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Description

PUMP SYSTEM HAVING OPEN-LOOP TORQUE CONTROL

Technical Field

The present disclosure relates generally to a pump system, and
5 more particularly, to a pump system having open-loop torque control.

Background

Hydraulic tool systems typically employ multiple actuators
provided with high-pressure fluid from a common pump. In order to efficiently
accommodate the different flow and/or pressure requirements of the individual
10 actuators, the pump of these systems generally has a variable displacement. That
is, based on the individual and/or combined flow and pressure requirements of
the actuators, the displacement of the pump changes to meet demands of the
actuators while remaining within torque absorption limitations placed on the
pump by an associated engine.

15 Generally, one or both of the pump's displacement and discharge
pressure are measured by different sensors, and an associated controller
responsively commands a corresponding displacement change to manage torque
absorption. An exemplary pump of this type is described in U.S. Patent No.
5,515,829 that issued to Wear et al. on 14 May 1996 ("the '829 patent").

20 Although the pump described above may be adequate for many
applications, it may also require valuable computing time from the controller and
multiple feedback loops to properly maintain a desired torque absorption as
displacement and pressure change. The multiple feedback loops can affect a
responsiveness of the pump and possibly cause pump and/or engine instabilities.
25 In addition, the sensors utilized for control of the pump may add unnecessary cost
and complexity to the system.

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The disclosed pump system is directed to overcoming one or more of the problems set forth above and/or other problems of the prior art.

Summary

In one aspect, the present disclosure is directed to a pump system.

5 The pump system may include a pump with a displacement that is variable, and an actuator movable to adjust the displacement of the pump. The pump system may also include an electro-hydraulic valve fluidly connected to the actuator and configured to control movement of the actuator, and a variable resistor mechanically connected to at least one of the actuator and the pump. The
10 variable resistor may be adjustable by movement of the at least one of the actuator and the pump to vary a current passing through the electro-hydraulic valve.

In another aspect, the present disclosure is directed to method of controlling a pump. The method may include operating the pump to pressurize a
15 fluid, and generating an electronic signal indicative of a command to adjust a displacement of the pump. The method may also include hydro-mechanically adjusting the displacement of the pump based on the signal. Hydro-mechanically adjusting the displacement the pump also simultaneously modifies a resistance of the signal.

20 Brief Description of the Drawings

Fig. 1 is a pictorial illustration of an exemplary disclosed machine;

Fig. 2 is a schematic illustration of an exemplary disclosed pump system that may be utilized in conjunction with the machine of Fig. 1; and

Fig. 3 is a schematic illustration of another exemplary disclosed
25 pump system that may be used in conjunction with the machine of Fig. 1.

Detailed Description

Fig. 1 illustrates an exemplary machine 10 performing a particular function at a worksite 12. Machine 10 may embody a stationary or mobile machine, with the particular function being associated with an industry such as mining, construction, farming, transportation, power generation, oil and gas, or another industry known in the art. For example, machine 10 may be an earth moving machine such as the excavator depicted in Fig. 1, in which the particular function includes the removal of earthen material from worksite 12 that alters the geography of worksite 12 to a desired form. Machine 10 may alternatively embody a different earth moving machine such as a motor grader or a wheel loader, or a non-earth moving machine such as a passenger vehicle, a stationary generator set, or a pumping mechanism.

Machine 10 may be equipped with multiple systems that facilitate operation thereof at worksite 12, for example a tool system 14, a drive system 16, and an engine system 18 that provides power to tool system 14 and drive system 16. During the performance of most tasks, power from engine system 18 may be split between tool system 14 and drive system 16. That is, during machine travel between excavation sites, a mechanical output of engine system 18 may be converted to a rotation of traction devices that propel machine 10, in some examples by way of a hydraulic or hydro-mechanical transmission (not shown). When parked at an excavation site and actively moving material, the mechanical output of engine system 18 may be converted to hydraulic power supplied to one or more working actuators of tool system 14.

