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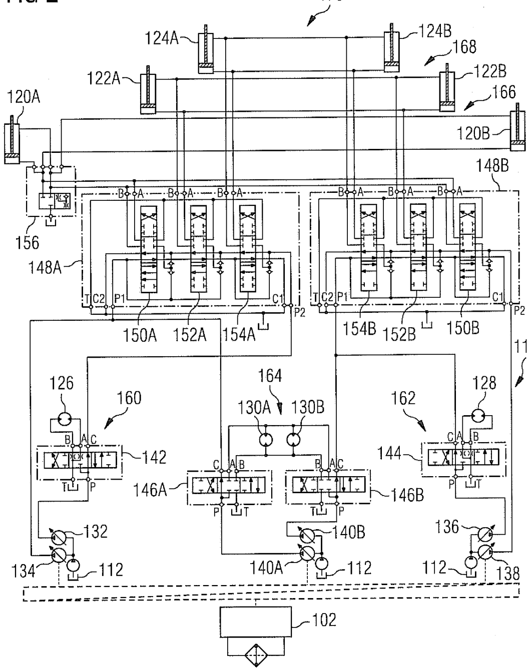
(54) System and method for providing hydraulic power to a plurality of hydraulic circuits of a machine

(57) A system (116) for providing hydraulic power to a hydraulic system of a machine allows assigning individual hydraulic pumps (132-140B) to different hydraulic circuits (160-170) of the hydraulic system. The system (116) reduces flow sharing between the different hydraulic circuits (160-170) to avoid pressure drop losses. A plurality of control valves (142-150B) regulate the flow to the different circuits and may be switched to selectively associate one or more hydraulic pumps (132-140B) to a particular hydraulic circuit. The distribution of the pumps may be determined based on priorities of the different hydraulic circuits and the flow required by each circuit. The flow rate for each hydraulic circuit is controlled by the displacement of the associated hydraulic pumps.

FIG 2



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Description

Technical Field

[0001] The present disclosure generally relates to a hydraulic power system, in particular to a system and method for providing hydraulic power to a plurality of hydraulic circuits of a machine.

Background

[0002] Hydraulic machines, for example, hydraulic excavators, use engines to drive hydraulic pumps, which in turn provide hydraulic power to a plurality of hydraulic circuits of the hydraulic machines. Each hydraulic circuit may include one or more actuators, for example, hydraulic cylinders and/or hydraulic motors. The plurality of hydraulic circuits each may require a flow of hydraulic fluid from the plurality of hydraulic pumps to operate the associated hydraulic cylinders or hydraulic motors. The amount of flow required by each hydraulic circuit may vary depending on an operator input. The hydraulic pumps may be controlled to supply the hydraulic system with the hydraulic flow required by each of the plurality of hydraulic circuits.

[0003] Various control systems have been implemented to control power distribution within hydraulic machines including a plurality of hydraulic pumps. In some systems, the total flow required by the plurality of hydraulic circuits is determined and divided by the number of hydraulic pumps. The resulting flow is converted into a flow command for each hydraulic pump. The hydraulic flow provided by each of the plurality of hydraulic pumps on the basis of this flow command is distributed to the plurality of hydraulic circuits depending on the hydraulic flow demand of each circuit. For example, one or more control valves may be configured to direct part of the hydraulic flow from one hydraulic pump to one hydraulic circuit, and direct another part of the hydraulic flow from the hydraulic pump to another one of the hydraulic circuits.

[0004] The disclosed systems and methods are directed to overcoming one or more problems of the prior art systems.

Summary of the Disclosure

[0005] In one aspect, the present disclosure relates to a system for providing hydraulic power to a plurality of hydraulic circuits of a machine. The system comprises a plurality of hydraulic pumps for supplying the plurality of hydraulic circuits with hydraulic fluid, a plurality of control valves operable to associate each of the plurality of hydraulic pumps with one of the plurality of hydraulic circuits for supplying hydraulic fluid exclusively to the associated hydraulic circuit, and a control unit. The control unit is configured to determine a hydraulic flow required by each of the plurality of hydraulic circuits, determine a number of hydraulic pumps to be associated with each of the plurality of hydraulic circuits based on the hydraulic flow required by the plurality of hydraulic circuits, operate the plurality of control valves to exclusively associate the determined number of hydraulic pumps with each of the plurality of hydraulic circuits, and operate the plurality of hydraulic pumps to supply the required hydraulic flow to each of the plurality of hydraulic circuits.

[0006] In another aspect of the present disclosure, a machine comprises an engine, a plurality of hydraulic pumps powered at least in part by the engine, a plurality of hydraulic circuits, and a plurality of control valves operable to associate each of the plurality of hydraulic pumps with one of the plurality of hydraulic circuits for supplying hydraulic fluid exclusively to the associated hydraulic circuit. The machine further comprises a control unit operatively connected to the plurality of hydraulic pumps and the plurality of control valves. The control unit is configured to determine a hydraulic flow required by each of the plurality of hydraulic circuits, determine a number of hydraulic pumps to be associated with each of the plurality of hydraulic circuits based on the hydraulic flows required by the plurality of hydraulic circuits, operate the plurality of control valves to exclusively associate the determined number of hydraulic pumps with each of the plurality of hydraulic circuits, and operate the plurality of hydraulic pumps to supply the required hydraulic flow to each of the plurality of hydraulic circuits.

