve 724. It is contemplated, however, that the accumulator pressure sensor 741 may alternatively be disposed between accumulator 708 and charge valve 722 or directly connected to accumulator 708 in some fashion, if desired. Signals from pressure sensors 739 and accumulator pressure sensor 741 may be directed to controller 700 for use in regulating operation of charge and/or discharge valves 722, 724 and/or for use in monitoring the operational health of the accumulator. In one example, the accumulator pressure sensor 741 is an example of the pressure sensor 104 shown in FIG. 1.

[0052] Controller 700 may be configured to selectively cause accumulator 708 to charge and discharge, thereby improving performance of machine 610. In particular, a typical swinging motion of implement system 614 instituted by swing motor 649 may consist of segments of time during which swing motor 649 is accelerating a swinging movement of implement system 614, and segments of time during which swing motor 649 is decelerating the swinging movement of implement system 614. The acceleration segments may require significant energy from swing motor 649 that is conventionally realized by way of pressurized fluid supplied to swing motor 649 by pump 658, while the deceleration segments may produce significant energy in the form of pressurized fluid that is conventionally wasted through discharge to tank 660. Both the acceleration and the deceleration segments may require swing motor 649 to convert significant amounts of hydraulic energy to swing kinetic energy, and vice versa. After pressurized fluid passes through swing motor 649, however, it still contains a large amount of energy. If the fluid passing through swing motor 649 is selectively collected within accumulator 708 during the deceleration segments, this energy can then be returned to (i.e., discharged) and reused by swing motor 649 during the ensuing acceleration segments. Swing motor 649 can be assisted during the acceleration segments by selectively causing accumulator 708 to discharge pressurized fluid into the higher-pressure chamber of swing motor 649 (via discharge valve 724, passage 728, selector valve 720, and the appropriate one of first and second chamber conduits 684, 686), alone or together with high-pressure fluid from pump 658, thereby propelling swing motor 649 at the same or greater rate with less pump power than otherwise possible via pump 658 alone. Swing motor 649 can be assisted during the deceleration segments by selectively causing accumulator 708 to charge with fluid exiting swing motor 649, thereby providing additional resistance to the motion of swing motor 649 and lowering a restriction and cooling requirement of the fluid exiting swing motor 649. In other examples, the stored energized fluid in the accumulator 708 can be directed to other functions, such as a second hydraulic circuit where the stored energized fluid can be reused.

[0053] The actuator operational parameters may also be monitored by controller 700. For example, sensor(s) 743 may be associated with the generally horizontal swinging motion of work tool 616 imparted by swing motor 649 (i.e., the motion of frame 642 relative to undercarriage member 644). For example, sensor 743 may embody a rotational position or speed sensor associated with the operation of swing motor 649, an angular position or speed sensor associated with the pivot connection between frame 642 and undercarriage mem-

ber 644, a local or global coordinate position or speed sensor associated with any linkage member connecting work tool 616 to undercarriage member 644 or with work tool 616 itself, a displacement sensor associated with movement of input device 648, or any other type of sensor known in the art that may generate a signal indicative of a swing position, speed, acceleration, force, or other swing-related parameter of machine 610. The signal generated by sensor(s) 743 may be sent to and recorded by controller 700 during each excavation work cycle. It is contemplated that controller 700 may derive a swing speed based on a position signal from sensor 743 and an elapsed period of time, if desired. In another example, the controller 700 may determine a position (angular or linear—depending on the actuator) during a full or partial actuation cycle (either swing or stroke cycle).

[0054] Alternatively or additionally, sensor(s) 743 may be associated with the vertical pivoting motion of work tool 616 imparted by hydraulic cylinders 628 (i.e., associated with the lifting and lowering motions of boom 624 relative to frame 642). Specifically, sensor 743 may be an angular position or speed sensor associated with a pivot joint between boom 624 and frame 642, a displacement sensor associated with hydraulic cylinders 628, a local or global coordinate position or speed sensor associated with any linkage member connecting work tool 616 to frame 642 or with work tool 616 itself, a displacement sensor associated with movement of input device 648, or any other type of sensor known in the art that may generate a signal indicative of a pivoting position or speed of boom 624. It is contemplated that controller 700 may derive a pivot speed based on a position signal from sensor 743 and an elapsed period of time, if desired. Again, sensor may be also associated with the hydraulic cylinder to measure acceleration or force.

