

(51) International Patent Classification:
E02F 9/22 (2006.01)(21) International Application Number:
PCT/US2016/066987(22) International Filing Date:
15 December 2016 (15.12.2016)

(25) Filing Language: English

(26) Publication Language: English

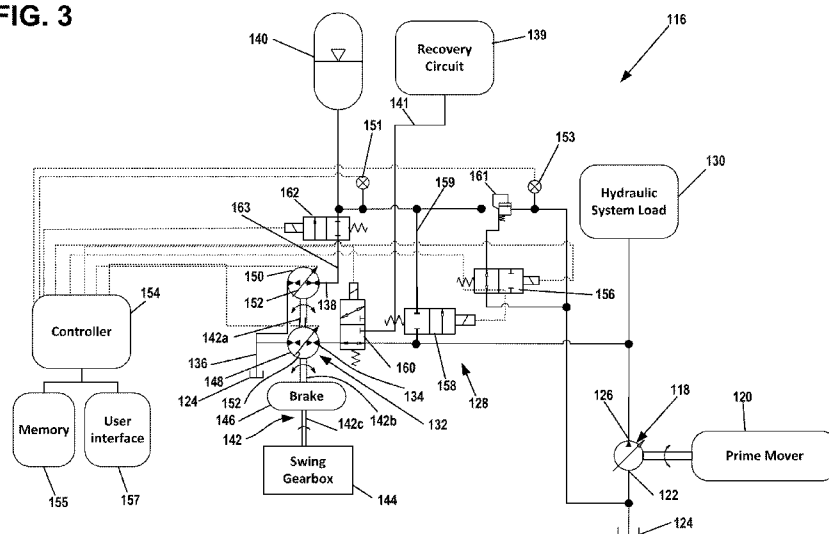
(30) Priority Data:
62/269,704 18 December 2015 (18.12.2015) US
62/291,103 4 February 2016 (04.02.2016) US(71) Applicant: **EATON CORPORATION** [US/US]; 1000
Eaton Boulevard, Cleveland, Ohio 44122 (US).(72) Inventors: **LARISH, Chad Anthony**; 12828 Hideaway
Trail, Minnetonka, Minnesota 55305 (US). **WANG,
Meng**; 8575 Magnolia Tr., Apt#104, Eden Prairie, Min-
nesota 55344 (US). **DANZL, Per William**; 4013 Lynn Av-
enue, Edina, Minnesota 55416 (US).(74) Agent: **BRUESS, Steven C.**; Merchant & Gould P.C.,
P.O. Box 2903, Minneapolis, Minnesota 55402-0903 (US).(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,
BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM,
DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN,
KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA,
MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG,
NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS,
RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY,
TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN,
ZA, ZM, ZW.(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ,
TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU,
TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE,
DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU,
LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,
SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ,
GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: ACCUMULATOR MANAGEMENT

FIG. 3



(57) Abstract: Effectively managing the activity of an accumulator in a hydraulic system can improve the efficiency and safety of the system. A hydraulic system includes a variable displacement pump and a hydraulic transformer. The hydraulic transformer includes an output shaft mechanically connected to a working load. The working load is a swing gearbox for an excavator. The hydraulic system also includes an accumulator fluidly connected to the pump by a pump line. The accumulator is also fluidly connected to the hydraulic transformer by a transformer line. The hydraulic system further includes a pre-charge valve positioned on the pump line between the accumulator and the pump. Fluid passes to the accumulator from the pump through the pre-charge valve along the pump line when the pump is first powered on.

ACCUMULATOR MANAGEMENT

5 CROSS-REFERENCE TO RELATED APPLICATIONS

This application is being filed on December 15, 2016 as a PCT International Patent Application and claims the benefit of U.S. Patent Application Serial No. 62/269,704, filed on December 18, 2015, and claims the benefit of U.S. Patent Application Serial No. 62/291,103, filed on February 4, 2016, the disclosures of which are incorporated herein by
10 reference in their entireties.

BACKGROUND

Mobile pieces of machinery (e.g., excavators) often include hydraulic systems having hydraulically powered linear and rotary actuators used to power various active
15 machine components (e.g., linkages, tracks, rotating joints, etc.). Typically, the linear actuators include hydraulic cylinders and the rotary actuators include hydraulic motors. By accessing a user interface of a machine control system, a machine operator can control movement of the various machine components.

A typical piece of mobile machinery includes a prime mover (e.g., a diesel engine, spark ignition engine, electric motor, etc.) that functions as an overall source of power for
20 the piece of mobile machinery. Commonly, the prime mover powers one or more hydraulic pumps that provide pressurized hydraulic fluid for driving the active machine components of the piece of machinery. The prime mover is typically required to be sized to satisfy a peak power requirement of the system. Because the prime mover is designed to
25 satisfy peak power requirements, the prime mover often does not operate at peak efficiency under average working loads.

The operation of the active hydraulic components of the type described above can be characterized by frequent accelerations and decelerations (e.g., overrunning hydraulic loads). Due to throttling, there is often substantial energy loss associated with
30 decelerations. Accumulators are often used to recover energy losses associated with such decelerations and to supplement the power of the prime mover. Such accumulators are configured to store high amounts of energy for on-demand use in hydraulic systems. However, there is a need for improved systems for maintaining consistent energy storage within the accumulator while also maintaining a safely operating accumulator.

SUMMARY

The present disclosure relates generally to series of control valves that manage accumulator behavior.

5 In a first aspect of the present disclosure, a hydraulic system is disclosed. The hydraulic system includes a variable displacement pump and a hydraulic transformer. The hydraulic transformer includes an output shaft mechanically connected to a working load. The working load is a swing gearbox for an excavator. The hydraulic system also includes an accumulator fluidly connected to the pump by a pump line. The accumulator is also
10 fluidly connected to the hydraulic transformer by a transformer line. The hydraulic system further includes a pre-charge valve positioned on the pump line between the accumulator and the pump. Fluid passes to the accumulator from the pump through the pre-charge valve along the pump line when the pump is first powered on.

 In a second aspect of the present disclosure, a method of operating a hydraulic
15 system is disclosed. The method includes powering on a hydraulic pump that is fluidly connected to a hydraulic circuit and an accumulator circuit. The method also includes opening a pre-charge valve positioned along an accumulator line. The accumulator line is connected to the pump and the accumulator circuit. The method includes providing fluid flow from the pump along the accumulator line and charging an accumulator connected to
20 the accumulator line prior to providing fluid flow to the hydraulic circuit. The method also includes closing the pre-charge valve.

 In a third aspect of the present disclosure, a hydraulic system is disclosed. The hydraulic system includes a variable displacement pump and a hydraulic fluid tank connected to the pump. The hydraulic system also includes an accumulator that is fluidly
25 connected to the pump by a pump line. The hydraulic system includes a pre-charge valve positioned on the pump line between the accumulator and the pump. Fluid passes to the accumulator from the pump through the pre-charge valve along the pump line when the pump is first powered on. The hydraulic system also includes a drain valve positioned between the accumulator and the hydraulic fluid tank. The drain valve opens to drain the
30 fluid from the accumulator to the hydraulic fluid tank when the pump is powered off. The hydraulic system further includes a hydraulic transformer fluidly connected to the accumulator by a transformer line. The hydraulic transformer includes an output shaft mechanically connected to a working load. The working load is a swing gearbox for an excavator. Further, the hydraulic system includes a transformer valve positioned on the

transformer line between the hydraulic transformer and the accumulator. The transformer valve, pre-charge valve, and drain valve are capable of closing simultaneously to fluidly isolate the accumulator from the pump, accumulator, and hydraulic transformer.

A variety of additional aspects will be set forth in the description that follows. The aspects can relate to individual features and to combinations of features. It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the broad inventive concepts upon which the embodiments disclosed herein are based.

DRAWINGS

The following drawings are illustrative of particular embodiments of the present disclosure and therefore do not limit the scope of the present disclosure. The drawings are not to scale and are intended for use in conjunction with the explanations in the following detailed description. Embodiments of the present disclosure will hereinafter be described in conjunction with the appended drawings, wherein like numerals denote like elements.

FIG. 1 and FIG. 2 show a mobile piece of excavation equipment that is an example of one type of machine on which hydraulic systems in accordance with the principles of the present disclosure can be used;

FIG. 3 is a schematic diagram of a hydraulic system in accordance with the principles of the present disclosure; and

FIG. 4 is a schematic diagram of a hydraulic system in accordance with the principles of the present disclosure.

DETAILED DESCRIPTION

Reference will now be made in detail to aspects of the present disclosure that are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like structure.

The hydraulic system described herein is configured to more efficiently and safely manage the operation of an accumulator in a hydraulic circuit. Specifically, the hydraulic system described herein is configured to charge the accumulator with a baseline pump immediately after startup and prior to operation of other hydraulic components within the hydraulic circuit. Additionally, the system has the ability to fluidly isolate the accumulator in the instance of an accumulator failure so as to protect the hydraulic system, and attached components, along with limiting the maximum pressure held within the

accumulator. Once isolated, the accumulator can then be safely drained. Further, it is preferred that, once the hydraulic system is powered down, the accumulator also be simultaneously emptied to prevent an accidental output of any energy stored in the accumulator. Such an accident could occur during maintenance. Therefore, the hydraulic circuit disclosed herein is configured to immediately vent any stored energy left in the hydraulic accumulator to the tank upon shutdown of the hydraulic system.

FIGS. 1 and 2 depict an example excavator 100 including an upper structure 102 supported on an undercarriage 104. The undercarriage 104 includes a propulsion structure for carrying the excavator 100 across the ground. For example, the undercarriage 104 can include left and right tracks. The upper structure 102 is pivotally movable relative to the undercarriage 104 about a pivot axis 106 (i.e., a swing axis). In certain embodiments of the present disclosure, the transformer input/output shafts of described herein can be used for pivoting the upper structure 102 about the pivot axis 106 relative to the undercarriage 104.

The upper structure 102 can support and carry a prime mover (e.g., a diesel engine, a spark ignition engine, an electric motor, or other power source) of the machine and can also include a cab 108 in which an operator interface is provided. A boom 110 is carried by the upper structure 102 and is pivotally moved between raised and lowered positions by a boom cylinder 110c. An arm 112 is pivotally connected to a distal end of the boom 110. An arm cylinder 112c is used to pivot the arm 112 relative to the boom 110. The excavator 100 also includes a bucket 114 pivotally connected to a distal end of the arm 112. A bucket cylinder 114c is used to pivot the bucket 114 relative to the arm 112. In certain embodiments, the boom cylinder 110c, the arm cylinder 112c, and the bucket cylinder 114c can be controlled by, and part of, the hydraulic circuit described herein.

Figure 3 shows a hydraulic system 116 in accordance with the principles of the present disclosure. The hydraulic system 116 includes a variable displacement pump 118 driven by a prime mover 120. The variable displacement pump 118 includes an inlet 122 that draws low pressure hydraulic fluid from a tank 124 (i.e., a low pressure reservoir). The variable displacement pump 118 also includes an outlet 126 through which high pressure hydraulic fluid is output. The outlet 126 is preferably fluidly coupled to a plurality of different working load circuits. For example, the outlet 126 is shown coupled to a first load circuit 128 and a second load circuit 130. The first load circuit 128 includes a hydraulic transformer 132 including a first port 134, a second port 136, and a third port 138. The first port 134 of the hydraulic transformer 132 is fluidly connected to the outlet

126 of the variable displacement pump 118. The first port 134 is also fluidly connected to the second load circuit 130 and a recovery circuit 139. The second load circuit 130 and recovery circuit 139 can both be fluidly connected to the boom cylinder 110c, the arm cylinder 112c, and the bucket cylinder 114c. The second port 136 is fluidly connected to
5 the tank 124. The third port 138 is fluidly connected to a hydraulic pressure accumulator 140.