As illustrated in Fig. 2, engine system 18 may include a heat engine 20, for example an internal combustion engine, that is coupled with a pump system 24. Pump system 24 may include a collection of components that are driven by engine 20 to hydraulically power tool and/or drive systems 14,16. Specifically, pump system 24 may include a low-pressure tank 26, and a pump 28 fluidly connected to tank 26 by way of an inlet passage 30 and to systems 14, 16

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by way of an outlet passage 32. Pump 28 may be driven by engine 20 to draw in low-pressure fluid from tank 26 and discharge the fluid at an elevated pressure to systems 14, 16. Pump system 24 may also include a displacement actuator 34 associated with pump 28 and movable to vary a displacement of pump 28, a
5 displacement control valve 36 operable to cause movement of displacement actuator 34, and a controller 38 configured to regulate operation of displacement control valve 36.

Pump 28 may be a swashplate-type pump and include multiple piston bores (not shown), and pistons (not shown) held against a tiltable
10 swashplate 40. One piston may be slidably disposed within each of the bores and biased into engagement with a driving surface (not shown) of swashplate 40. The pistons may reciprocate within the piston bores to produce a pumping action as swashplate 40 rotates relative to the pistons (swashplate 40 may rotate while the pistons and associated bores remain stationary, or the pistons and bores may
15 collectively rotate while swashplate 40 remains stationary). Swashplate 40 may be selectively tilted relative to a longitudinal axis of the pistons to vary a displacement of the pistons within their respective bores. Although shown in Fig. 2 as producing only a unidirectional flow of pressurized fluid, it is contemplated that pump 28 may alternatively be an over-center pump or rotatable in opposing
20 directions to produce flows of fluid in two directions, if desired.

When swashplate 40 rotates relative to the pistons, the angled driving surface of swashplate 40 may drive each piston through a reciprocating motion within each bore. When the piston is retracting from the bore, fluid may be allowed to enter the bore from inlet passage 30. When the piston is moving
25 into the associated bore under the force of the driving surface of swashplate 40, the piston may force the fluid at an elevated pressure from the bore toward systems 14, 16 via outlet passage 32. The angular setting of swashplate 40 relative to the pistons may affect a discharge rate of the pressurized fluid and be adjustable by displacement actuator 34.

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Displacement actuator 34 may include components that function to adjust the tilt angle of swashplate 40 and subsequently the effective displacement volume of each piston/bore pairing of pump 28. Specifically, displacement actuator 34 may include one or more control pistons 42 that directly or indirectly press against a portion of swashplate 40 to urge swashplate 40 to tilt relative to the axial direction of the pump's pistons. In the disclosed embodiment, control piston 42 is a dual-acting piston that is movable in response to a force imbalance caused by fluid pressure acting on opposing sides of a piston member. In particular, control piston 42 may be continuously connected at one end (e.g., at a rod-end) 44 to outlet passage 32 via a first actuator passage 46, and selectively connected at an opposing end (e.g., at a head-end) 48 to outlet passage 32 via a second actuator passage 50. The connection location of second actuator passage 50 to outlet passage 32 may be downstream of the connection location of first actuator passage 46. When fluid of a sufficient pressure is introduced into end 48 of displacement actuator 34, displacement actuator 34 may be caused to move swashplate 40 from a maximum displacement position toward a minimum displacement position by an amount and/or at a rate corresponding to the force imbalance across the piston member of displacement actuator 34. It is contemplated that displacement actuator 34 may alternatively include a spring-biased single-acting piston, if desired.

Displacement control valve 36 may be associated with displacement actuator 34 to control a flow of fluid from outlet passage 32 through second actuator passage 50 into second end 48, thereby controlling in which direction (i.e., which of a displacement-increasing and a displacement-decreasing direction) swashplate 40 of pump 28 is moved by displacement actuator 34. Displacement control valve 36 may be a spring-biased, electro-hydraulic control valve that is movable based on a command from controller 38. In particular, displacement control valve 36 may include a first valve element 52 that is pilot-operated to control fluid flows to and from displacement actuator 34, and a

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second valve element 54 that is solenoid-operated to control movement of first valve element 52 when energized by controller 38

First valve element 52 may be movable between a first position at which second end 48 of displacement actuator 34 receives pressurized fluid via second actuator passage 50, and a second position (shown in Fig. 2) at which fluid flow through second actuator passage 50 into second end 48 is blocked and second end 48 is instead connected to tank 26. A first pilot passage 56 may direct pilot fluid from outlet passage 32 to a first end 58 of first valve element 52 to urge first valve element 52 toward the first position, and a second pilot passage 60 may direct pilot fluid from outlet passage 32 to a second end 62 of first valve element 52 to urge first valve element 52 toward the second position. First pilot passage 56 may connect to outlet passage 32 at a location upstream of the connection locations of second actuator passage 50 and second pilot passage 60 with outlet passage 32, and downstream of the connection location of first actuator passage 46 with outlet passage 32. Second pilot passage 60 may connect to outlet passage 32 at a connection location downstream of second actuator passage 50 and upstream of systems 14, 16. First valve element 52 may be spring-biased toward the second position. A restricted orifice 64 may be placed within second pilot passage 60 to create a pressure drop that facilitates control of first valve element 52.

Second valve element 54 may be movable from a first position at which second pilot passage 60 is pressurized by fluid from outlet passage 32, toward a second position at which second pilot passage 60 is fluidly connected to tank 26. Second valve element 54 may be selectively energized by controller 38 to move toward the second position, and spring-biased toward the first position. When second valve element 54 is in the second position and second pilot passage 60 is fluidly connected to tank 26, a pressure drop may be generated across restricted orifice 64 (i.e., a pressure within second pilot passage 60 between restricted orifice 64 and first valve element 52 may be reduced) that allows the

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pressurized fluid within first pilot passage 56 to move first valve element 52 toward the second position. Second valve element 54 may be infinitely variable, and movable to any position between its first and second positions, thereby affecting a corresponding variable movement of first element 54 between its first
5 and second position and, subsequently, a movement of displacement actuator 34. It should be noted that the magnitude of the electrical current passing through the solenoid of second valve element 54 may correspond with the position achieved by second valve element 54. In other words, a particular current may be selectively applied to second valve element 54 by controller 38 to cause second
10 valve element 54 to move to a desired position that results in movement of first valve element 52 also to a desired position and a corresponding desired velocity of displacement actuator 34 and tilt angle of swashplate 40.

One or more pressure relief or pressure limiting valves 66 may also be fluidly communicated with second pilot passage 60. Pressure relief valve
15 66 may be spring-biased and movable in response to a pressure of second pilot passage 60 to selectively connect second pilot passage 60 with tank 26, thereby relieving or limiting excessive fluid pressures.

Controller 38 may embody a single or multiple microprocessors, field programmable gate arrays (FPGAs), digital signal processors (DSPs), etc.
20 that include a means for controlling an operation of pump system 24. Numerous commercially available microprocessors can be configured to perform the functions of controller 38. It should be appreciated that controller 38 could readily embody a microprocessor separate from that controlling other machine-related functions, or that controller 38 could be integral with a machine
25 microprocessor and be capable of controlling numerous machine functions and modes of operation. If separate from the general machine microprocessor, controller 38 may communicate with the general machine microprocessor via datalinks or other methods. Various other known circuits may be associated with controller 38, including power supply circuitry, signal-conditioning circuitry,

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actuator driver circuitry (i.e., circuitry powering solenoids, motors, or piezo actuators), and communication circuitry.

Controller 38 may be in communication with second valve element 54 via an electrical circuit 68, and be configured to energize second valve element 54 by selectively directing an electrical current through circuit 68. The amount of current directed through circuit 68 by controller 38 may correspond with a desired amount of torque that should be absorbed by pump 28 (i.e., with a torque limit of pump 28), and result in a specific change in the tilt angle of swashplate 40. The desired amount of torque may be determined based on operating conditions of engine 20, as is known in the art, such that engine stall does not occur and engine 20 functions in an efficient manner. Because the solenoid of second valve element 54 may be a relatively constant-resistance device, controller 38 may vary the current passing through circuit 68 and thereby regulate motion of second valve element 54 (and the subsequent motion of swashplate 40), by adjusting a voltage applied to circuit 68.

As is known in the art, an amount of torque absorbed by a pump is proportional to a product of the pump's displacement and a pressure of fluid discharged from the pump (i.e., $\text{Torque} \approx \text{Displacement} \times \text{Pressure}$). Accordingly, when controller 38 adjusts a voltage applied to second valve element 54 and the angle of swashplate 40 responsively changes, the amount of torque absorbed by pump 28 should likewise change in an immediate step-wise manner. However, this step-wise change in displacement may also have a longer term effect on the pressure of pump system 24, as the displacement change may cause fluid to be discharged into pump system 24 at a faster or slower rate (depending on the displacement change direction). The rising or lowering of system pressure, if left unchecked, could cause an actual torque absorption of pump 28 to deviate away from the desired torque absorption amount after the change in swashplate angle has been implemented. In conventional systems, sensory feedback is required to provide information regarding displacement

position and/or discharge pressure to help ensure that the desired amount of torque is being absorbed. In the disclosed system, however, a desired torque absorption of pump 28 may be maintained without the use of any such sensors. Instead of additional sensors, pump system 24 may include a variable resistor 67
5 that functions to adjust a total resistance of circuit 68 as swashplate 40 moves, thereby varying the amount of current passing through the solenoid of second valve element 54.

In the disclosed embodiment, variable resistor 67 may be an electro-mechanical device having a sliding contact (not shown), also known as a
10 wiper, that functions as an adjustable voltage divider. The wiper may be mechanically connected to one or both of displacement actuator 34 or swashplate 40, and be configured to vary a resistance of circuit 68 during displacement-adjusting movements of the associated component(s). In other words, as displacement actuator 34 and/or swashplate 40 moves to adjust a displacement of
15 pump 28 in response to a voltage change implemented by controller 38, the wiper of variable resistor 67 may also simultaneously move to adjust a resistance of circuit 68. This adjustment of the resistance of circuit 68, for a given applied voltage, may result in a change in the current passing through second valve element 54 and the torque absorption of pump 28. Accordingly, variable resistor
20 67 may function as a feedback mechanism for pump system 24 such that a desired torque absorption level of pump 28 may be maintained, even as the pressure of system 24 changes as a result of a swashplate angle change.

A signal conditioning device 74 may be connected to circuit 68 and configured to condition the current passing through the solenoid of second
25 valve element 54, if desired. Although shown as being located between variable resistor 67 and the solenoid of second valve element 54, it is contemplated that signal conditioning device 74 could be positioned at any other location along circuit 68, such as between controller 38 and second valve element 54 or between variable resistor 67 and a ground 76, as desired. Signal conditioning device 74

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may include, for example, additional resistors, capacitors, amplifiers, and other known electronic components.

Fig. 3 illustrates another embodiment of pump system 24. Similar to pump system 24 of Fig. 2, pump system 24 of Fig. 3 includes tank 26, pump 28, displacement control valve 36, and controller 38. However, pump system 24 of Fig. 3 may be a load-sense type of system. That is, the connection of second actuator passage 50 with outlet passage 32 may be located between a valve stack 70 (i.e., a stack of one or more control valves) and a working actuator 72 of tool and/or drive systems 14, 16. In this manner, a load on working actuator 72 may be sensed and used to help control the motion of first valve element 52.

Industrial Applicability

The disclosed pump system may be applicable to any machine where precise control over torque absorption in a simplified manner is desired. The disclosed pump system may provide for precise control of torque absorption by utilizing a variable resistor to vary current directed through a displacement control valve based on changing pump displacement. The disclosed system may be simple, as no sensor or costly feedback control loops are required. Operation of pump system 24 will now be described.

During operation, engine 20 may drive pump 28 to rotate and pressurize fluid. The pressurized fluid may be discharged from pump 28 into outlet passage 32 and directed into working actuators 72 of tool and/or drive systems 14, 16. As the pressurized fluid passes through working actuators 72, hydraulic power in the fluid may be converted to mechanical power used to move machine 10.

The fluid discharge direction and displacement of pump 28 may be regulated, at least in part, based on a desired torque absorption amount. Controller 38 may determine the desired torque absorption amount in a conventional manner, and then generate an open-loop torque command that results in application of a corresponding voltage to the solenoid of second valve

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element 54. Second valve element 54, in response to the applied voltage, may move to a particular position between its first (i.e., flow-blocking) position and its second (i.e., flow-passing position), thereby moving first valve element 52 to a particular position between its first and second position. The movement of first
5 valve element 52 to the particular position may result in a desired force imbalance across the piston member of displacement actuator 34 that functions to change a tilt angle of swashplate 40 and resulting displacement of pump 28. This displacement change, in conjunction with the instantaneous pressure of pump system 24, may cause pump 28 to absorb the desired amount of torque.

10 After the displacement of pump 28 has been changed, however, the pressure within pump system 24 may gradually change (i.e., increase or decrease based on the displacement change direction). This changing pressure, if left unaccounted, may cause the actual torque absorption of pump 28 to deviate from the desired torque absorption amount. Accordingly, as the displacement of
15 pump 28 changes, variable resistor 67 may adjust the resistance of circuit 68. This adjustment to the resistance of circuit 68 may function to change the current flowing through the solenoid of second valve element 54, thereby varying the tilt angle of swashplate 40 such that a relatively constant torque absorption of pump 28 may be maintained.

20 It will be apparent to those skilled in the art that various modifications and variations can be made to the disclosed pump system. Other embodiments will be apparent to those skilled in the art from consideration of the specification and practice of the disclosed pump system. It is intended that the specification and examples be considered as exemplary only, with a true scope
25 being indicated by the following claims and their equivalents.

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Claims

1. A pump system (24), comprising:
a pump (28) having a displacement that is variable;
5 an actuator (34) movable to adjust the displacement of the pump;
an electro-hydraulic valve (36) fluidly connected to the actuator
and configured to control movement of the actuator; and
a variable resistor (67) mechanically connected to at least one of
the actuator and the pump, and being adjustable by movement of the at least one
10 of the actuator and the pump to vary a current passing through the electro-
hydraulic valve.
2. The pump system of claim 1, wherein the actuator is fluidly
connected at a first end (44) to an output of the pump and at an opposing second
end (48) to the electro-hydraulic valve.
- 15 3. The pump system of claim 2, wherein the electro-hydraulic
valve includes:
a pilot-operated valve element (52) movable from a first position
at which the second end of the actuator is fluidly connected to the output of the
pump, and a second position at which the second end of the actuator is fluidly
20 connected to a low-pressure tank (26); and
a solenoid-operated valve element (54) operable to control
movement of the pilot-operated valve element between the first and second
positions.
4. The pump system of claim 3, further including:
25 at least one working actuator (72);
an outlet passage (32) extending from the pump to the at least one
working actuator;

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a control valve (72) disposed within the outlet passage and configured to regulate operation of the at least one working actuator;

a first pilot passage (56) extending from the outlet passage, at a first location upstream of the control valve, to a first end (58) of the pilot-operated valve element;

a second pilot passage (60) extending from the outlet passage, at a second location upstream of the control valve and downstream of the first location, to a second end (62) of the pilot-operated valve element; and

a restricted orifice (64) disposed within the second pilot passage.

5 5. The pump system of claim 4, wherein the solenoid-operated valve element is configured to selectively relieve pressure in the second pilot passage by an amount corresponding to current passing through the electro-hydraulic valve.

15 6. The pump system of claim 5, wherein the pilot-operated valve element is spring-biased toward the second position.

7. The pump system of claim 6, further including at least one of pressure relief or pressure limiting device (66) fluidly connected to the second end of the pilot-operated valve element.

20 8. The pump system of claim 1, further including a controller (38) in communication with the electro-hydraulic valve and configured to issue an open-loop torque command to the electro-hydraulic valve.

9. The pump of claim 3, further including:
at least one working actuator (72);
an outlet passage (32) extending from the pump to the at least one
25 working actuator;

a control valve (72) disposed within the outlet passage and configured to regulate operation of the at least one working actuator;

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a first pilot passage (56) extending from the outlet passage, at a first location upstream of the control valve, to a first end (58) of the pilot-operated valve element;

5 a second pilot passage (60) extending from the outlet passage, at a second location between the control valve and the at least one working actuator, to a second end (62) of the pilot-operated valve element; and

a restricted orifice (64) disposed within the second pilot passage.

10. A method of controlling a pump (28), comprising:
- 10 operating the pump to pressurize a fluid;
- generating an electronic signal indicative to adjust a displacement of the pump; and
- hydro-mechanically adjusting the displacement of the pump based on the signal,
- wherein hydro-mechanically adjusting the displacement the pump
- 15 also simultaneously modifies a resistance of the electronic signal.

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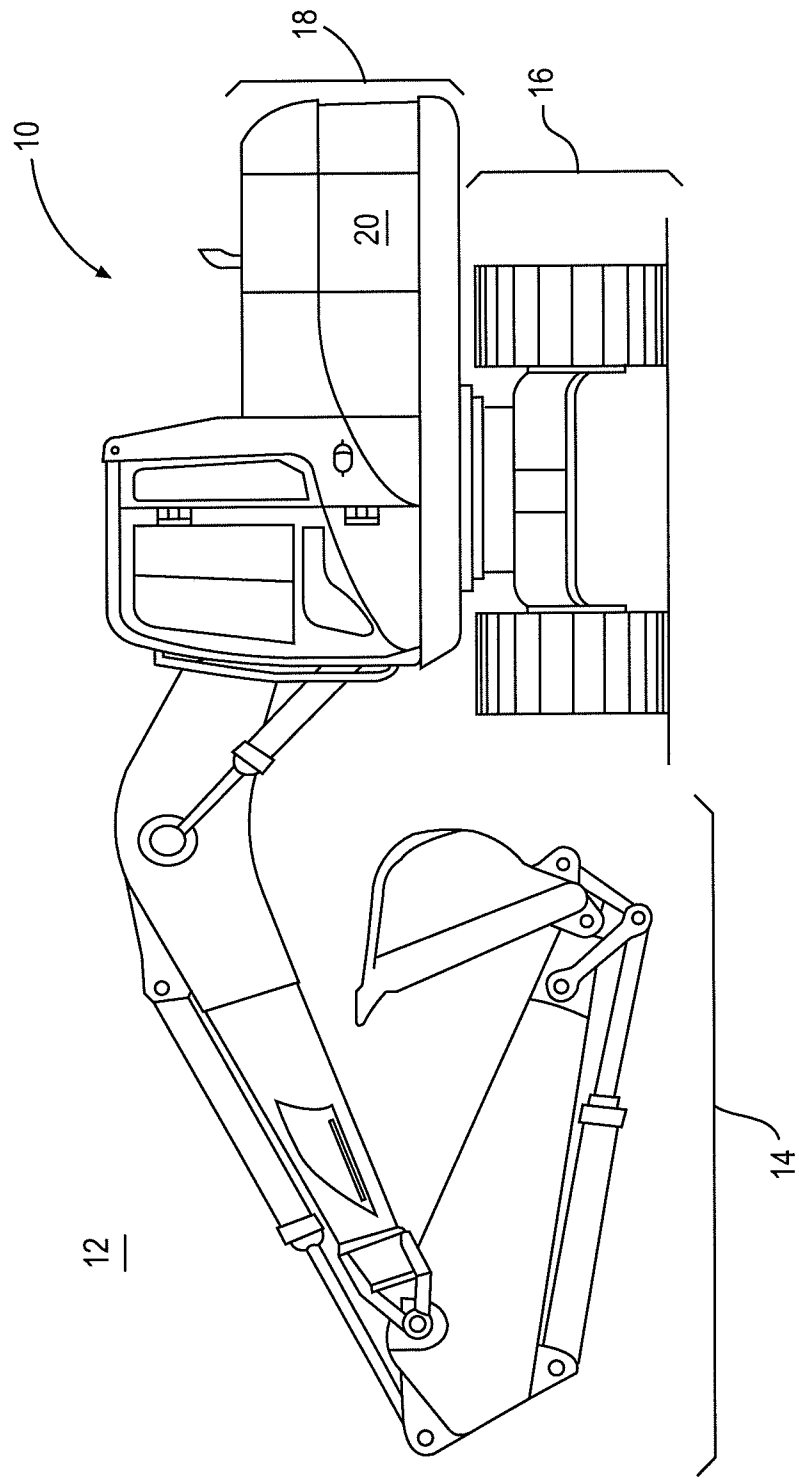


FIG. 1

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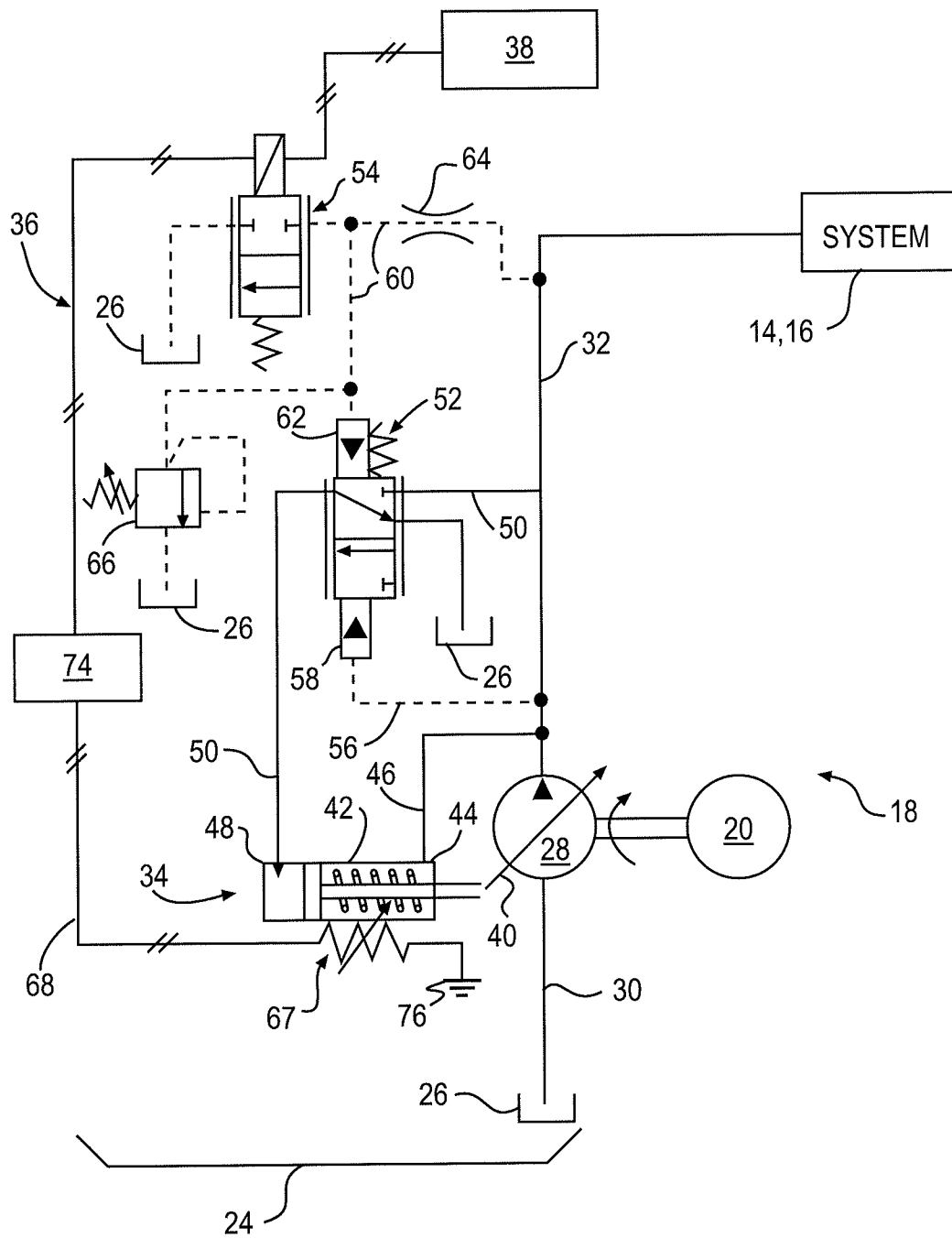