[0055] In yet an additional embodiment, sensor(s) 743 may be associated with the tilting force of work tool 616 imparted by hydraulic cylinder 638. Specifically, sensor 743 may be a pressure sensor associated with one or more chambers within hydraulic cylinder 638 or any other type of sensor known in the art that may generate a signal indicative of a tilting force of machine 610 generated during a dig and dump operation of work tool 616. Signals from pressure sensors 743 may be directed to controller 700 for use in regulating operation of charge and/or discharge valves 722, 724 and/or for use in monitoring the operational health of the accumulator.

[0056] FIG. 6 depicts a diagram of a process 1000 for determining the operability or health of the accumulator. Before initiating the process, it is desirable to park the machine on level ground for consistent readings. Further, the implement and/or linkages of the machine may be placed in a predefined position. At step 1010, the actuator can be moved in a manner to direct pressurized fluid from a chamber of the actuator to the accumulator for charging the accumulator to a desired pressure, such as a fully charged working pressure (Pacc). The controller may command appropriate machine components for this operation. It would be desirable to maintain the implement and/or linkages of the machine at the predefined position during the movement of the actuator. Moreover, it would be desirable to move the actuator at full speed. Prior to step 1010, the accumulator can be fully discharged to a minimum working pressure (Paccmin).

[0057] The controller 700 may record and store the value of the minimum working pressure. For instance, one or more maps relating the accumulator pressure and the actuator position, speed, acceleration and/or force, for hydraulic cylinders

and/or swing motors may be stored in the memory of controller 700. Each of these maps may include a collection of data in the form of tables, graphs, and/or equations. In one example, desired accumulator pressure range and actuator operational parameter (position, speed, acceleration, or force) may form the coordinate axis of a 2-D table for monitoring the accumulator health (see FIG. 7). The charging rate and/or discharging rate of the accumulator at the desired actuator operational parameter (position, speed, acceleration, or force) may be related in another separate 2-D map or together with the desired actuator operational parameter in a single 3-D map. Controller 700 may be configured to allow the operator to directly modify these maps and/or to select specific maps from available relationship maps stored in the memory of controller 700 for desired accumulator health monitoring. It is contemplated that the maps may additionally or alternatively be automatically selectable based on modes of machine operation.

[0058] At step 1020, a relationship can be determined (e.g., with the controller) by continuously recording the actuator operational parameter and the accumulator pressure during charging of the accumulator. The relationship could also be determined during discharging of the accumulator, in which such case the cycle may begin with at least a partially, if not fully, charged accumulator, as appreciated by those skilled in the art. For example, the relationship may be a single point plot. Alternatively, the relationship may be series of single points on a plot, which may even be characterized to define a charging curve can be determined (e.g., with the controller) by continuously recording the actuator operational parameter and the accumulator pressure. This can show the relationship of the rise in accumulator pressure from minimum working pressure to the fully charged working pressure and an actuator operational parameter, such as, e.g., the position of the actuator, during the charging of the accumulator. At step 1030, the determined relationship, such as, e.g., the charging curve, can be compared (e.g., with the controller) to a previously defined relationship or range to determine the amount of error, if any, between the relationships or range at a selected pressure or position (see, e.g., FIG. 7). The previously defined charging curve or range may be preprogrammed within the memory of the controller at the manufacturing facility, programmed within the memory during operation of the machine, downloaded to the memory from an external controller, or other methods known in the art.

[0059] If the error is outside of a predefined threshold range (i.e., the accumulator is not healthy), the controller can send a signal to the operator for notification of a potential accumulator issue. The notification provided by the controller may be a visual feedback like an alert message, an audio feedback like a warning alarm, or any other type of feedback. Based on the notification, one or more remedial actions such as re-charging of the hydraulic accumulator 708, overhauling of the hydraulic accumulator 708 or replacement of its seals in case of the piston-based accumulator may be performed. However, if the error is inside a predefined threshold range (i.e., the accumulator is healthy), the controller can send a signal to the operator for notification of a healthy accumulator or send no signal.

INDUSTRIAL APPLICABILITY

[0060] On usage, the hydraulic accumulator 102 or 708 may lose the pre-charge pressure due to a variety of reasons. For example, reasons may be component failure such as, e.g.,

piston seal failure in the piston-based accumulator or bladder failure in the bladder-based accumulator. Further, gain in pre-charge pressure can be attributed by leakage of fluid between the chambers of the accumulator, such as, e.g., from the first chamber 302 of accumulator 102 into the second chamber 304 or from chamber to gas chamber as an example. Accordingly, if the pre-charge pressure is too high or too low, then the hydraulic accumulator 102 or 708 may require servicing or overhauling. Hence, the health of the hydraulic accumulator 102 or 708 may require to be checked once every few months or at least once a year after installation in a machine.

[0061] Determining the health of the accumulator 102 or 708 may overcome some of the problems of connecting a pressure gauge and/or a modular kit to the gas valve, such as, e.g., valve 308 of the hydraulic accumulator 102, where accessibility is an issue, or where operator or service time is unnecessarily required. The systems and methods described herein may relate to an automated process for monitoring and diagnosing the health of the hydraulic accumulator 102 or 708, without requiring physical connection to a gas valve, i.e., without use of a gas gauge or sensor. The systems and methods described herein may determine an approximate pre-charge pressure and/or frictional values associated with the separator of the hydraulic accumulator 102 or 708 to improve diagnosis of the accumulator health.

[0062] The diagnosis of the health and the determination of the approximate pre-charge pressure and/or the frictional values may be performed in real time by monitoring the pressure readings provided by the pressure sensor 104 or 741, and subsequently performing the necessary processing of the readings required for the determination.

[0063] The controller 108 or 700 may determine if the approximate pre-charge pressure determined by the controller lies within the predefined threshold range. If the approximate pre-charge pressure is either too high or too low, that is, outside the range, then the operator may be suitably notified. Based on the notification, one or more remedial actions such as re-charging of the hydraulic accumulator 102 or 708 replacement of the seal may be performed.

[0064] In case of the piston-based accumulator, the systems and methods described herein may determine the seal effectiveness of the separator 306. If the determined frictional values of the separator, such as, e.g., the separator 306, lie within the predefined threshold range it may be indicative that the seals of the hydraulic accumulator 102 or 708 are in an acceptable condition and its seals may be retained. For example, loss in pre-charge pressure can be due to component failure such as piston seal failure or bladder failure such that fluid leakage occurs from the second chamber to the first chamber, or gas leakage from the chamber to the atmosphere. Gain in pre-charge pressure can be due to fluid leakage from the first chamber into the second chamber.

[0065] The exemplary process 1000 for determining the operational health of a hydraulic accumulator is shown in FIG. 6. As previously mentioned, the accumulator could be tied to various embodiments of actuators such as, e.g., a swing motor or a hydraulic cylinder. For example, the process can be applied to the machine 610 with the swing motor 649 and the accumulator 708 shown in FIGS. 4-5. The machine 610 can be preferably park on level ground, with the linkage preferably at a predefined position and the stick 630 preferably positioned vertically or fully extended. For a swing motor, the operator can move the input device 648 to a position to rotate

the machine **610** at a desired swing speed, such as full swing speed, between two points of the actuator operational parameters. For example, the swing motor **649** can rotate between first and second angular positions **x1**, **x2** in order to fully discharge the accumulator **708** to a first pressure or the minimum working pressure (Paccmin) as sensed by the accumulator pressure sensor **741**. The controller **700** may record and store the value of the minimum working pressure. After rotating the machine **610**, the operator can quickly pull the input device **648** back to neutral. The controller **700** can continuously record the swing speed and/or the relative angular position and the accumulator charge pressure during swing travel between the first and second angular positions **x1**, **x2** to a second pressure, such as, e.g., the fully charged working pressure (Pacc) to define a charge curve (step **1010** and step **1020**).

[0066] For a hydraulic cylinder, the operator can move the input device **648** to a position to move the machine linkage at a desired speed between two points of the actuator operational parameters. For example, after fully discharging the accumulator, the hydraulic cylinder **628** can be moved between first and second linear positions. The controller **700** may record and store the value of the minimum working pressure, and the controller **700** can continuously record the relative linear position and the accumulator charge pressure during movement between the first and second positions to a second pressure, such as, e.g., the fully charged working pressure (Pacc) to define a charge curve.

[0067] Returning to the swing motor configuration, the charge curve can be determined to show the relationship of the rise in accumulator pressure from minimum working pressure (Paccmin) to the fully charged working pressure (Pacc) and the angular position change of the swing motor **649** during the charging of the accumulator **708**. Moreover, FIG. 7 is a representative plot **1100** showing the relationship between the actuator operational parameter **1102** (shown as swing angular position) and the accumulator pressure **1104** during charging. The determined charge curve, for example, curve TD1, can be compared to a previously defined charge curve **1120** at a selected operational parameter such as angular position **x3** to determine the degree of error E between the curves TD1 and **1120**, if any, (see step **1030**). If the error is outside of a predefined threshold range such as, e.g., plus or minus about 10-20% of previously defined charge curve **1120** (i.e., the accumulator **708** can be determined to be not healthy), the controller **700** can send a signal to the operator for notification of a potential accumulator issue. Warning strategies can be implemented to notify the operator of degree of failure and when to service accumulator. However, if the error is inside a predefined threshold range (i.e., the accumulator can be determined to be healthy), the controller **700** can send a signal to the operator for notification of a healthy accumulator or send no signal. FIG. 7 depicts an exemplary determined curve TD1 greater than the previously defined threshold charge curve or range **1120** which may suggest fluid leakage from the first chamber **302** into the second chamber **304**; and an exemplary determined curve TD2 that is less than the previously defined threshold charge curve or range **1120** which may suggest fluid leakage from the gas chamber into the oil chamber, or into the atmosphere.

[0068] While aspects of the present disclosure have been particularly shown and described with reference to the embodiments above, it will be understood by those skilled in the art that various additional embodiments may be contemplated

by the modification of the disclosed machines, systems and methods without departing from the spirit and scope of what is disclosed. Such embodiments should be understood to fall within the scope of the present disclosure as determined based upon the claims and any equivalents thereof.

What is claimed is:

1. A system to diagnose a health of a hydraulic accumulator, the system comprising:
 - a hydraulic actuator;
 - a hydraulic accumulator fluidly coupled to the hydraulic actuator, wherein the hydraulic accumulator is configured to be charged from movement of the actuator;
 - a pressure sensor associated with the hydraulic accumulator to determine an accumulator pressure; and
 - a controller in communication with the pressure sensor, the controller configured to:
 - determine a relationship between an actuator operational parameter associated with the movement of the actuator and the accumulator pressure; and
 - compare the relationship to a previously defined relationship to determine an error, if any, between the determined relationship and the previously defined relationship.
2. The system of claim 1, wherein the controller configured to:
 - determine a charge curve based on the relationship between the actuator operational parameter associated with a movement of the actuator and the accumulator pressure; and
 - compare the charge curve to a previously defined charge curve to determine an error between the charge curve and the previously defined charge curve.
3. The system of claim 1, wherein the actuator is a swing motor.
4. The system of claim 3, wherein the actuator operational parameter is a swing angular position.
5. The system of claim 3, wherein the actuator operational parameter is a swing angular speed.
6. The system of claim 1, wherein the controller is configured to notify an operator if the error is outside a predefined threshold range.
7. The system of claim 1, wherein the actuator is a hydraulic cylinder.
8. The system of claim 7, wherein the actuator operational parameter is a linear position of the hydraulic cylinder.
9. The system of claim 7, wherein the actuator operational parameter is a speed of the hydraulic cylinder.
10. The system of claim 1, wherein a valve is fluidly coupled between the actuator and the hydraulic accumulator for selective charging of the hydraulic accumulator.
11. A method of diagnosing an operational health of a hydraulic accumulator, the method comprising:
 - moving a hydraulic actuator to charge a hydraulic accumulator fluidly coupled to the actuator,
 - storing an accumulator pressure during the movement of the actuator;
 - determining a relationship between an actuator operational parameter associated with the movement of the actuator and the accumulator pressure; and
 - comparing the determined relationship to a previously defined relationship to determine an error, if any, between the determined relationship and the previously defined relationship.

12. The method of claim **11**, further comprising:
determining a charge curve based on the relationship between the actuator operational parameter associated with a movement of the actuator and the accumulator pressure; and
comparing the charge curve to a previously defined charge curve to determine an error between the charge curve and the previously defined charge curve.

13. The method of claim **11**, wherein the moving an actuator to a position step includes rotating a swing motor between a first position and a second position.

14. The method of claim **13**, wherein the actuator operational parameter includes a swing angular position.

15. The method of claim **11**, further including reducing the hydraulic accumulator to a minimum accumulator pressure prior to the moving step.

16. The method of claim **11**, further including notifying an operator if the error is outside a predefined threshold range about the relationship.

17. The method of claim **11**, wherein the moving an actuator to a position step includes moving a hydraulic cylinder between a first position and a second position.

18. The method of claim **17**, wherein the actuator operational parameter includes a linear position.

19. A machine comprising:

a pump;

a hydraulic actuator selectively moved by fluid provided by the pump;

a hydraulic accumulator fluidly coupled to the hydraulic actuator, wherein the hydraulic accumulator is configured to be charged with pressurized fluid resulting from movement of the actuator;

a pressure sensor associated with the hydraulic accumulator to determine an accumulator pressure; and

a controller in communication with the pressure sensor, the controller configured to:

determine a relationship between an actuator operational parameter associated with the movement of the actuator and the accumulator pressure; and

compare the relationship to a previously defined relationship to determine an error, if any, between the determined relationship and the previously defined relationship.

20. The machine of claim **19**, wherein the hydraulic actuator is a hydraulic swing motor, and the actuator operational parameter is a swing angular position.

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