[0007] In another aspect of the present disclosure, a method of operating a machine including a plurality of hydraulic circuits, a plurality of hydraulic pumps and a plurality of control valves comprises the steps of determining a hydraulic flow required by each of the plurality of hydraulic circuits and determining a number of hydraulic pumps to be associated with each of the plurality of hydraulic circuits based on the hydraulic flows required by the plurality of hydraulic circuits. The method further comprises the steps of operating the plurality of control valves to exclusively associate the determined number of hydraulic pumps with each of the plurality of hydraulic circuits for supplying a flow of hydraulic fluid exclusively to the associated hydraulic circuit, and operating the plurality of hydraulic pumps to supply the required flow to each of the plurality of hydraulic circuits.

[0008] In a further aspect, the present disclosure relates to a computer program comprising computer-executable instructions which, when executed by a computer, cause the computer to perform the steps of determining a hydraulic flow required by each of a plurality of hydraulic circuits of a machine, determining a number of hydraulic pumps of the machine to be associated with each of the plurality of hydraulic circuits based on the hydraulic flows required by the plurality of hydraulic circuits, operating a plurality of control valves of the machine to exclusively associate the determined number of hydraulic pumps with each of the plurality of hydraulic circuits for supplying a flow of hydraulic fluid exclusively to the associated hydraulic circuit, and operating the plurality of hydraulic pumps to supply the required hydraulic flow to each of the plurality of hydraulic circuits.

[0009] Other features and aspects of the disclosure will be apparent from the following description and the accompanying drawings.

Brief Description of the Drawings

[0010]

Fig. 1 is a schematic illustration of a machine in accordance with an exemplary embodiment of the present disclosure;

Fig. 2 schematically illustrates a system for providing hydraulic power to a plurality of hydraulic circuits in accordance with an exemplary embodiment of the present disclosure; and

Fig. 3 is a logical block diagram of an exemplary control process for the system of Fig. 2 in accordance with the present disclosure.

Detailed Description

[0011] The following is a detailed description of exemplary embodiments of the present disclosure. The exemplary embodiments described herein are intended to teach the principles of the present disclosure, enabling those of ordinary skill in the art to implement and use the present disclosure in many different environments and for many different applications. Therefore, the exemplary embodiments are not intended to be, and should not be considered as a limiting description of the scope of protection. Rather, the scope of protection shall be defined by the appended claims.

[0012] The present disclosure may be based in part on the realization that, when flow sharing occurs between different hydraulic circuits, pressure drop losses may occur. According to the present disclosure, each of a plurality of hydraulic pumps on a machine is associated with only one hydraulic circuit at a time to provide hydraulic power exclusively to the associated hydraulic circuit. Accordingly, flow sharing between different hydraulic circuits and the resulting pressure drop losses may be reduced.

[0013] Further, the present disclosure may be based in part on the realization that variable displacement hydraulic pumps may be used to control the hydraulic flow supplied to each hydraulic circuit, while open center valves arranged in a unique schematic may be used primarily for direction control of the pump flow into the corresponding circuits and, at the same time, provide the necessary damping during a transition.

[0014] In addition, the present disclosure may be based in part on the realization that the plurality of hydraulic pumps may be allocated to the plurality of hydraulic circuits during a flow limited condition such that circuit flow ratios between the hydraulic circuits can be maintained. Further, the present disclosure may be based in part on the realization that reducing the pump displacement of the variable displacement pumps may allow maintaining a desired engine speed under overload conditions. Moreover, the present disclosure may be based in part on the realization that controlling a pump pressure during overrunning load conditions of associated hydraulic circuits may minimize a pressure drop across the pump-to-actuator spool area.

[0015] Referring now to the drawings, an exemplary embodiment of a machine 100 is schematically shown in Fig. 1. Machine 100 may be a hydraulic excavator, for example, a large mining excavator, or any other work machine that includes a hydraulic system, for example, a loader or the like. Machine 100 includes an engine 102. Engine 102 may provide power for machine 100 and its various components. Suitable engines may include gasoline powered engines, diesel powered engines, electrically powered engines or any combination of different types of engines. In one embodiment, engine 102 may be a diesel engine that generates and transfer power to other components of machine 100 through a power transfer mechanism, for example, a shaft or gearbox (not shown). Engine 102 may produce a mechanical power output that may be converted to hydraulic power, for example, by one or more pumps powered by engine 102.

[0016] Machine 100 may further include an operator station or cab 104 containing controls for operating machine 100, for example, an input device 106. Input device 106 may be embodied as joysticks, levers, buttons, and the like and may be operatively connected to a hydraulic system 108 of machine 100.

[0017] In some embodiments, cab 104 may further include interfaces such as a display for conveying information to an operator, and may include a keyboard, a touch screen or any other suitable mechanism for receiving an input from an operator to control or operate machine 100, hydraulic system 108 and/or other machine components. Alternatively or additionally, an operator may be located outside of cab 104 and/or some distance away from machine 100 and may control machine 100, hydraulic system 108 and/or other machine components remotely.

[0018] