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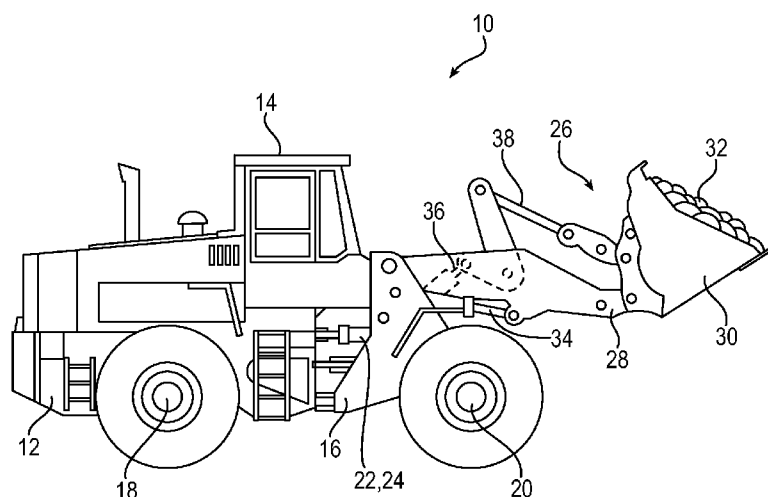


FIG. 1

(57) **Abstract:** A single motor for servicing both an auxiliary circuit and a boost circuit of a regenerative hydraulic system. The hydraulic system includes at least one hydraulic pump that collectively or singly supplies hydraulic fluid to one or more hydraulic motors for an auxiliary function and to a fluid communication line selectively in fluid communication with a port of a hydraulic pump for boost, and a single auxiliary electric motor for driving the at least one hydraulic pump. By driving the two circuits independently using the single electric motor, overall cost of the hydraulic system is reduced and additional components such as another electric motor and inverter are eliminated.

INDEPENDENTLY CONTROLLED HYDRAULIC CIRCUITS

Related Application Data

This application claims the benefit of U.S. Provisional Application No.
5 62/014,399 filed June 19, 2014, which is hereby incorporated herein by
reference.

Field of Invention

The present invention relates generally to hydraulic systems, and more
10 particularly to a hydraulic system having multiple hydraulic circuits driven by the
same drive source.

Background

An excavator is an example of a construction machine that uses multiple
15 hydraulic actuators or cylinders to accomplish a variety of tasks, such as
operation of a boom, an arm, a bucket, and swing. These actuators are fluidly
connected to a pump that provides pressurized fluid to extend and retract
chambers within the actuators. This pressurized fluid force acting on the
actuator surface causes movement of actuators and connected work tools.
20 Once the hydraulic energy is utilized, pressurized fluid is drained from the
chambers to return to a low pressure reservoir. The fluid being drained is at a
higher pressure than the pressure in the reservoir and hence this remaining
energy is wasted once it enters the reservoir. To recover this energy, the
hydraulic system could utilize a servo system in which a regenerative capable
25 electric motor would power or be powered by a fixed displacement, bi-directional
pump. A regenerative capable inverter would supply power to the electric motor
when the pump is required to provide power to the cylinder and would consume
and regenerate power to power storage when the cylinder has hydraulic power
needing to be drained.

30 In a typical unbalanced (differential) hydraulic cylinder, the cross-sectional
area of the head-end or extend chamber is greater than the cross-sectional area
of the rod-end or retract chamber. When the cylinder is extended, more fluid is
needed to fill the head-end chamber of the cylinder than is being discharged

from the rod-end chamber. Conversely, less fluid is needed to fill the rod-end chamber than is being discharged from the head-end chamber when the cylinder is being retracted.

A boost system may be provided having a pump for supplying fluid to a fluid make-up/communication line that is in communication with inlet/outlet ports of the bi-directional pump(s) that supplies fluid to the cylinder, and a motor driving the pump. The make-up/communication line selectively is in fluid communication with one of the inlet/outlet ports of the bi-directional pump when the other of the inlet/output ports is supplying pressurized fluid to the cylinder, thereby to provide hydraulic fluid at a desired inlet pressure to prevent cavitation. A steering system may also be provided having a pump for supplying fluid to a hydraulic circuit separate from the main task actuators.

Summary of Invention

The present invention provides a single motor for servicing both an auxiliary circuit and a boost circuit of a regenerative hydraulic system. The hydraulic system includes at least one hydraulic pump that collectively or singly supplies hydraulic fluid to one or more hydraulic motors for an auxiliary function and to a fluid communication line selectively in fluid communication with a port of a hydraulic pump for boost, and a single auxiliary electric motor for driving the at least one hydraulic pump. By driving the two circuits independently using the single electric motor, overall cost of the hydraulic system is reduced and additional components such as another electric motor and inverter are eliminated.

According to one aspect of the invention a hydraulic system for a vehicle is provided that includes at least one primary hydraulic pump operable in one direction for supplying hydraulic fluid from a first port to an extend chamber of an unbalanced actuator and operable in another direction for supplying hydraulic fluid from a second port to a retract chamber of the actuator, at least one primary electric motor for driving the at least one primary hydraulic pump, at least one auxiliary hydraulic pump that collectively or singly supplies hydraulic fluid to one or more hydraulic motors for steering and to a fluid communication line

selectively in fluid communication with one of the first or second ports for boost, and a single auxiliary electric motor for driving the at least one hydraulic pump.

The at least one auxiliary hydraulic pump may include at least one auxiliary hydraulic pump for supplying hydraulic fluid for steering and at least one
5 hydraulic pump for supplying hydraulic fluid for boost, and wherein the at least one auxiliary hydraulic pump for steering and the at least one hydraulic pump for boost are driven by the single auxiliary electric motor.

The at least one auxiliary hydraulic pump for steering and the at least one hydraulic pump for boost may be variable displacement pumps.

10 The single auxiliary electric motor may be mechanically connected to the at least one auxiliary hydraulic pump for steering and the at least one hydraulic pump for boost.

The at least one auxiliary hydraulic pump for boost may include first and second auxiliary hydraulic pumps for supplying hydraulic fluid for boost, and
15 wherein the at least one auxiliary hydraulic pump for steering and the first and second auxiliary hydraulic pumps for boost are driven by the single auxiliary electric motor.

The at least one auxiliary hydraulic pump for steering may be a variable displacement pump, the first auxiliary hydraulic pump for boost may be a
20 variable displacement over-center hydraulic pump, and the second auxiliary hydraulic pump for boost may be a fixed displacement pump.

The variable displacement over-center hydraulic pump and the fixed displacement pump may be each sized to provide half of the boost flow.

The single auxiliary electric motor may be mechanically connected to the
25 at least one auxiliary hydraulic pump for steering and the first and second auxiliary hydraulic pumps for boost.

The at least one auxiliary hydraulic pump for steering may be a variable displacement pump and the at least one auxiliary hydraulic pump for boost may be a fixed displacement pump.

30 The system may further include a bypass valve between the at least one auxiliary hydraulic pump for boost and the at least one primary hydraulic pump for directing fluid from the at least one auxiliary hydraulic pump for boost to a reservoir.

The system may further include a control valve for opening and closing the bypass valve.

The single auxiliary electric motor may be mechanically connected to the at least one auxiliary hydraulic pump for steering and the at least one hydraulic
5 pump for boost.

The at least one auxiliary hydraulic pump may be a variable displacement pump.

The system may further include an accumulator for supplying hydraulic fluid to the fluid communication line for boost, wherein the accumulator is
10 charged by the at least one auxiliary hydraulic pump.

The system may further include a pressure reducing valve, wherein the accumulator and the at least one auxiliary hydraulic pump are configured to supply hydraulic fluid to the communication line, and wherein the pressure reducing valve reduces the pressure of the fluid from the at least one auxiliary
15 hydraulic pump.

The single auxiliary electric motor may be mechanically connected to the at least one auxiliary hydraulic pump.

The at least one auxiliary hydraulic pump may be a fixed displacement pump.

20 Whereby flow of hydraulic fluid from the at least one auxiliary hydraulic pump to the one or more hydraulic motors for steering may be determined by motor speed.

The system may further include a boost power transfer unit connected to the fluid communication line and a boost activation valve, wherein the boost
25 actuation valve is configured to divert hydraulic fluid from the at least one auxiliary hydraulic pump to the boost power transfer unit to produce boost flow.

The boost power transfer unit may include a hydraulic motor and a hydraulic pump driven by the motor.

The hydraulic motor may be a fixed displacement motor and the hydraulic
30 pump may be a fixed displacement pump mechanically connected to the hydraulic motor.

The single auxiliary electric motor may be mechanically connected to the at least one auxiliary hydraulic pump.

The system may further include an accumulator for supplying hydraulic fluid to the fluid communication line for boost, wherein the accumulator is charged by the boost power transfer unit.

According to another aspect of the invention, a hydraulic system for a vehicle is provided that includes at least one primary hydraulic pump operable in one direction for supplying hydraulic fluid from a first port to an extend chamber of an unbalanced actuator and operable in another direction for supplying hydraulic fluid from a second port to a retract chamber of the actuator, at least one primary electric motor for driving the at least one primary hydraulic pump, an auxiliary hydraulic pump for supplying hydraulic fluid at least to a hydraulic motor for steering, at least one additional source of pressurized fluid for supplying hydraulic fluid to a fluid communication line selectively in fluid communication with one of the first or second ports for boost, and a single auxiliary electric motor for directly or indirectly powering the auxiliary hydraulic pump and the at least one additional source of pressurized hydraulic fluid.

The at least one additional source of pressurized fluid may include at least one auxiliary hydraulic pump for boost.

The at least one additional source of pressurized fluid may include an accumulator for boost, wherein the accumulator is charged by the auxiliary hydraulic pump.

The at least one additional source of pressurized fluid may include a boost power transfer unit for boost.

The system may further include a boost actuation valve configured to divert hydraulic fluid from the auxiliary hydraulic pump to the boost power transfer unit to produce boost flow.

The at least one additional source of pressurized fluid may additionally include an accumulator for supplying hydraulic fluid to the fluid communication line for boost, wherein the accumulator is charged by the boost power transfer unit.

According to still another aspect of the invention, a hydraulic system for a vehicle is provided that includes a first hydraulic circuit, a second hydraulic circuit, a hydraulic pump for supplying hydraulic fluid at least to the first hydraulic circuit, at least one additional source of pressurized fluid for supplying hydraulic

fluid to the second hydraulic circuit, and a single electric motor for directly or indirectly powering the hydraulic pump and the at least one additional source of pressurized hydraulic fluid.

5 The first circuit may be a boost circuit and the second circuit may be a steering circuit.

The hydraulic pump may be configured to supply hydraulic fluid to a hydraulic motor for steering.

10 The at least one additional source of pressurized fluid may be configured to supply hydraulic fluid to a fluid communication line selectively in fluid communication with a port of a hydraulic pump for boost.

The first and second circuits may be independently driven boost circuits.

The single electric motor may be a variable rotational speed motor.