The fluid recovery circuit 139 is connected to the first port 134 via flow line 141 and a flow control valve 160 (i.e., a mode valve). The flow control valve 160 is between the first port 134 and the recovery circuit 139. The flow control valve 160 is movable
10 between first and second positions. In the first position, the flow control valve 160 fluidly connects the output side 126 of the pump 122 to the first port 134 of the transformer 132. In the second position, the flow control valve 160 fluidly connects the first port 134 to the recovery circuit 139. The recovery circuit 139, for example, can contain the boom cylinder 110c, the arm cylinder 112c, and the bucket cylinder 114c. Therefore, fluid flow can be
15 supplied by the recovery circuit 139 to the transformer 132 when an element in the circuit is performing certain movements. For example, the lowering of the boom can cause pressurized fluid to leave the boom cylinder 110c and travel to the first port 134 of the transformer 132. By directing pressurized hydraulic fluid to the transformer 132, potential energy corresponding to the element in the recovery circuit 139 can be recovered and
20 stored in the accumulator 140 and/or can be transferred to an external load 144. Additionally, in certain embodiments, the energy can also be transferred back toward the variable displacement pump 122 in the form of pressurized hydraulic fluid pumped out of the transformer 132. In this way, the hydraulic transformer 132 allows for the recovery and use of potential energy corresponding to the element in the recovery circuit 139.

25 The hydraulic transformer 132 includes a shaft 142 that couples to the external load 144. In the depicted embodiment, the external load 144 is the swing gearbox that is used to pivot (i.e., swing) the upper structure 102 of the excavator 100 about the pivot axis 106 relative to the undercarriage 104. Thus, the external load 144 represents the load used to accelerate and decelerate pivotal movement of the upper structure 102 about the pivot
30 axis 106. A brake 146 can be used to selectively slow the rotation of the shaft 142.

The hydraulic transformer 132 includes first and second variable volume positive displacement pump/motor units 148, 150 connected by the shaft 142. The shaft 142 includes a first portion 142a that connects the first pump/motor unit 148 to the second

pump/motor unit 150, and a second portion 142b that connects to an output/input shaft 142c.

In one embodiment, each of the first and second pump/motor units 148, 150 includes a rotating group (e.g., cylinder block and pistons) that rotates with the shaft 142, and a swash plate 152 that can be positioned at different angles relative to the shaft 142 to change the amount of pump displacement per each shaft rotation. The volume of hydraulic fluid displaced across a given one of the pump/motor units 148, 150 per rotation of the shaft 142 can be varied by varying the angle of the swash plate 152 corresponding to the given pump/motor unit. Varying the angle of the swash plate 152 also changes the torque transferred between the shaft 142 and the rotating group of a given pump/motor unit. When the swash plates 152 are aligned perpendicular to the shaft 142, no hydraulic fluid flow is directed through the pump/motor units 148, 150. The swash plates 152 can be over-the-center swash plates that allow for bi-directional rotation of the shaft 142. The angular positions of the swash plates 152 are individually controlled by the electronic controller 154 based on the operating condition of the system 116. The hydraulic transformer 132 can be operated in a variety of different modes. Examples of such modes are disclosed in U.S. Pat. Pub. No. 2013/0061587, which is herein incorporated by reference in its entirety.

By controlling the displacement rates and displacement directions of the pump/motor units 148, 150, fluid power (pressure times flow) at a particular level can be converted to an alternate level, or supplied as shaft power used to drive the external load 144. When a deceleration of the external load 144 is desired, the hydraulic transformer 132 can act as a pump taking low pressure fluid from the tank 124 and directing it either to the accumulator 140 for storage, returned to the recovery circuit (i.e. meter-less supply directly to the boom cylinder), to the second load circuit 130 connected to the variable displacement pump 118, or a combination of the two. In some embodiments, a clutch can be used in addition to, or in place of, the brake 146 to disengage the output/input shaft 142c from the external load 144. In such an embodiment, the hydraulic transformer 132 can function as a stand-alone hydraulic transformer (e.g., a conventional hydraulic transformer) when no shaft work is required to be applied to the external load 144. This is achieved by taking energy from the system 116 at whatever pressure is dictated by the other associated system loads (e.g., the load corresponding to the second load circuit 130) and storing the energy, without throttling, at the current accumulator pressure. In the same way, unthrottled energy can also be taken from the accumulator 140 at its current pressure

and supplied to the system 116 at the desired operating pressure. Proportioning of power flow by the hydraulic transformer 132 can be controlled by controlling the positions of the swash plates 152 on the pump/motor units 148, 150.

5 The system 116 further includes an electronic controller 154 that interfaces with the prime mover 120, the variable displacement pump 118, the hydraulic transformer 132, and a series of control valves to control the operation of the system 116. The electronic controller can include memory storage 155 and a user interface 157 to allow the user to modify the operation of the electronic controller 154. It will be appreciated that the electronic controller 154 can also interface with various other sensors and other data
10 sources provided throughout the system 116. For example, the electronic controller 154 can interface with a pressure sensor 151 incorporated into the system 116 for measuring the hydraulic pressure in the accumulator 140, a pressure sensor 153 for sensing an accumulator leak, the hydraulic pressure provided by the variable displacement pump 118 to the first and second load circuits 128,130, the pressures at the pump and tank sides of the hydraulic transformer 132, and other pressures within the system 116. Moreover, the
15 electronic controller 154 can interface with a rotational speed sensor that senses a speed of rotation of the output/input shaft 142. Additionally, the electronic controller 154 can be used to monitor a load on the prime mover 120 and can control the hydraulic fluid flow rate across the variable displacement pump 118 at a given rotational speed of the drive
20 shaft 142 powered by the prime mover 120.

As mentioned above, the electronic controller 154 can control operation of a series of control valves in the system 116. The first operation performed by the system 116, and controlled by the electronic controller 154, is a pre-charge of the accumulator 140 upon startup of the variable displacement pump 118. This pre-charge operation is
25 carried out by the electronic controller 154 by first closing a valve 156 so as to prevent the accumulator 140 from draining to the tank 124. The electronic controller 154 then ensures a control valve 162 is closed and opens a control valve 158 to allow the variable displacement pump 118 to pump fluid directly to accumulator 140 before such fluid operates the hydraulic transformer 132. Additionally, in some embodiments, the variable
30 displacement pump 118 pumps fluid directly to accumulator 140 before pumping fluid to the second load circuit 130. By allowing fluid to flow along a pump line 159, on which valve 158 is positioned, at the startup of the variable displacement pump 118, it ensures the accumulator 140 is charged to a minimum pressure prior to operating the excavator 100. This allows the excavator 100 to almost immediately either 1) use the energy stored

in the accumulator 140 after startup; or 2) operate at full power without concern that the accumulator is being charged. This avoids the need to delay operation of the excavator 100 or operate it at reduced performance until the hydraulic transformer 132 has had a chance to charge the accumulator 140. Once the electronic controller 154 observes a desired
5 pressure from the pressure sensor 151, valve 158 is closed by the electronic controller 154 and the accumulator is sealed off, thereby storing energy within the accumulator 140.

The electronic controller 154 can also use valve 158 to perform a second operation in the system 116. During operation of the excavator 100, it is sometimes advantageous to store energy in the accumulator 140 during a low power cycle. A low
10 power cycle occurs when the variable displacement pump 118 is operating at only a portion of its full pumping capacity. The energy stored during a low power cycle can then be used to power the second load circuit 130 during high power cycle situations, where more fluid flow is required. During a low power cycle, the electronic controller 154 opens
15 valve 158 and closes valve 162, thereby allowing fluid to flow from the outlet 126 of the variable displacement pump 118 to the second load circuit 130 and also to the accumulator 140 along pump line 159, thereby charging the accumulator 140. To ensure that the accumulator 140 does not become overcharged past a maximum designed pressure, a pressure relief valve 161 bleeds off excess pressure beyond a maximum set level for the accumulator 140. Once the excavator 100 requires a higher power demand, the electronic
20 controller 154 closes valve 158, storing the energy in the accumulator 140, and supplies flow only to the second load circuit 130. Further, once the excavator 100 encounters a high power cycle, the electronic controller 154 opens the control valve 162, allowing energy stored in the accumulator 140 to be supplied to the hydraulic transformer 132 via a transformer line 163 or to the second load circuit 130.

The electronic controller 154 can also control the system 116 so as to improve the overall safety. Because the accumulator 140 stores energy that can be dangerous if released at the wrong time, the electronic controller 154 can operate the valve system so as to isolate the accumulator 140. An isolation operation can be performed if there is a fault or failure in the hydraulic system 116 where an energy release from the accumulator 140
30 could create a dangerous or damaging condition. To perform the isolation operation, the electronic controller 154 closes valve 158 and valve 162. When both valves 158, 162 are closed, the accumulator 140 cannot provide flow to the hydraulic transformer 132 or hydraulic system load 130 and, alternatively, the accumulator 140 cannot receive fluid flow from the variable displacement pump 118 or the hydraulic transformer 132. In some

embodiments, after an isolation operation has been carried out, the accumulator 140 can be drained to tank 124 by opening valve 156, which is normally closed. This allows the energy stored in the accumulator 140 to be safely drained to the tank 124 so that the accumulator 140 does not present a risk of accidentally dissipating stored energy to the system 116.

In other embodiments, an isolation operation may be carried out by the electronic controller 154 if there has been a fault or failure detected in the accumulator 140. A detection of an accumulator 140 fault can be sensed by sensor 153 reading a high pressure, which could indicate a leak in the accumulator 140, or a mechanical failure with the internal parts of the accumulator 140. The isolation event can be either manually triggered by an operator or automatically triggered by the electronic controller 154. When automatically triggered, the electronic controller 154 monitors the pressure reading of sensor 153, and if the reading exceeds a predetermined value, indicating an accumulator 140 fault, the electronic controller 154 closes valves 156, 158, and 162 so as to isolate the accumulator 140 from the system 116. After the isolation operation has been completed, the accumulator 140 can be bled externally from the system so as to prevent any potential damage to the system 116 and its operators.

As noted above, the energy stored in the accumulator 140 can present certain safety concerns. This is also the case when the system 116 is shut down. If the system 116 is shut down and there is energy still stored in the accumulator 140, a potential safety risk could exist as the energy could remain stored in the accumulator 140 for a significant amount of time. This is particularly relevant when maintenance is being performed on the system 116. If the operator is unaware that there is energy still stored in the accumulator 140, the operator could become injured if the energy is allowed to escape from the accumulator 140 unexpectedly. To mitigate this issue, the electronic controller 154 can perform a drain operation at the shutdown of system 116. To perform a drain operation, once the system 116 is powered down, specifically the variable displacement pump 118, the electronic controller opens valve 156 so as to allow any energy stored in the accumulator to drain to the tank 124.

FIG. 4 shows a hydraulic system 216 in accordance with the principles of the present disclosure. The system 216 operates in a similar manner to the system 116. Specifically, a series of control valves 256, 258, 260, 262, in a first load circuit 232 operate similarly to the series of control valves 156, 158, 160, 162 in the system 116.

Differing from the system 116, the system 216 includes a more detailed pilot pump arrangement 240, recovery circuit 239, and second load circuit 230.

The hydraulic system 216 includes a pair of variable displacement pumps 218, 219 driven by a prime mover 220. Each pump 218, 219 is connected to a hydraulic fluid tank 224 at inlets 222, 223 and the second load circuit 230 at outlets 226, 227. Further, the pumps 218, 219 are connected to one another by a rotatable shaft 225.

The second load circuit 230 includes a first boom control valve 264, a second boom control valve 266, a swing control valve 268, a bucket control valve 270, a first arm control valve 272, a second arm control valve 274, and left and right track control valves 276, 278. The control valves of the second load circuit 230 control the operation of their attached element (i.e., boom, bucket, track, etc.). Further, the control valves of the second load circuit 230 control fluid flow to either hydraulic cylinders or additional pumps. The operation of the control valves in the second load circuit 230 can be controlled by an electric controller (not shown) similar to the controller 154 of the system 116. As shown, the first pump 218 and a first load circuit 228 are fluidly connected to first boom control valve 264, swing control valve 268, second arm control valve 274, and the left track control valve 276. In other embodiments, the first pump 218 can also be connected to other control valves. The second pump 219 is fluidly connected to second boom control valve 266, bucket control valve 270, first arm control valve 272, and the right track control valve 278. In other embodiments, the second pump 219 can also be connected to other control valves.

The recovery circuit 239 is shown to include a pair of regeneration valves 280, 282. The regeneration valves 280, 282 are fluidly connected to boom cylinders 284 that are used to raise and lower the boom. When lowering the boom, pressurized fluid is forced from the boom cylinders 284, and the regeneration valves 280, 282 can control the flow of such fluid to either the tank 224 or the control valve 260 and then to the transformer 232. Therefore, as discussed with respect to the recovery circuit 139 in the system 116 above, energy can be harvested from the gravity assisted/powered movement of lowering the boom. In other embodiments, the recovery circuit 139 can include additional regeneration valves connected to other elements in the second load circuit 230 (i.e., arm, bucket, etc.).

The system 216 also includes a pilot pump arrangement 240. A pilot pump 286 can be a smaller pump used to supplement the first and second pumps 218, 219 in low consumption periods. Additionally, the pilot pump 286 can provide fluid flow to a brake valve 288 that controls a hydraulic brake 246 secured to an output shaft 242 of the

hydraulic transformer 232. Further, the pilot pump arrangement 240 can include a plurality of electronic pressure relief valves 290 in fluid communication with the first and second boom control valves 264, 266 and the pilot pump 286. The electronic proportional relief valves 290 allows the system 216 to electronically control the pilot pressure signal to the
5 first and second boom control valves 264, 266 thereby controlling the flow supplied to the boom cylinders 284. All of the valves shown in the system 216 can be controlled by the electric controller so as to maximize the efficiency and effectiveness of the system 216.

The various embodiments described above are provided by way of illustration only and should not be construed to limit the claims attached hereto. Those skilled in the
10 art will readily recognize various modifications and changes that may be made without following the example embodiments and applications illustrated and described herein, and without departing from the true spirit and scope of the following claims.

WE CLAIM:

1. A hydraulic system comprising:
a variable displacement pump;
a hydraulic transformer having an output shaft mechanically connected to a working load, wherein the working load is a swing gearbox for an excavator;
an accumulator fluidly connected to the pump by a pump line and fluidly connected to the hydraulic transformer by a transformer line; and
a pre-charge valve positioned on the pump line between the accumulator and the pump, wherein fluid passes to the accumulator from the pump through the pre-charge valve along the pump line when the pump is first powered on.
2. The hydraulic system of claim 1, further comprising a drain valve fluidly connected to the accumulator and a hydraulic tank on a drain line.
3. The hydraulic system of claim 1, wherein the hydraulic system is part of an excavator, the excavator including an upper structure supported on an undercarriage, the undercarriage including a propulsion structure for carrying the excavator across the ground, and the upper structure being pivotally movable relative to the undercarriage about a pivot axis.
4. The hydraulic system of claim 1, further comprising a transformer valve positioned on the transformer line between the hydraulic transformer and the accumulator, wherein the transformer valve and pre-charge valve are capable of closing simultaneously to fluidly isolate the accumulator from the pump, accumulator, and hydraulic transformer.
5. The hydraulic system of claim 1, further comprising a flow control valve positioned on a flow line between the hydraulic transformer and a recovery circuit, the flow control valve being movable between first and second positions, wherein, in the first position, the flow control valve fluidly connects the variable displacement pump to the hydraulic transformer, and wherein, in the second position, the flow control valve fluidly connects the hydraulic transformer to the recovery circuit, wherein the recovery circuit includes at least one hydraulic cylinder.

6. The hydraulic system of claim 1, further comprising a pressure sensor in communication with the accumulator and a controller in communication with the pressure sensor, wherein the controller controls the operation of the pre-charge valve based on a reading from the pressure sensor.
7. A method of operating a hydraulic system comprising;
powering on a hydraulic pump, the pump being fluidly connected to a hydraulic circuit and an accumulator circuit;
opening a pre-charge valve positioned along an accumulator line, the accumulator line being connected to the pump and the accumulator circuit;
providing fluid flow from the pump along the accumulator line;
charging an accumulator connected to the accumulator line prior to providing fluid flow to the hydraulic circuit; and
closing the pre-charge valve.
8. The method of claim 7, further comprising monitoring a pressure reading at a pressure sensor in the accumulator and comparing the pressure reading to a predetermined pre-charge pressure value prior to providing fluid flow to the hydraulic circuit.
9. The method of claim 8, further comprising providing a controller in communication with the pre-charge valve and automatically controlling the operation of the pre-charge valve by way of the controller in response to a pressure reading at the pressure sensor.
10. The method of claim 7, further comprising powering off the hydraulic pump and simultaneously opening a drain valve, the drain valve being positioned along a drain line that is fluidly connected to the accumulator and a hydraulic tank.
11. The method of claim 10, further comprising closing the drain valve, pre-charge valve, and a transformer valve during a hydraulic system failure, the transformer valve being positioned on a transformer line connecting the hydraulic circuit and the accumulator.

12. The method of claim 11, wherein the hydraulic circuit includes a hydraulic transformer.
13. The method of claim 7, wherein the hydraulic circuit includes at least one of a boom cylinder, arm cylinder, and bucket cylinder of an excavator, the excavator including an upper structure supported on an undercarriage, the undercarriage including a propulsion structure for carrying the excavator across the ground, and the upper structure being pivotally movable relative to the undercarriage about a pivot axis.
14. A hydraulic system comprising:
a variable displacement pump;
a hydraulic fluid tank connected to the pump;
an accumulator fluidly connected to the pump by a pump line;
a pre-charge valve positioned on the pump line between the accumulator and the pump, wherein fluid passes to the accumulator from the pump through the pre-charge valve along the pump line when the pump is first powered on;
a drain valve positioned between the accumulator and the hydraulic fluid tank, wherein the drain valve opens to drain the fluid from the accumulator to the hydraulic fluid tank when the pump is powered off;
a hydraulic transformer fluidly connected to the accumulator by a transformer line, the hydraulic transformer having an output shaft mechanically connected to a working load, wherein the working load is a swing gearbox for an excavator; and
a transformer valve positioned on the transformer line between the hydraulic transformer and the accumulator, wherein the transformer valve, pre-charge valve, and drain valve are capable of closing simultaneously to fluidly isolate the accumulator from the pump, accumulator, and hydraulic transformer.
15. The hydraulic system of claim 14, wherein the excavator includes an upper structure supported on an undercarriage, the undercarriage including a propulsion structure for carrying the excavator across the ground, and the upper structure being pivotally movable relative to the undercarriage about a pivot axis via the swing gearbox.