FIG. 2

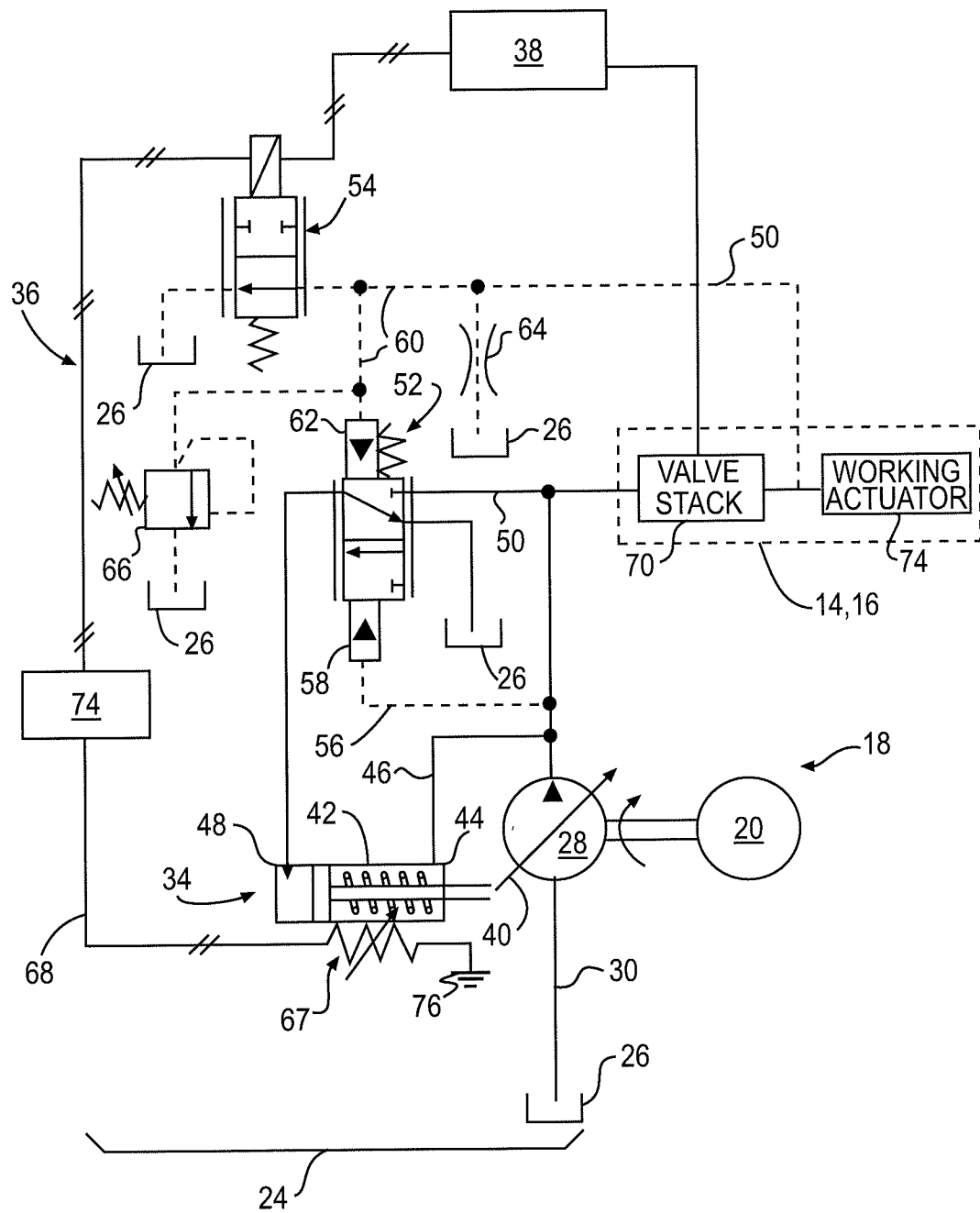


FIG.3