According to yet another aspect of the invention, a hydraulic system for a vehicle is provided that includes at least one primary hydraulic pump operable in
15 one direction for supplying hydraulic fluid from a first port to an extend chamber of an unbalanced actuator and operable in another direction for supplying hydraulic fluid from a second port to a retract chamber of the actuator, at least one primary electric motor for driving the at least one primary hydraulic pump, at least one auxiliary hydraulic pump that supplies hydraulic fluid to a fluid
20 communication line selectively in fluid communication with one of the first or second ports for boost, and a gear box connecting the at least one auxiliary hydraulic pump to the at least one primary electric motor to drive the at least one auxiliary hydraulic pump.

25 The system may further include an accumulator for supplying hydraulic fluid to the fluid communication line for boost, wherein the accumulator is charged by the at least one auxiliary hydraulic pump.

According to a further aspect of the invention, a hydraulic system for a vehicle is provided that includes at least one primary hydraulic pump operable in one direction for supplying hydraulic fluid from a first port to an extend chamber
30 of an unbalanced actuator and operable in another direction for supplying hydraulic fluid from a second port to a retract chamber of the actuator, at least one electric motor for driving the at least one primary hydraulic pump, and an accumulator for supplying hydraulic fluid to a fluid communication line selectively

in fluid communication with one of the first or second ports for boost, wherein the accumulator is charged by the at least one primary hydraulic pump and/or by flow from the retract chamber when the actuator is retracted.

The system may further include a control valve connecting the at least
5 one primary hydraulic pump to the accumulator, wherein the control valve is open when the accumulator is being charged by the at least one primary hydraulic pump and closed when the accumulator is not being charged by the at least one primary hydraulic pump.

The system may further include at least one other primary hydraulic pump
10 operable in one direction for supplying hydraulic fluid from a first port to an extend chamber of another unbalanced actuator and operable in another direction for supplying hydraulic fluid from a second port to a retract chamber of the other actuator, and at least one other electric motor for driving the at least one other primary hydraulic pump, wherein the accumulator is charged by the at
15 least one other primary hydraulic pump and/or by flow from the retract chamber when the other actuator is retracted.

The system may further include another control valve connecting the at least one other primary hydraulic pump to the accumulator, wherein the another control valve is open when the accumulator is being charged by the at least one
20 other primary hydraulic pump and closed when the accumulator is not being charged by the at least one other primary hydraulic pump.

The foregoing and other features of the invention are hereinafter described in greater detail with reference to the accompanying drawings.

25 **Brief Description of the Drawings**

Fig. 1 is a side view of an exemplary work machine.

Fig. 2 is a schematic illustration of an exemplary hydraulic system according to the invention.

Fig. 3 is a schematic illustration of another exemplary hydraulic system
30 according to the invention.

Fig. 4 is a schematic illustration of yet another exemplary hydraulic system according to the invention.

Fig. 5 is a schematic illustration of still another exemplary hydraulic system according to the invention.

Fig. 6 is a schematic illustration of a further exemplary hydraulic system according to the invention.

5 Fig. 7 is a schematic illustration of another exemplary hydraulic system according to the invention.

Fig. 8 is a schematic illustration of yet another exemplary hydraulic system according to the invention.

10 Fig. 9 is a schematic illustration of still another exemplary hydraulic system according to the invention.

Fig. 10 is a schematic illustration of a further exemplary hydraulic system according to the invention.

Detailed Description

15 The principles of the present invention relate generally to hydraulic actuation systems for extending and retracting at least one unbalanced hydraulic cylinder in a work machine, such as but not limited to hydraulic excavators, wheel loaders, loading shovels, backhoe shovels, mining equipment, industrial machinery and the like, having one or more actuated components such as lifting
20 and/or tilting arms, booms, buckets, steering and turning functions, traveling means, etc. The principles of this present invention have particular application to boost and auxiliary systems in the work machine's system.

Referring to the drawings, and initially to Fig. 1, an exemplary wheel loader is illustrated generally at reference numeral 10. The wheel loader 10
25 comprises a rear vehicle part 12 including a cab/compartment 14 and a front vehicle part 16, which parts each comprise a frame and respective drive axles 18 and 20. The vehicle parts 12 and 16 are coupled together with one another in such a way that they can be pivoted relative to one another about a vertical axis by means of hydraulic cylinders 22, 24 which are connected to the two parts on
30 opposite sides of the wheel loader. The hydraulic cylinders 22, 24 provide for steering, or turning, the wheel loader.

The wheel loader 10 further comprises an apparatus 26 for handling objects or material. The apparatus 26 comprises a lifting arm unit 28 and an

implement 30 in the form of a bucket which is mounted on the lifting arm unit. The bucket 30 is shown filled with material 32. One end of the lifting arm unit 28 is coupled rotatably to the front vehicle part 16 for bringing about a lifting movement of the bucket. The bucket is coupled rotatably to an opposite end of
5 the lifting arm unit for bringing about a tilting movement of the bucket.

The lifting arm unit 28 can be raised and lowered in relation to the front part 16 of the vehicle 10 by means of two hydraulic cylinders 34 on opposite sides of the lifting arm unit. The hydraulic cylinders 34 are each coupled at one end to the front vehicle part 16 and at the other end to the lifting arm unit 28.

10 The bucket 30 can be tilted in relation to the lifting arm unit 28 by means of a third hydraulic cylinder 36, which is coupled at one end to the front vehicle part and at the other end to the bucket via a link arm system 38.

The wheel loader 10 is shown and described to facilitate an understanding of the invention and not by way of limitation. As will be
15 appreciated, the wheel loader is just one example of a work machine that may benefit from the present invention. Other types of work machines (including work vehicles) include, without limitation, excavator loaders (backhoes), excavating machines, mining equipment, and industrial applications and the like having multiple actuation functions include lifting arms, booms, buckets, steering
20 and/or turning functions, and traveling means.

Turning now to Fig. 2, a hybrid wheel loader 10 includes a prime mover 50, such as an internal combustion engine, a generator set 52 mechanically connected to the prime mover 50, an electrical storage device 54 charged by the generator set 52, and a hydraulic system 56. The hydraulic system 56 may be a
25 hybrid electro-hydrostatic system that may comprise one or more actuator systems for extending and retracting a respective unbalanced hydraulic cylinder. By way of example, the system 56 has two such actuator systems 58 and 60 that may be used to control, for example, the lift and tilt cylinders 34 and 36 of the wheel loader 10. The hydraulic system 56 also has a steering/boost system 62
30 for driving the wheels/tracks of the loader 10 and for providing flow to a flow related circuit, such as providing make-up fluid for boost to the actuator systems 58 and 60, and a voltage bus 64, such as a direct current voltage bus. Although described as providing fluid for steering and boost, it will be appreciated that the

system 62 may be used to produce the flow requirements of two pressure related circuits, two flow related circuits, or a pressure related and a flow related circuit for any suitable operation.

Each system 58, 60, and 62 includes a regenerative drive 70, 72, 74,
5 such as an inverter, an electric motor 76, 78, 80, and at least one hydraulic pump 82, 84, 86 mechanically connected to the respective electric motor 76, 78, 80. The regenerative drives 70, 72, and 74 provide power to and consume power from the respective electric motors 76, 78, and 80. The electric motors 76 and 78 provide shaft power to or consume and regenerate shaft power from the
10 respective hydraulic pump 82 and 84, which may be fixed displacement bi-directional pumps. The hydraulic pumps 82 and 84 are operable in one direction for supplying pressurized fluid from one inlet/outlet port 90, 92 respectively to a head-end chamber 94, 96 of the respective cylinder 34, 36 for operating the cylinder in one direction, and operable in a second direction opposite the first
15 direction for supplying pressurized fluid from another inlet/outlet port 98, 100 to a rod-end chamber 102, 104 of the respective cylinder 34, 36 for operating the cylinder in a direction opposite the first direction. The hydraulic pumps 82 and 84 are connected to the respective cylinder 34, 36 through respective pump manifolds 106 and 108 housing respective control valves 110 and 112, and
20 connected through respective function manifolds 114 and 116 that each house one or more valves (not shown) that control cylinder speed during hydraulic regeneration or pressure dump. The manifolds 106, 108, 114 and 116 may also house pressure relief valves (not shown) that protect the pumps 82 and 84 and cylinders 34 and 36 from over pressurization. Check valves (not shown) may
25 also be provided in parallel with the relief valves in the circuit between the pump and respective load holding valves (not shown) to prevent the possibility of cavitation from occurring.

The control valves 110 and 112, which may be pilot-operated, three position shuttle valves, provide for the connection of the chambers 94, 102 and
30 96, 104, respectively to a fluid communication line 118. The control valve 110 is operated by differential pressure between the lines 120 and 122 to connect line 122 to the communication line 118 when pressure in the line 120 exceeds the pressure in the line 122 by a prescribed amount whereby make-up fluid can be

supplied through the communication line to line 122, and to connect the line 120 to the communication line 118 when pressure in the line 122 exceeds the pressure in the line 120 by a prescribed amount whereby excess fluid from the head-end chamber 94 of the hydraulic cylinder 34 can be accepted by the communication line 118. Similarly, the control valve 112 is operated by differential pressure between the lines 124 and 126 to connect line 126 to the communication line 118 when pressure in the line 124 exceeds the pressure in the line 126 by a prescribed amount whereby make-up fluid can be supplied through the communication line to line 126, and to connect the line 124 to the communication line 118 when pressure in the line 126 exceeds the pressure in the line 124 by a prescribed amount whereby excess fluid from the head-end chamber 96 of the hydraulic cylinder 34 can be accepted by the communication line 118.

Referring now to the combined steering/boost system 62 in detail, the system includes the regenerative drive 74, the electric motor 80, the at least one hydraulic pump 86, and an optional manifold (shown in Fig. 3). The hydraulic pump 86 collectively or singly supplies hydraulic fluid to one or more hydraulic circuits (not shown) for steering or other auxiliary function and to the fluid communication line 118 selectively in fluid communication with one of the inlet/outlet ports 90 and 98 via valve 110 and with one of the inlet/outlet ports 92 and 100 via valve 112 for boost or make-up flow. The boost flow fills the cylinders 34 and 36 in the extend direction to prevent fluid from dropping below a cavitation pressure that would damage the pump, and the system 62 manages excess flow in the retract direction.

In the illustrated embodiment, the system includes the hydraulic pump 86, herein referred to as the first hydraulic pump for supplying hydraulic fluid for the steering function via line 142, and a second hydraulic pump 88 for supplying hydraulic fluid to the fluid communication line 118 for boost. The first and second hydraulic pumps 86 and 88 are variable displacement pumps mechanically connected to and driven by the single electric motor 80. The steering/boost system 62 may be operated in constant speed mode for steering demands or variable speed when steering demands are below boost demands. The boost demands from the pumps 82 and 84 are translated to pump speed via

controls, and control requirements on one or both pumps 86 and 88 would be displacement reduction via pump control valves (not shown) to limit power losses. When boost is demanded, fluid is pumped by the second hydraulic pump 88 to the manifold, wherein the fluid may flow through suitable flow controls to the communication line 118, which then supplies the fluid to the valves 110 and 112.

Turning now to Fig. 3, an exemplary embodiment of the steering/boost system is shown at 162. The steering/boost system 162 is substantially the same as the above-referenced steering/boost system 62, and consequently the same reference numerals but indexed by 100 are used to denote structures corresponding to similar structures in the steering/boost systems. In addition, the foregoing description of the steering/boost system 62 is equally applicable to the steering/boost system 162 except as noted below. Moreover, it will be appreciated upon reading and understanding the specification that aspects of the steering/boost systems may be substituted for one another or used in conjunction with one another where applicable.

The steering/boost system 162 includes an electric motor 180, a first hydraulic pump 186, a second hydraulic pump 188, a third hydraulic pump 189, and a manifold 240. The first hydraulic pump 186 supplies hydraulic fluid to one or more hydraulic circuits (not shown) for steering or other auxiliary function via line 242 and the second and third hydraulic pumps 188 and 189 supply hydraulic fluid to the manifold 240 that communicates with the communication line 218 for providing boost. The first, second, and third hydraulic pumps 186, 188, and 189 are mechanically connected to and driven by the single electric motor 180. The first hydraulic pump 186 is a variable displacement hydraulic pump, the second hydraulic pump 188 is a variable displacement over-center hydraulic pump, and the third hydraulic pump 189 is a fixed displacement hydraulic pump. In the illustrated embodiment, the second hydraulic pump 188 is a variable displacement, pressure compensated, displacement controlled over-center hydraulic pump sized to provide half the total flow, and the third hydraulic pump 189 is a fixed displacement hydraulic pump sized to provide half the total flow.

The steering/boost system 162 may be operated in constant speed mode for steering demands, and if boost demand is at a maximum, full flow from both

the second hydraulic pump 188 and third hydraulic pump 189 are fed into the manifold 240. For maximum boost demand, each hydraulic pump 188 and 189 provides half of the demanded flow. When the boost demand is between half demand and maximum demand, the second hydraulic pump 188 is commanded to a lower displacement and flow from the second hydraulic pump and the third hydraulic pump 189, which delivers half the demand, are fed into the manifold 240. When the boost demand is half demand, the second hydraulic pump 188 is commanded to a null position where no fluid is pumped through the second hydraulic pump 188 and the third hydraulic pump 189 delivers half the demand. When the boost demand is below half demand, the second hydraulic pump 188 is commanded over-center to consume a portion of the flow of fluid from the third hydraulic pump 188 that is not required for boost. Where there is no boost demand, the second hydraulic pump 188 is commanded fully over-center to consume all of the flow of fluid from the third hydraulic pump 189.

The fluid received by the manifold 240 passes through one or more check valves 244 to the communication line 218. When fluid returns to the boost manifold 240 through the line 218, the fluid may flow through a relief valve 246 that controls back pressure to the reservoir. A pressure setting of the relief valve 246 may be controlled by a pilot valve 248, which may actuate the relief valve 246 to allow for fast cylinder movement, for example when the hydraulic pumps 188 and 180 are not supplying fluid for boost.

Turning now to Fig. 4, an exemplary embodiment of the steering/boost system is shown at 262. The steering/boost system 262 is substantially the same as the above-referenced steering/boost system 62, and consequently the same reference numerals but indexed by 200 are used to denote structures corresponding to similar structures in the steering/boost systems. In addition, the foregoing description of the steering/boost system 62 is equally applicable to the steering/boost system 262 except as noted below. Moreover, it will be appreciated upon reading and understanding the specification that aspects of the steering/boost systems may be substituted for one another or used in conjunction with one another where applicable.

The steering/boost system 262 includes an electric motor 280, a first hydraulic pump 286, a second hydraulic pump 288, and a manifold 340. The

first hydraulic pump 286 supplies hydraulic fluid to one or more hydraulic circuits (not shown) for steering or other auxiliary function via line 342 and the second hydraulic pump 288 supplies hydraulic fluid to the manifold 340 that communicates with the communication line 318 for providing boost. The first
5 and second hydraulic pumps 286 and 288 are mechanically connected to and driven by the single electric motor 280. The first hydraulic pump 286 is a variable displacement hydraulic pump and the second hydraulic pump 288 is a fixed displacement hydraulic pump.

The manifold 340 includes a check valve 344, a relief valve 346, a pilot
10 valve 348, a bypass valve 350, and a control valve 352. When steering is demanded and the boost demand is at a maximum, fluid is pumped from the second hydraulic pump 288 to the manifold 240 and the bypass valve 350 is controlled by the control valve 352 to be closed to allow the fluid to flow to the communication line 318. As the boost demand reduces, the control valve 352
15 reduces the pilot pressure behind the bypass valve 350 is opened to allow the fluid not demanded by boost to be diverted to reservoir. When steering is demanded and boost demand is at a minimum, the pressure of the fluid bypassed through bypass valve 350 is controlled by the control valve 352 to a minimum pressure. At the minimum pressure, the pressure on the cylinders is
20 not influenced by the boost, the check valve 344 is closed, and the bypass valve 350 is opened to divert all of the fluid to reservoir at the low pressure. When steering is not demanded and boost is demanded, the speed of the electric motor 280 may be varied to satisfy the requisite boost demand.

Turning now to Fig. 5, an exemplary embodiment of the hydraulic system
25 is shown at 356. The hydraulic system 356 is substantially the same as the above-referenced hydraulic system 56, and consequently the same reference numerals but indexed by 300 are used to denote structures corresponding to similar structures in the systems. In addition, the foregoing description of the hydraulic system 56 is equally applicable to the hydraulic system 356 except as
30 noted below. Moreover, it will be appreciated upon reading and understanding the specification that aspects of the systems may be substituted for one another or used in conjunction with one another where applicable.

The hydraulic system 356 includes actuator systems 358 and 360 for controlling lift and tilt cylinders 334 and 336, a steering/boost system 362 and a voltage bus (not shown). Each system 358, 360, and 362 includes a regenerative drive (not shown), an electric motor 376, 378, 380, and at least one
5 hydraulic pump 382, 384, 386 mechanically connected to the respective electric motor 376, 378, 380. The hydraulic pumps 382 and 384 are connected to the respective cylinder 334, 336 through respective pump manifolds 406 and 408 housing respective control valves 410 and 412.

The steering/boost system 362 includes the electric motor 380, the
10 hydraulic pump 386, such as a variable displacement hydraulic pump mechanically connected to and driven by the single electric motor 380, and an additional source of pressurized fluid, such as an accumulator 430. The hydraulic pump 386 supplies hydraulic fluid to one or more hydraulic circuits (not shown) for steering or other auxiliary function via line 442, charges the
15 accumulator 430, and may additionally supply hydraulic fluid to a communication line 418 for boost. The accumulator 430 supplies hydraulic fluid to the communication line 418 for boost. The accumulator 430 may be charged by the hydraulic pump 386 at maximum boost pressure set via a remote control valve 432. When the accumulator 430 is being charged, a control valve 434 may be
20 closed to prevent fluid flow to the valves 410 and 412. After the accumulator 430 is charged, flow from the accumulator provides boost at low demand, and when the cylinders 334 and 336 are retracted, the accumulator 430 is refilled by return flow from the cylinders 334 and 336.

The steering/boost system 362 also includes a check valve 444, a relief
25 valve 446, a pilot valve 448, a pressure reducing valve 450 for reducing the pressure of the fluid flowing from the pump 386 to the communication line 418, a pressure based stroking mechanism 452, a flow based stroking mechanism 454, a pressure compensation valve 456, and a remote compensation valve 458. As noted above, after the accumulator 430 has been charged and during low boost
30 demands, fluid is delivered from the accumulator 430 to the valves 410 and 412 to passively provide boost. As the boost demand increases and when steering is not demanded or the demand is low, flow is directed from the pump 386 at a boost pressure level and combines with the fluid from the accumulator 430.

When steering is demanded, the valve 430 controls the remote compensation valve 458 which controls the steering pressure level. If the boost demand is above the demand the accumulator 430 can supply, the fluid flows from the pump 386 to the pressure reducing valve 450, which reduces the pressure of the fluid from the steering pressure level to the boost pressure level. The reduced pressure fluid then combines with the fluid from the accumulator 430 and is directed to the valves 410 and 412.

Turning now to Fig. 6, an exemplary embodiment of the steering/boost system is shown at 462. The steering/boost system 462 is substantially the same as the above-referenced steering/boost system 62, and consequently the same reference numerals but indexed by 400 are used to denote structures corresponding to similar structures in the steering/boost systems. In addition, the foregoing description of the steering/boost system 62 is equally applicable to the steering/boost system 462 except as noted below. Moreover, it will be appreciated upon reading and understanding the specification that aspects of the steering/boost systems may be substituted for one another or used in conjunction with one another where applicable.

The steering/boost system 462 includes the electric motor 480, a hydraulic pump 486 mechanically connected to and driven by the single electric motor 480, a boost power transfer unit 532, and a boost actuation valve 534. The boost power transfer unit 532 includes a hydraulic motor 536, such as a fixed displacement motor, and a hydraulic pump 538, such as a fixed displacement pump mechanically connected to the hydraulic motor 536. The hydraulic motor 536 drives the hydraulic pump 538, which pumps fluid to the communication line 518 for boost. The transfer unit 532 may be bidirectional to regenerate by diverting pressure back to the steering circuit or dump boost to reservoir.

The hydraulic pump 486 may be a fixed displacement hydraulic pump that is sized to provide for maximum steering (or other auxiliary function) and maximum boost demand via the boost power transfer unit 532. When steering is demanded and boost is not demanded, the speed of the electric motor 480 may be varied to provide the required steering demand to the steering line 542. When steering and boost are demanded, the speed of the motor 480 is

increased to speed up the hydraulic pump 486, and the boost actuation valve 534 diverts fluid from the hydraulic pump 486 to the boost power transfer unit 532, which delivers boost flow to the communication line 518. The steering demand may be for high pressure/low flow, while the boost demand is for low pressure/high flow. The power transfer unit 532 may transform the high pressure steering flow demand to the lower pressure boost demand. The hydraulic power provided by the hydraulic pump 486 does not need to be throttled to the boost demand, which minimizes power losses due to pressure drops, and the on demand design reduces bypass power losses. It will be appreciated that the hydraulic pump 486 and the power transfer unit 532 may be replaced by a single triple pump gear pump.

Turning now to Fig. 7, an exemplary embodiment of the steering/boost system is shown at 562. The steering/boost system 562 is substantially the same as the above-referenced steering/boost system 462, and consequently the same reference numerals but indexed by 100 are used to denote structures corresponding to similar structures in the steering/boost systems. In addition, the foregoing description of the steering/boost system 462 is equally applicable to the steering/boost system 562 except as noted below. Moreover, it will be appreciated upon reading and understanding the specification that aspects of the steering/boost systems may be substituted for one another or used in conjunction with one another where applicable.

The steering/boost system 562 includes the electric motor 580, a hydraulic pump 586 mechanically connected to and driven by the single electric motor 580, a boost power transfer unit 632 having a hydraulic motor 636 and a hydraulic pump 638, a boost actuation valve 632, an accumulator 630, such as a low pressure accumulator, a boost fill/dump valve 644, and a boost accumulator isolation valve 646. The hydraulic pump 586 supplies hydraulic fluid to one or more hydraulic circuits (not shown) for steering or other auxiliary function via line 642 and directs fluid to the boost power transfer unit 632. The boost power transfer unit 632 charges the accumulator 630 and may additionally supply hydraulic fluid to a communication line 618 for boost. After the accumulator 630 is charged, the boost fill/dump valve 644 is closed and flow from the accumulator provides boost at low demand. When the cylinders are retracted, the

accumulator 630 is refilled by return flow from the cylinders. When the cylinder speed is high, the boost fill/dump valve 644 can send flow to the reservoir, and the boost accumulator isolation valve 646 will be closed to keep the pressure in the accumulator 630.

5 As noted above, after the accumulator 630 has been charged and during low boost demands, fluid is delivered from the accumulator 630 to passively provide boost. If the boost demand is above the demand the accumulator 630 can supply, the speed of the motor 580 is increased to speed up the hydraulic pump 586. The boost actuation valve 634 then diverts fluid from the hydraulic
10 pump 586 to the boost power transfer unit 632, which delivers boost flow to the communication line 618 individually or combines with fluid from the accumulator 630.

Turning now to Fig. 8, an exemplary embodiment of the steering/boost system is shown at 662. The steering/boost system 662 is substantially the
15 same as the above-referenced steering/boost system 562, and consequently the same reference numerals but indexed by 100 are used to denote structures corresponding to similar structures in the steering/boost systems. In addition, the foregoing description of the steering/boost system 562 is equally applicable to the steering/boost system 662 except as noted below. Moreover, it will be
20 appreciated upon reading and understanding the specification that aspects of the steering/boost systems may be substituted for one another or used in conjunction with one another where applicable.

The steering/boost system 662 includes the electric motor 680, a hydraulic pump 686 mechanically connected to and driven by the single electric
25 motor 680, a boost power transfer unit 732 having a hydraulic motor 736 and a hydraulic pump 738, a boost actuation valve 734, an accumulator 730, such as a low pressure accumulator, a boost fill/dump valve 744, and a boost accumulator isolation valve 746. The hydraulic pump 586 supplies hydraulic fluid to one or more hydraulic circuits (not shown) for steering or other auxiliary function via line
30 742 and directs fluid through the boost actuation valve 734 to the accumulator 730 or to the boost power transfer unit 732 to supply hydraulic fluid to a communication line 718 for boost. When the cylinders are retracted, the accumulator 730 is refilled by return flow from the cylinders through the boost

power transfer unit 732. When the cylinder speed is high, the boost fill/dump valve 744 can send flow to the reservoir, and the boost accumulator isolation valve 746 will be closed to keep the pressure in the accumulator 730.

After the accumulator 730 has been charged and during low boost
5 demands, fluid is delivered from the accumulator 730 to the boost power transfer unit 732 to provide boost. If the boost demand is above the demand the accumulator 730 can supply, the speed of the motor 680 is increased to speed up the hydraulic pump 686. The boost actuation valve 734 then diverts fluid from the hydraulic pump 686 to the boost power transfer unit 732, which delivers
10 boost flow to the communication line 718 individually or combined with fluid from the accumulator 730.

Turning now to Fig. 9, an exemplary embodiment of the steering/boost system is shown at 762. The steering/boost system 762 is substantially the same as the above-referenced steering/boost system 62, and consequently the
15 same reference numerals but indexed by 700 are used to denote structures corresponding to similar structures in the steering/boost systems. In addition, the foregoing description of the steering/boost system 62 is equally applicable to the steering/boost system 762 except as noted below. Moreover, it will be appreciated upon reading and understanding the specification that aspects of the
20 steering/boost systems may be substituted for one another or used in conjunction with one another where applicable.

The hydraulic system 756 includes actuator systems, one shown at 758, for controlling lift cylinder 734 and tilt cylinder (not shown), and a steering/boost system 762. The actuator system 758 and boost system 762 share an electric
25 motor 776, the system 758 includes at least one hydraulic pump 782 mechanically connected to the electric motor 776, and the system 762 includes at least one hydraulic pump 788 connected to the electric motor 776 by gear box 791 for boost and at least one hydraulic pump 786 for steering.

The steering/boost system 762 additionally includes an additional source
30 of pressurized fluid, such as an accumulator 830. The hydraulic pump 786 supplies hydraulic fluid to one or more hydraulic circuits (not shown) for steering or other auxiliary function via line 842 and directs fluid through a pressure reducing valve 850 to the accumulator 830 to precharge the accumulator 830.

During system operation, the hydraulic pump 788 can charge the accumulator 830 and can deliver boost flow through shuttle valves 844 and 846 individually or combined with fluid from the accumulator 830.

Turning now to Fig. 10, an exemplary embodiment of the hydraulic system is shown at 856. The hydraulic system 856 is substantially the same as the above-referenced hydraulic system 356, and consequently the same reference numerals but indexed by 500 are used to denote structures corresponding to similar structures in the systems. In addition, the foregoing description of the hydraulic system 356 is equally applicable to the hydraulic system 856 except as noted below. Moreover, it will be appreciated upon reading and understanding the specification that aspects of the systems may be substituted for one another or used in conjunction with one another where applicable.

The hydraulic system 856 includes actuator systems 858 and 860 for controlling lift and tilt cylinders 834 and 836, a boost system 862 and a voltage bus (not shown). Each system 858, 860 includes a regenerative drive (not shown), an electric motor 376, 378 and at least one hydraulic pump 382, 384 mechanically connected to the respective electric motor 376, 378. The hydraulic pumps 882 and 884 are connected to the respective cylinder 834, 836 through respective pump manifolds 906 and 908 housing respective control valves 910 and 912 and respective control valves 911 and 913, and connected through respective function manifolds 914 and 916 that each house one or more valves (not shown) that control cylinder speed during hydraulic regeneration or pressure dump. The manifolds 906, 908, 914 and 916 may also house pressure relief valves (not shown) that protect the pumps 882 and 884 and cylinders 834 and 836 from over pressurization. Check valves (not shown) may also be provided in parallel with the relief valves in the circuit between the pump and respective load holding valves (not shown) to prevent the possibility of cavitation from occurring.

The boost system 862 includes a source of pressurized fluid, such as an accumulator 930 that supplies hydraulic fluid to the communication line 918 for boost, a control valve 934 that may be opened/closed to allow/prevent fluid flow to the valves 910 and 912, a relief valve 946 that controls back pressure to the reservoir, and a pilot valve 948 that controls a pressure setting of the relief valve 946. The accumulator 930 is internally charged by one of the primary pumps

882 and 884, and thus an additional boost pump is not provided. For example, one of the pumps 882 or 884 may be run when not in use for actuation, for example at low torque, to pump fluid through the respective valve 911, 913 to charge the accumulator 930. When the pumps 882 and 884 are not charging the accumulator, the valves 911 and 913 are closed as shown in Fig. 10. When the accumulator 930 is being charged, the control valve 934 may be closed to prevent fluid flow to the valves 910 and 912. After the accumulator 930 is charged, flow from the accumulator provides boost, and when the cylinders 834 and 836 are retracted, the accumulator 930 is refilled by return flow from the cylinders 834 and 836.

It will be appreciated that steering may be provided by a steering pump driven by a motor connected to the voltage bus, and the steering pump may be smaller in size than the steering pump in Fig. 2, for example.

Although the invention has been shown and described with respect to a certain embodiment or embodiments, it is obvious that equivalent alterations and modifications will occur to others skilled in the art upon the reading and understanding of this specification and the annexed drawings. In particular regard to the various functions performed by the above described elements (components, assemblies, devices, compositions, etc.), the terms (including a reference to a "means") used to describe such elements are intended to correspond, unless otherwise indicated, to any element which performs the specified function of the described element (i.e., that is functionally equivalent), even though not structurally equivalent to the disclosed structure which performs the function in the herein illustrated exemplary embodiment or embodiments of the invention. In addition, while a particular feature of the invention may have been described above with respect to only one or more of several illustrated embodiments, such feature may be combined with one or more other features of the other embodiments, as may be desired and advantageous for any given or particular application.

30

Claims

What is claimed is:

1. A hydraulic system for a vehicle including:
 - 5 at least one primary hydraulic pump operable in one direction for supplying hydraulic fluid from a first port to an extend chamber of an unbalanced actuator and operable in another direction for supplying hydraulic fluid from a second port to a retract chamber of the actuator;
 - at least one primary electric motor for driving the at least one primary
 - 10 hydraulic pump;
 - at least one auxiliary hydraulic pump that collectively or singly supplies hydraulic fluid to one or more hydraulic circuits for steering and to a fluid communication line selectively in fluid communication with one of the first or second ports for boost; and
 - 15 a single auxiliary electric motor for driving the at least one hydraulic pump.
2. The hydraulic system according to claim 1, wherein the at least one auxiliary hydraulic pump includes at least one auxiliary hydraulic pump for supplying hydraulic fluid for steering and at least one hydraulic pump for supplying hydraulic fluid for boost, and wherein the at least one auxiliary
- 20 hydraulic pump for steering and the at least one hydraulic pump for boost are driven by the single auxiliary electric motor.
3. The hydraulic system according to claim 2, wherein the at least one
- 25 auxiliary hydraulic pump for steering and the at least one hydraulic pump for boost are variable displacement pumps.
4. The hydraulic system according to claim 2 or 3, wherein the single auxiliary electric motor is mechanically connected to the at least one auxiliary
- 30 hydraulic pump for steering and the at least one hydraulic pump for boost.
5. The hydraulic system according to claim 2, wherein the at least one auxiliary hydraulic pump for boost includes first and second auxiliary hydraulic

pumps for supplying hydraulic fluid for boost, and wherein the at least one auxiliary hydraulic pump for steering and the first and second auxiliary hydraulic pumps for boost are driven by the single auxiliary electric motor.

5 6. The hydraulic system according to claim 5, wherein the at least one auxiliary hydraulic pump for steering is a variable displacement pump, the first auxiliary hydraulic pump for boost is a variable displacement over-center hydraulic pump, and the second auxiliary hydraulic pump for boost is a fixed displacement pump.

10

 7. The hydraulic system according to claim 6, wherein the variable displacement over-center hydraulic pump and the fixed displacement pump are each sized to provide half of the boost flow.

15 8. The hydraulic system according to any of claims 5-7, wherein the single auxiliary electric motor is mechanically connected to the at least one auxiliary hydraulic pump for steering and the first and second auxiliary hydraulic pumps for boost.

20 9. The hydraulic system according to claim 2, wherein the at least one auxiliary hydraulic pump for steering is a variable displacement pump and the at least one auxiliary hydraulic pump for boost is a fixed displacement pump.

 10. The hydraulic system according to claim 9, further including a
25 bypass valve between the at least one auxiliary hydraulic pump for boost and the at least one primary hydraulic pump for directing fluid from the at least one auxiliary hydraulic pump for boost to a reservoir.

 11. The hydraulic system according to claim 10, further including a
30 control valve for opening and closing the bypass valve.

 12. The hydraulic system according to any of claims 9-11, wherein the single auxiliary electric motor is mechanically connected to the at least one

auxiliary hydraulic pump for steering and the at least one hydraulic pump for boost.

13. The hydraulic system according to claim 1, wherein the at least one
5 auxiliary hydraulic pump is a variable displacement pump.

14. The hydraulic system according to claim 13, further including an
accumulator for supplying hydraulic fluid to the fluid communication line for
boost, wherein the accumulator is charged by the at least one auxiliary hydraulic
10 pump.

15. The hydraulic system according to claim 14, further including a
pressure reducing valve, wherein the accumulator and the at least one auxiliary
hydraulic pump are configured to supply hydraulic fluid to the communication
15 line, and wherein the pressure reducing valve reduces the pressure of the fluid
from the at least one auxiliary hydraulic pump.

16. The hydraulic system according to any of claims 13-15, wherein
the single auxiliary electric motor is mechanically connected to the at least one
20 auxiliary hydraulic pump.

17. The hydraulic system according to claim 1, wherein the at least one
auxiliary hydraulic pump is a fixed displacement pump.

25 18. The hydraulic system according to claim 17, whereby flow of
hydraulic fluid from the at least one auxiliary hydraulic pump to the one or more
hydraulic motors for steering is determined by motor speed.

19. The hydraulic system according to claim 17 or 18, further including
30 a boost power transfer unit connected to the fluid communication line and a
boost activation valve, wherein the boost actuation valve is configured to divert
hydraulic fluid from the at least one auxiliary hydraulic pump to the boost power
transfer unit to produce boost flow.

20. The hydraulic system according to claim 19, wherein the boost power transfer unit includes a hydraulic motor-pump mechanically connected to a hydraulic pump-motor and a hydraulic pump driven by the motor.

5 21. The hydraulic system according to claim 20, wherein the hydraulic motor is a fixed displacement motor and the hydraulic pump is a fixed displacement pump mechanically connected to the hydraulic motor.

22. The hydraulic system according to any of claims 17-21, wherein
10 the single auxiliary electric motor is mechanically connected to the at least one auxiliary hydraulic pump.

23. The hydraulic system according to any of claims 17-22, further including an accumulator for supplying hydraulic fluid to the fluid communication
15 line for boost, wherein the accumulator is charged by the boost power transfer unit or the at least one auxiliary hydraulic pump.

24. A hydraulic system for a vehicle including:
at least one primary hydraulic pump operable in one direction for
20 supplying hydraulic fluid from a first port to an extend chamber of an unbalanced actuator and operable in another direction for supplying hydraulic fluid from a second port to a retract chamber of the actuator;
at least one primary electric motor for driving the at least one primary hydraulic pump;
25 an auxiliary hydraulic pump for supplying hydraulic fluid at least to a hydraulic circuit for an auxiliary function;
at least one additional source of pressurized fluid for supplying hydraulic fluid to a fluid communication line selectively in fluid communication with one of the first or second ports for boost; and
30 a single auxiliary electric motor for directly or indirectly powering the auxiliary hydraulic pump and the at least one additional source of pressurized hydraulic fluid.

25. The hydraulic system according to claim 24, wherein the at least one additional source of pressurized fluid includes at least one auxiliary hydraulic pump for boost.

5 26. The hydraulic system according to claim 24, wherein the at least one additional source of pressurized fluid includes an accumulator for boost, wherein the accumulator is charged by the auxiliary hydraulic pump.

10 27. The hydraulic system according to claim 24, wherein the at least one additional source of pressurized fluid includes a boost power transfer unit for boost.

15 28. The hydraulic system according to claim 27, further including a boost actuation valve configured to divert hydraulic fluid from the auxiliary hydraulic pump to the boost power transfer unit to produce boost flow.

20 29. The hydraulic system according to claim 27 or 28, wherein the at least one additional source of pressurized fluid additionally includes an accumulator for supplying hydraulic fluid to the fluid communication line for boost, wherein the accumulator is charged by the boost power transfer unit.

30. A hydraulic system for a vehicle including:
a first hydraulic circuit;
a second hydraulic circuit;
25 a hydraulic pump for supplying hydraulic fluid at least to the first hydraulic circuit;
at least one additional source of pressurized fluid for supplying hydraulic fluid to the second hydraulic circuit; and
a single electric motor for directly or indirectly powering the hydraulic
30 pump and the at least one additional source of pressurized hydraulic fluid.

31. The hydraulic system according to claim 30, wherein the first circuit is a boost circuit and the second circuit is a steering circuit.

32. The hydraulic system according to claim 31, wherein the hydraulic pump is configured to supply hydraulic fluid to a hydraulic motor for steering.

33. The hydraulic system according to claim 31 or 32, wherein the at
5 least one additional source of pressurized fluid is configured to supply hydraulic fluid to a fluid communication line selectively in fluid communication with a port of a hydraulic pump for boost.

34. The hydraulic system according to claim 30, wherein the first and
10 second circuits are independently driven boost circuits.

35. The hydraulic system according to any preceding claim, wherein the single electric motor is a variable rotational speed motor.

36. A hydraulic system for a vehicle including:
at least one primary hydraulic pump operable in one direction for supplying hydraulic fluid from a first port to an extend chamber of an unbalanced actuator and operable in another direction for supplying hydraulic fluid from a second port to a retract chamber of the actuator;
20 at least one primary electric motor for driving the at least one primary hydraulic pump;
at least one auxiliary hydraulic pump that supplies hydraulic fluid to a fluid communication line selectively in fluid communication with one of the first or second ports for boost; and
25 a gear box connecting the at least one auxiliary hydraulic pump to the at least one primary electric motor to drive the at least one auxiliary hydraulic pump.

37. The hydraulic system according to claim 36, further including an
30 accumulator for supplying hydraulic fluid to the fluid communication line for boost, wherein the accumulator is charged by the at least one auxiliary hydraulic pump.

38. A hydraulic system for a vehicle including:
at least one primary hydraulic pump operable in one direction for
supplying hydraulic fluid from a first port to an extend chamber of an unbalanced
actuator and operable in another direction for supplying hydraulic fluid from a
5 second port to a retract chamber of the actuator;
at least one electric motor for driving the at least one primary hydraulic
pump; and
an accumulator for supplying hydraulic fluid to a fluid communication line
selectively in fluid communication with one of the first or second ports for boost,
10 wherein the accumulator is charged by the at least one primary hydraulic
pump and/or by flow from the retract chamber when the actuator is retracted.

39. The hydraulic system according to claim 38, further including a
control valve connecting the at least one primary hydraulic pump to the
15 accumulator, wherein the control valve is open when the accumulator is being
charged by the at least one primary hydraulic pump and closed when the
accumulator is not being charged by the at least one primary hydraulic pump.

40. The hydraulic system according to claim 38 or 39, further including:
20 at least one other primary hydraulic pump operable in one direction for
supplying hydraulic fluid from a first port to an extend chamber of another
unbalanced actuator and operable in another direction for supplying hydraulic
fluid from a second port to a retract chamber of the other actuator; and
at least one other electric motor for driving the at least one other primary
25 hydraulic pump,
wherein the accumulator is charged by the at least one other primary
hydraulic pump and/or by flow from the retract chamber when the other actuator
is retracted.

41. The hydraulic system according to claim 40, further including
30 another control valve connecting the at least one other primary hydraulic pump
to the accumulator, wherein the another control valve is open when the
accumulator is being charged by the at least one other primary hydraulic pump

and closed when the accumulator is not being charged by the at least one other primary hydraulic pump.

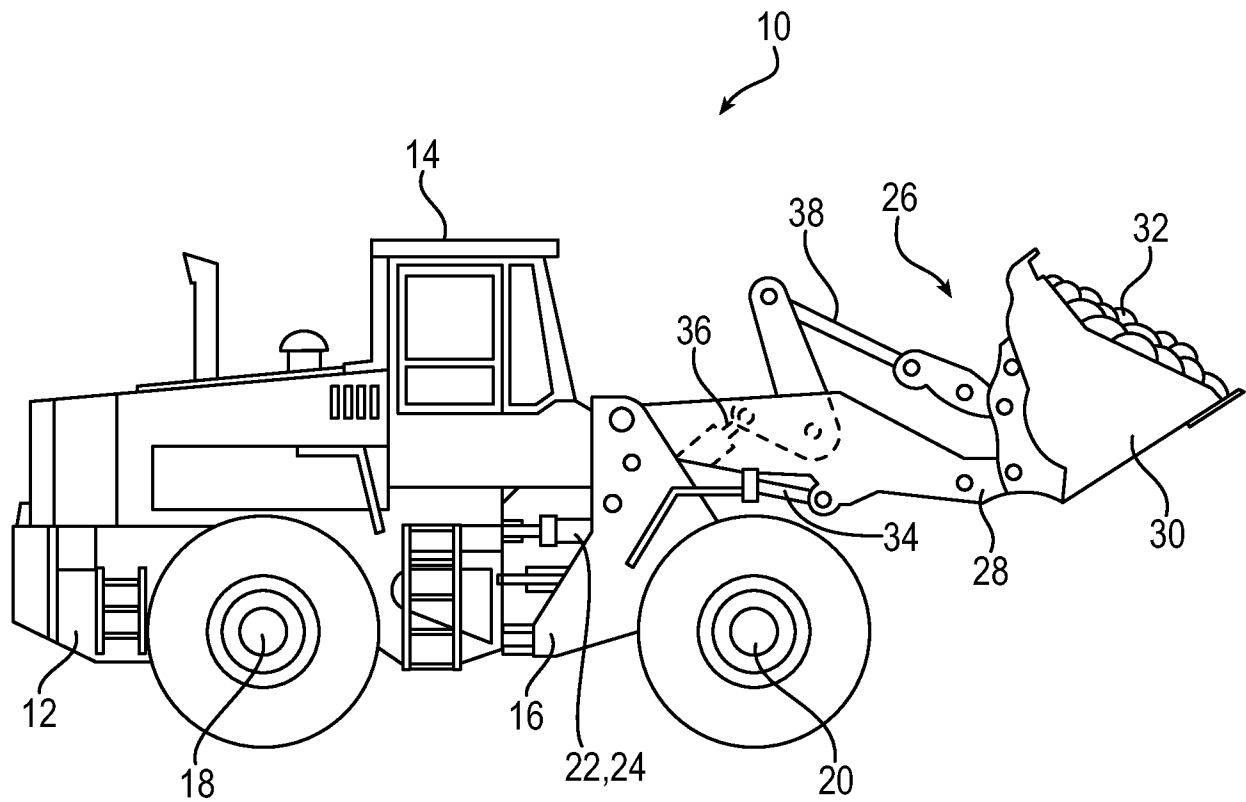


FIG. 1

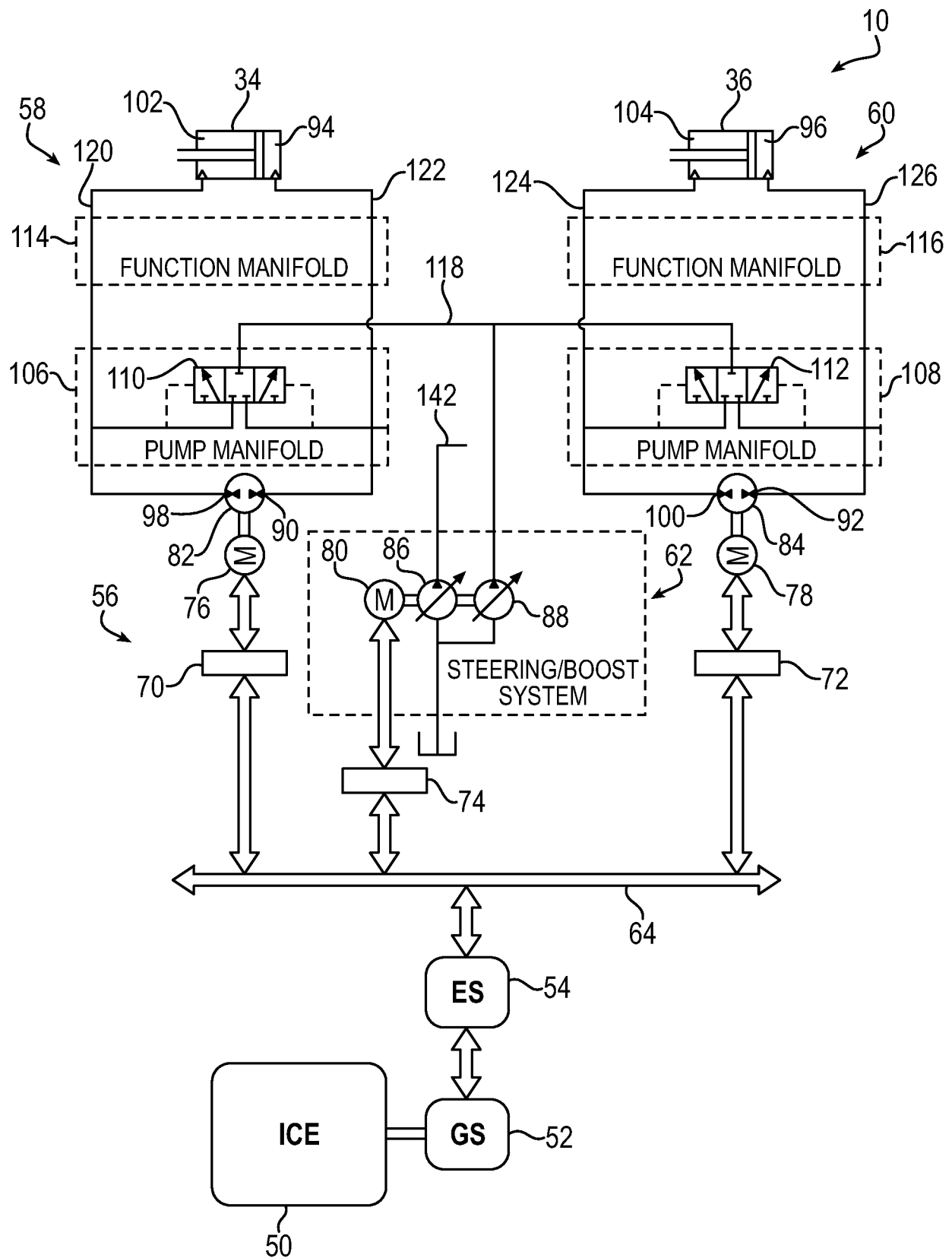


FIG. 2

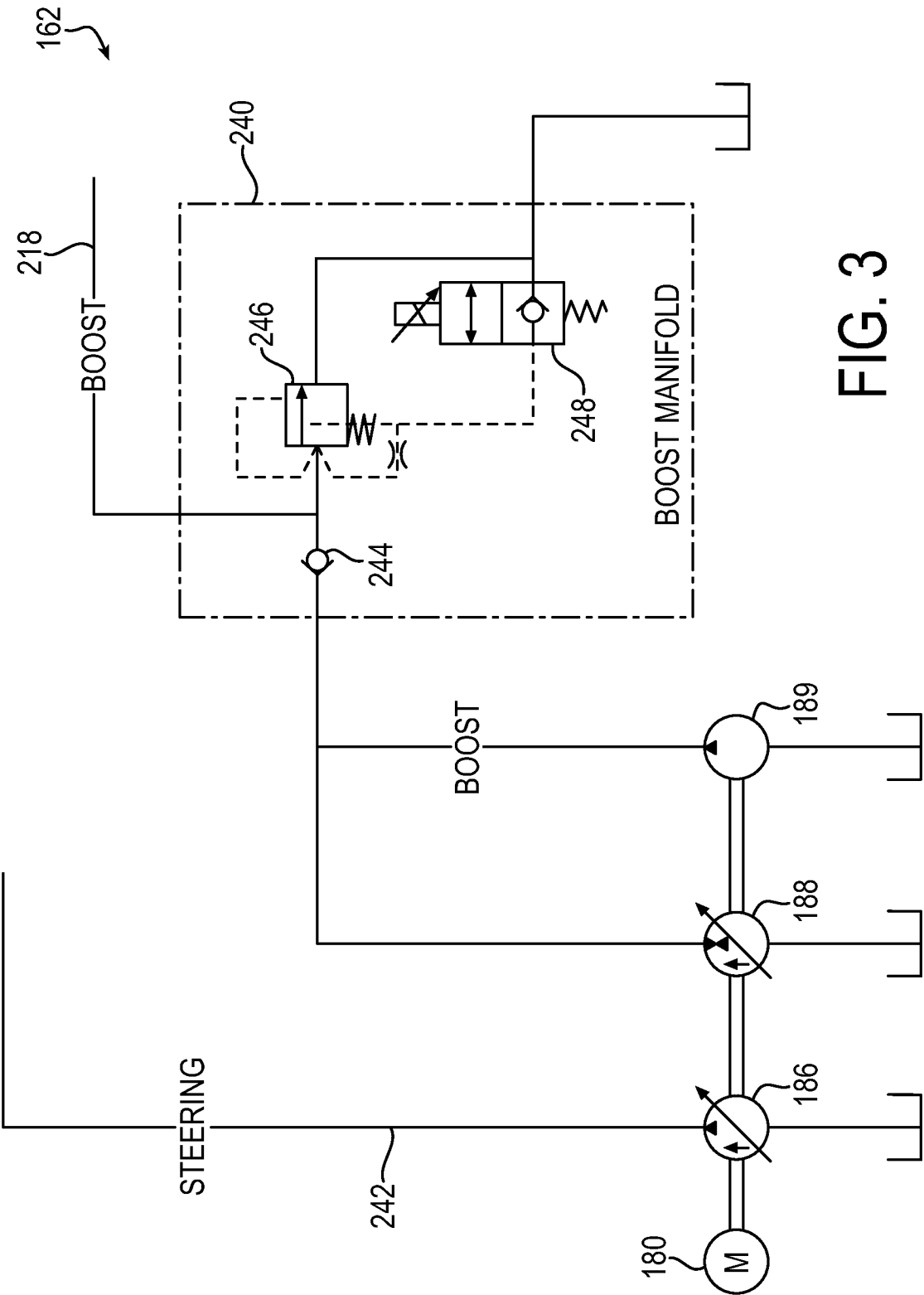


FIG. 3

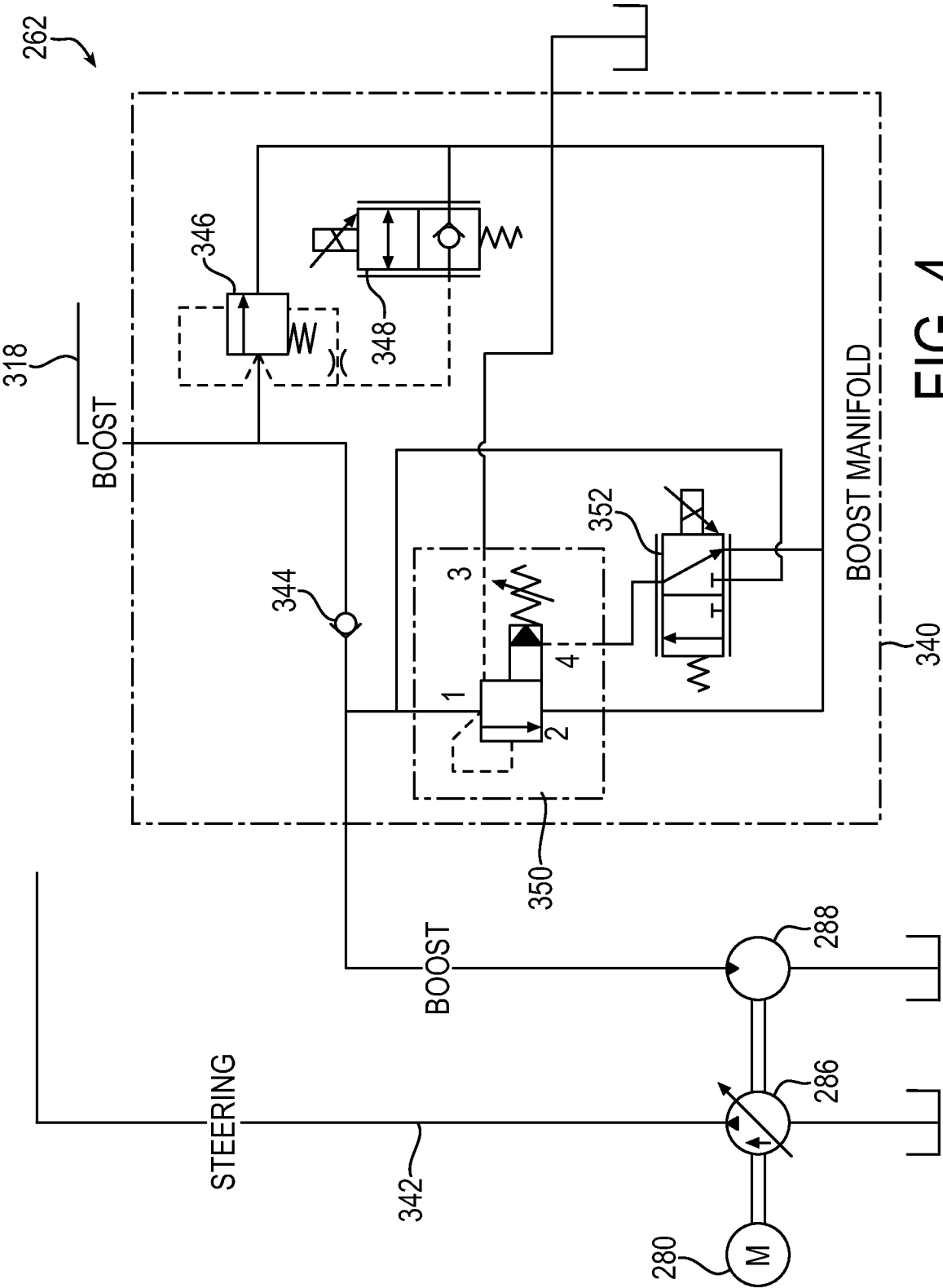


FIG. 4

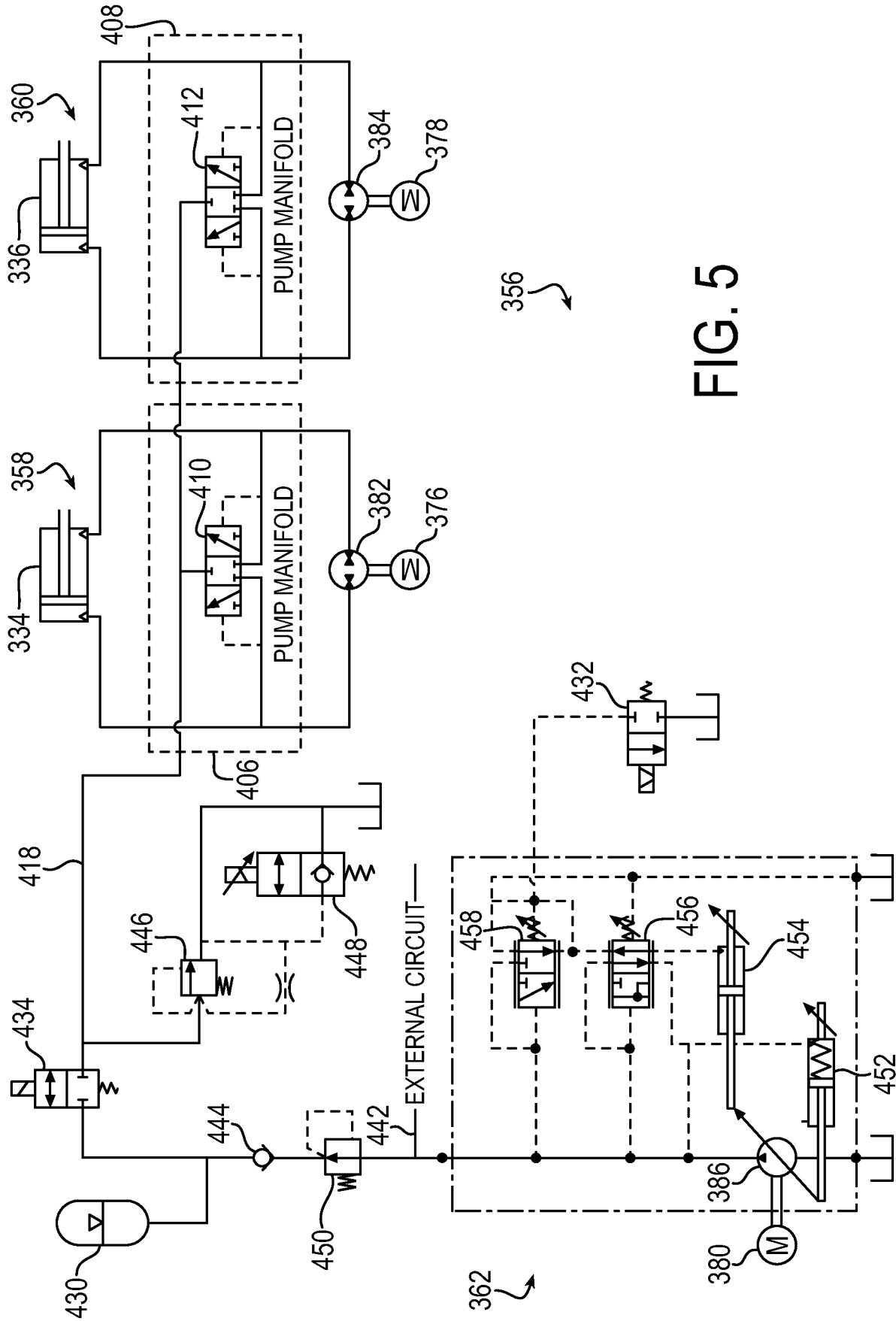


FIG. 5

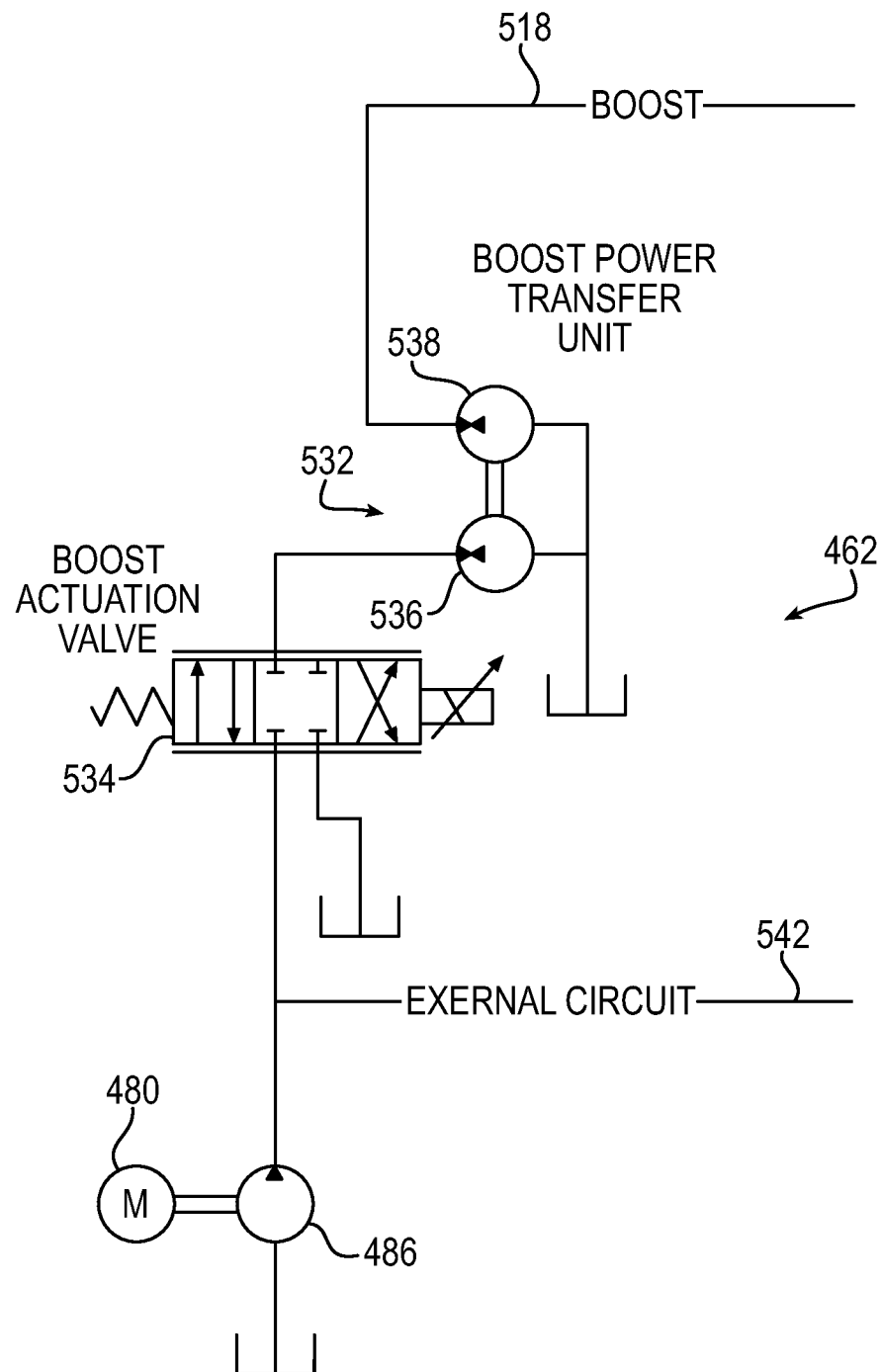


FIG. 6

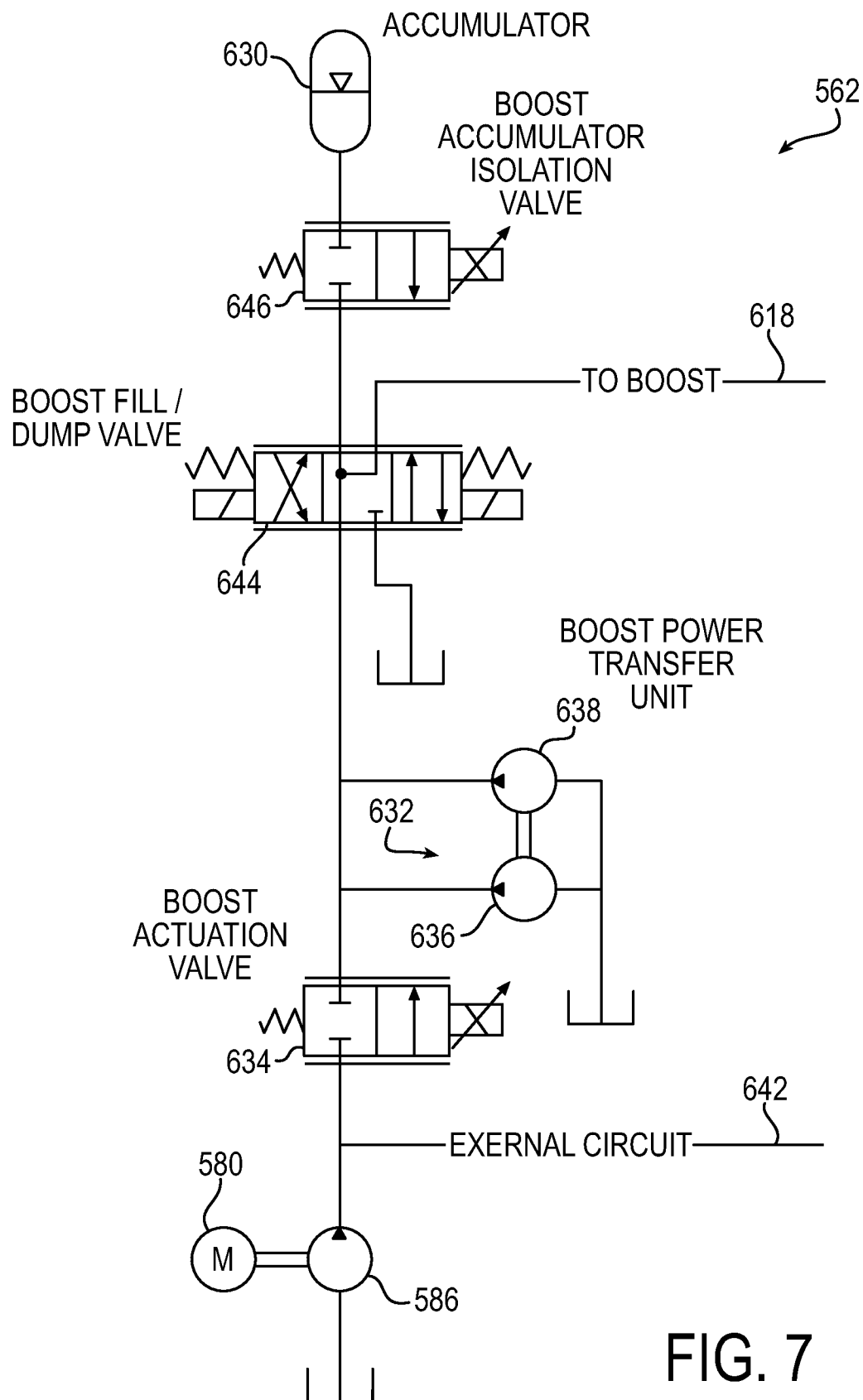