16. The hydraulic system of claim 14, further comprising a pressure sensor in communication with the accumulator and a controller in communication with the pressure sensor, wherein the controller automatically controls the operation of the pre-charge valve, drain valve, and transformer valve based on a reading from the pressure sensor.

17. The hydraulic system of claim 14, further comprising a flow control valve positioned on a flow line between the hydraulic transformer and a recovery circuit, the flow control valve being movable between first and second positions, wherein, in the first position, the flow control valve fluidly connects the variable displacement pump to the hydraulic transformer, and wherein, in the second position, the flow control valve fluidly connects the hydraulic transformer to the recovery circuit, wherein the recovery circuit includes at least one hydraulic cylinder.

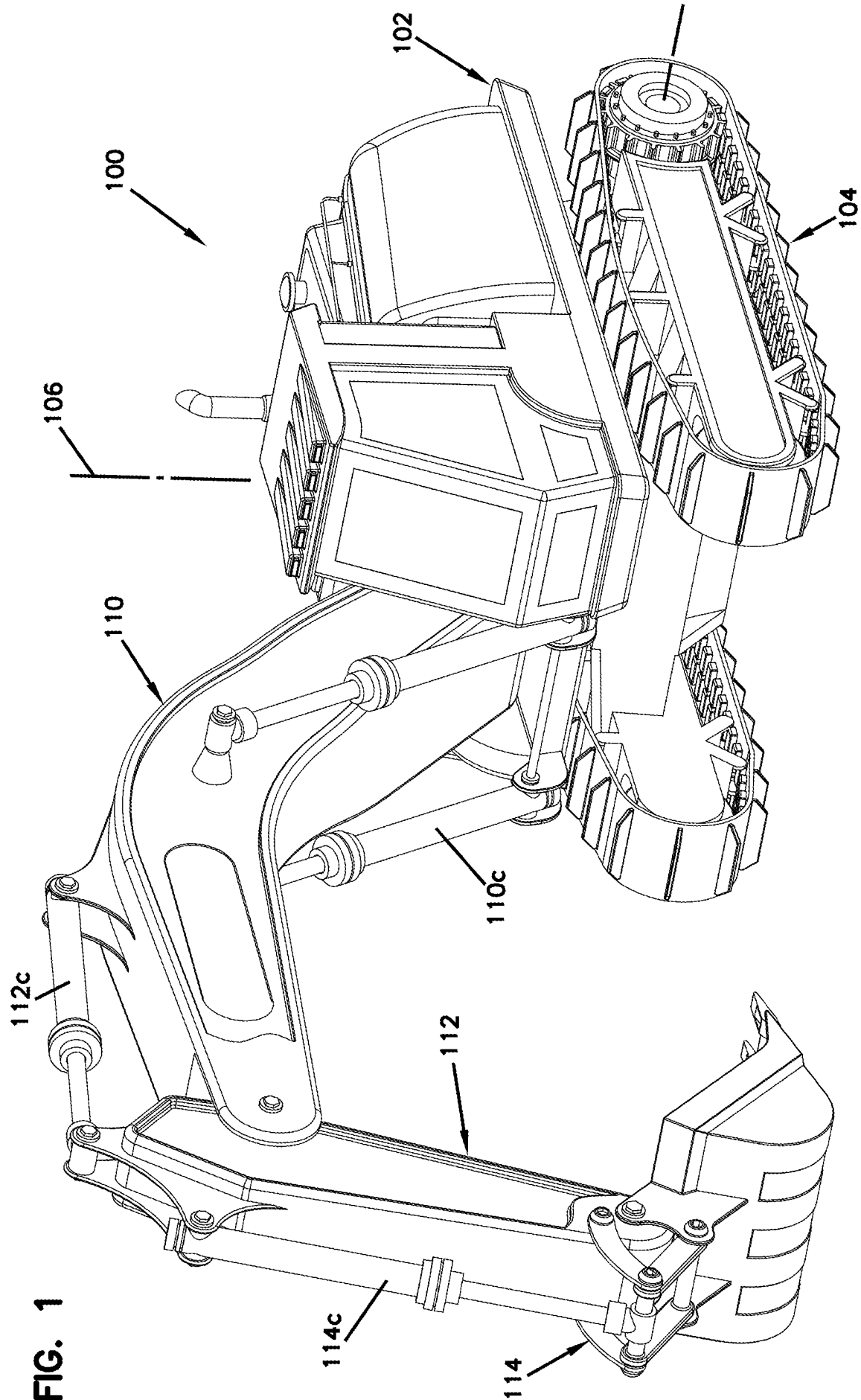


FIG. 1

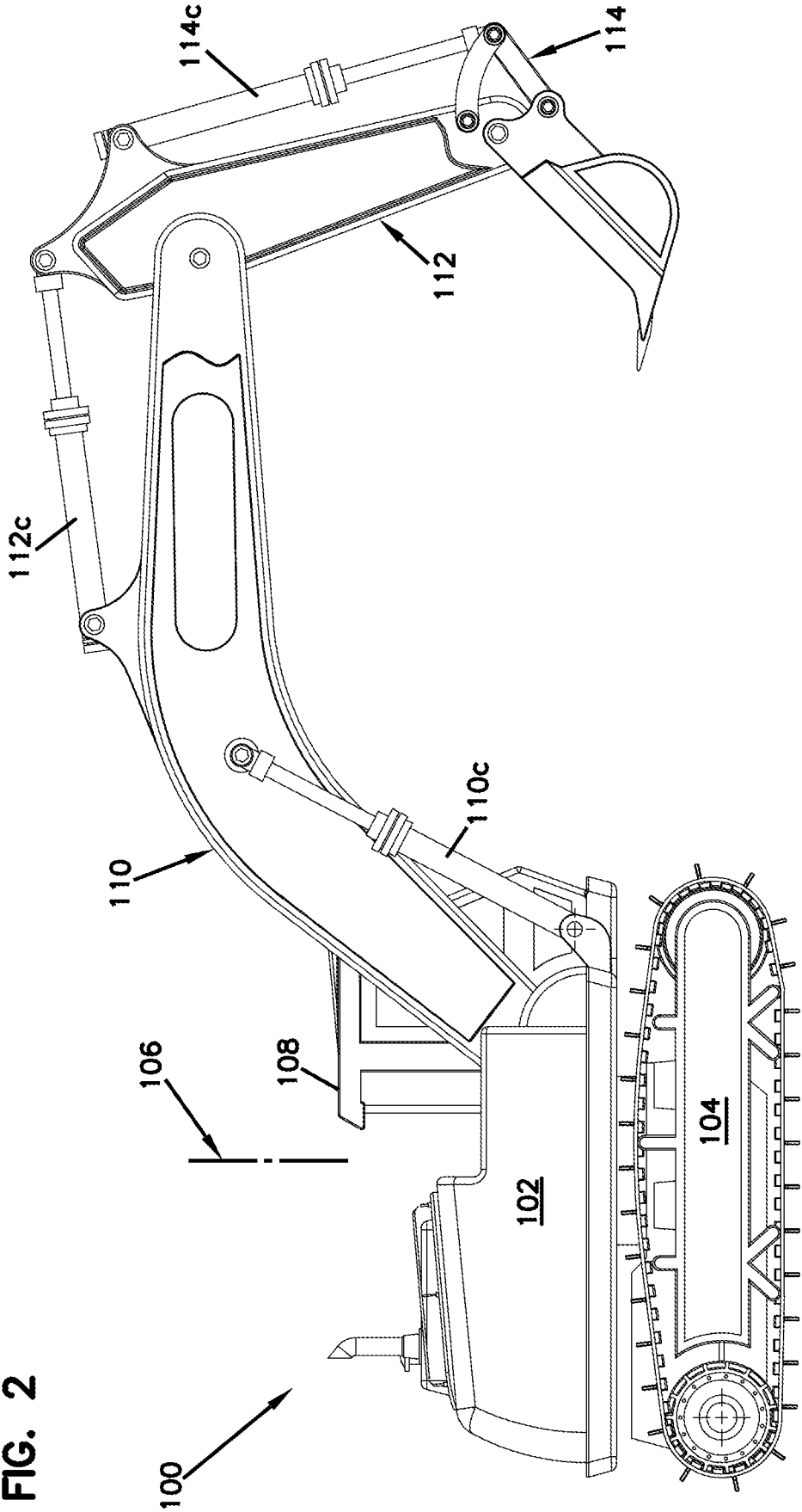


FIG. 3

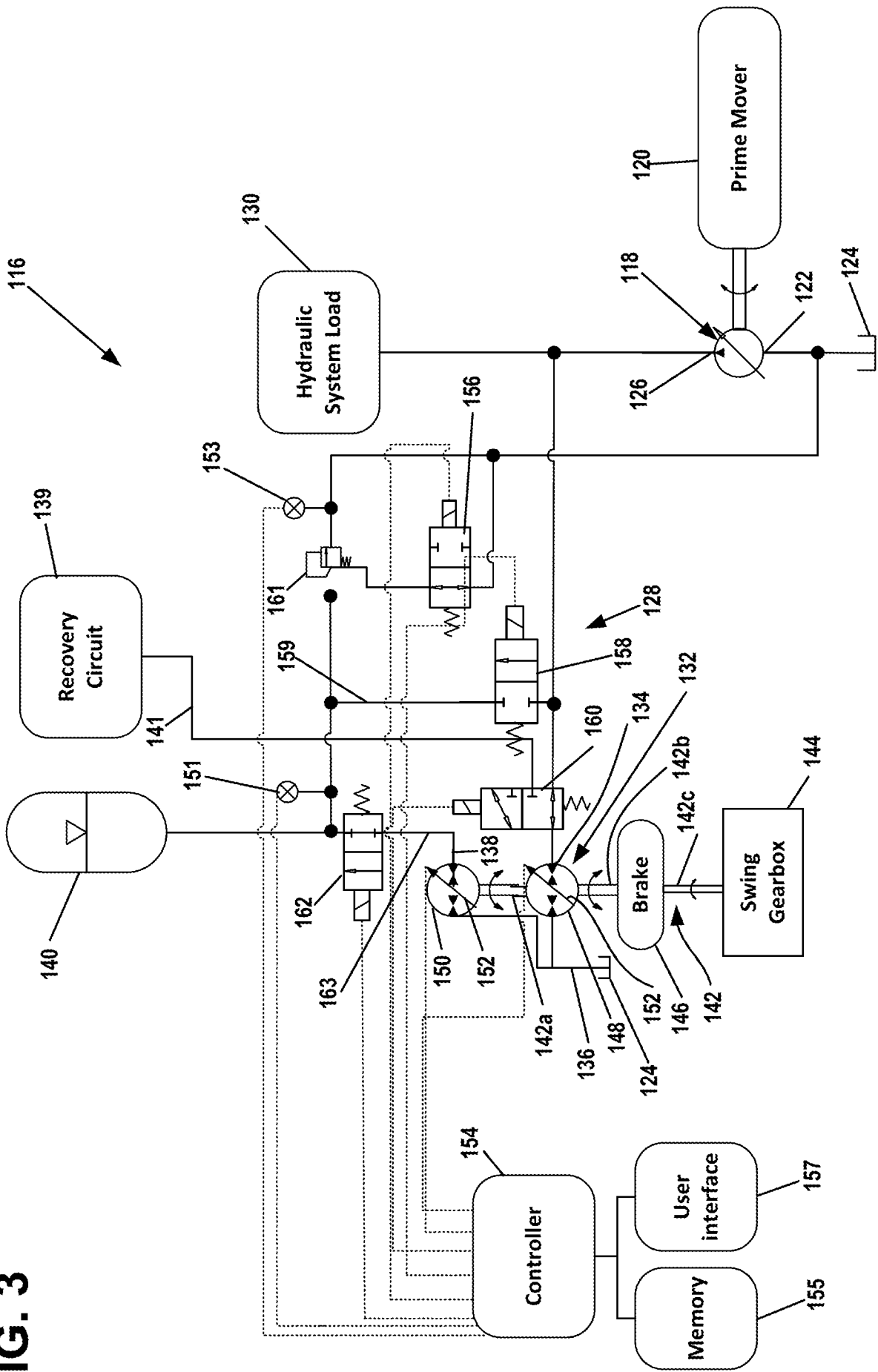
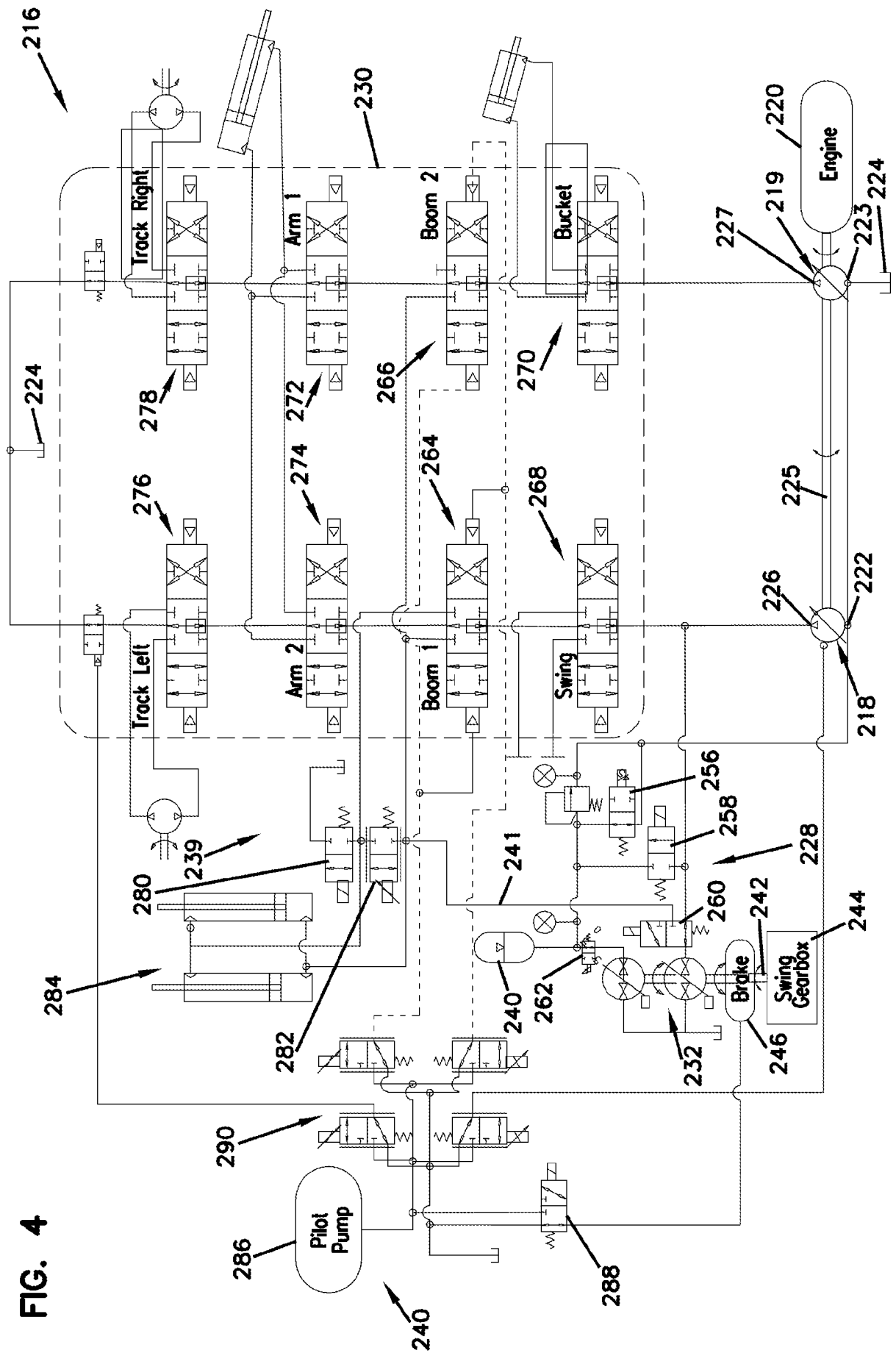


FIG. 4



A. CLASSIFICATION OF SUBJECT MATTER**E02F 9/22(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

E02F 9/22; F15B 13/02; F15B 1/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: excavator, hydraulic, pump, transformer, accumulator, pre-charge, valve, drain

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2014-0325972 A1 (CATERPILLAR INC.) 06 November 2014 See paragraphs [0007], [0011]–[0036]; and figures 1–2.	1–17
Y	WO 2009-066129 A1 (VOLVO COMPACT EQUIPMENT SAS et al.) 28 May 2009 See page 5, lines 4–16; page 6, line 26 – page 7, line 2; and figure 3.	1–17
A	US 2014-0166114 A1 (EATON CORPORATION) 19 June 2014 See paragraphs [0057]–[0061]; and figures 26–28.	1–17
A	US 2014-0123634 A1 (HEYBROEK et al.) 08 May 2014 See paragraphs [0049]–[0061], [0091]; and figures 2, 7.	1–17
A	US 2013-0232963 A1 (EATON CORPORATION) 12 September 2013 See paragraphs [0043]–[0061]; and figures 12–15.	1–17



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

28 March 2017 (28.03.2017)

Date of mailing of the international search report

03 April 2017 (03.04.2017)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea



Facsimile No. +82-42-481-8578

Authorized officer

BAE, Geun Tae

Telephone No. +82-42-481-3547



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/066987

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2014-0325972 A1	06/11/2014	CN 203926237 U	05/11/2014
WO 2009-066129 A1	28/05/2009	None	
US 2014-0166114 A1	19/06/2014	CN 105074231 A EP 2935907 A1 JP 2016-507706 A KR 10-2015-0095926 A WO 2014-099926 A1	18/11/2015 28/10/2015 10/03/2016 21/08/2015 26/06/2014
US 2014-0123634 A1	08/05/2014	CN 103562568 A CN 103562568 B EP 2715154 A1 EP 2715154 A4 EP 2940319 A1 WO 2012-166022 A1	05/02/2014 05/10/2016 09/04/2014 10/12/2014 04/11/2015 06/12/2012
US 2013-0232963 A1	12/09/2013	EP 2820313 A1 WO 2013-130768 A1	07/01/2015 06/09/2013