FIG. 7

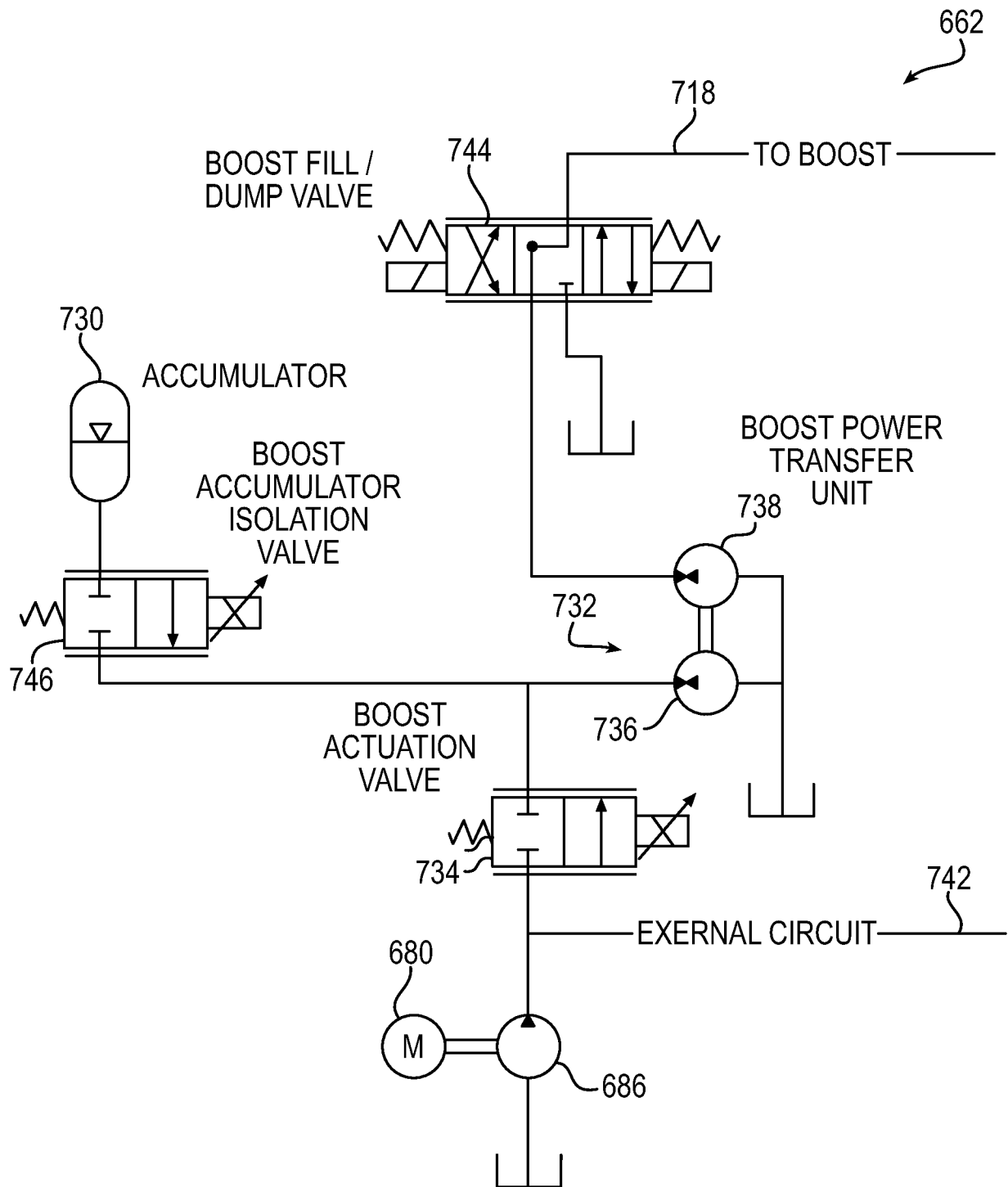


FIG. 8

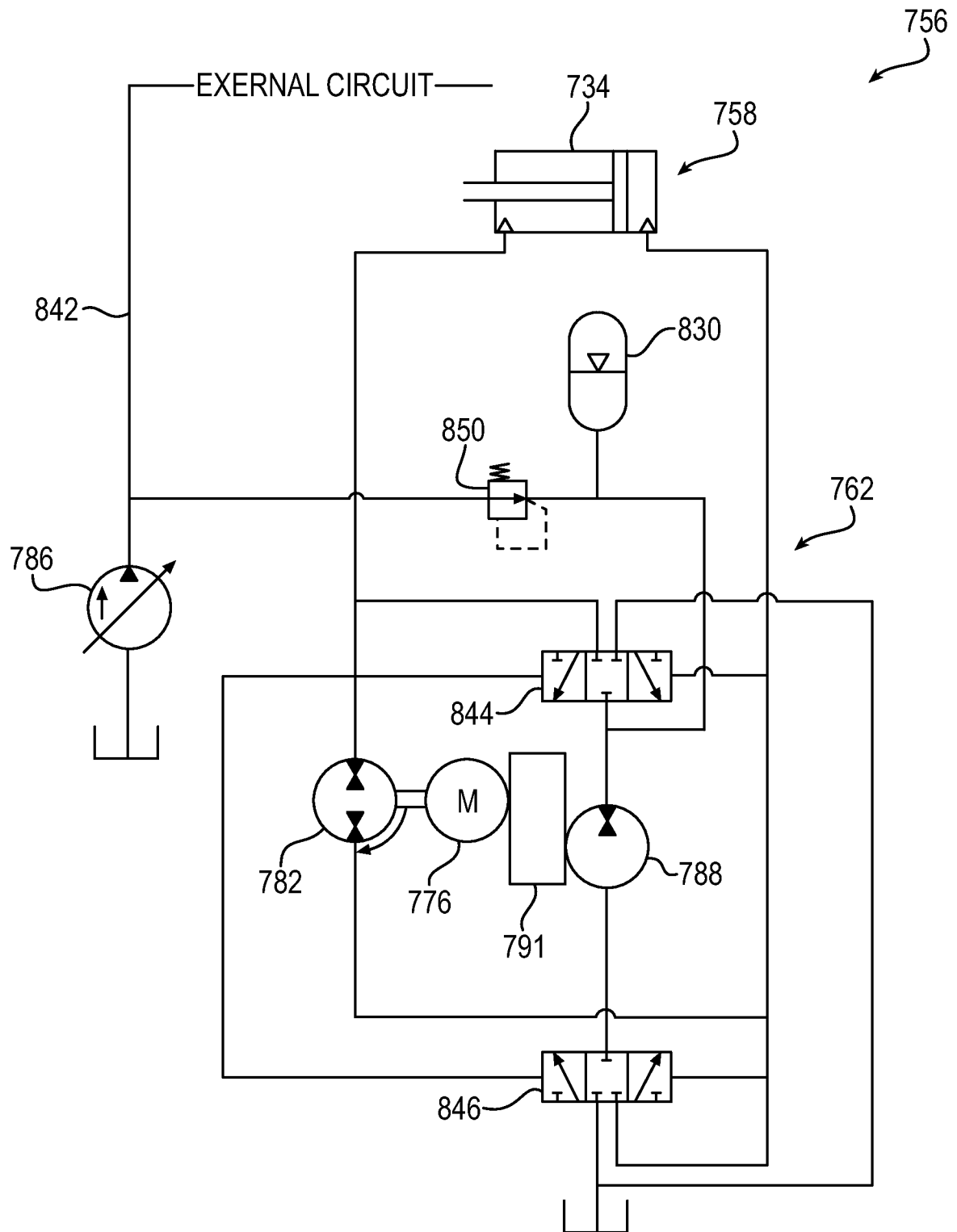


FIG. 9

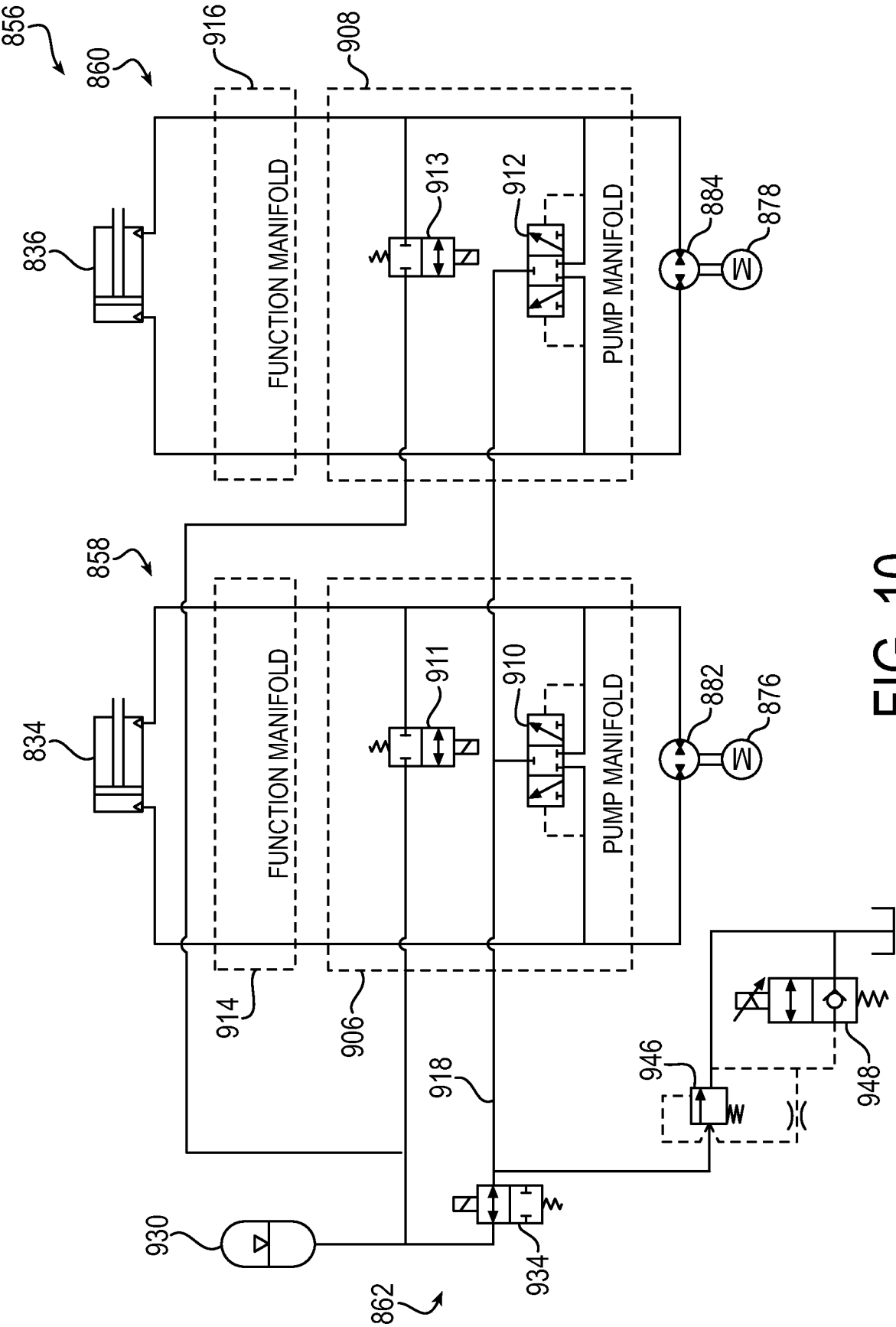


FIG. 10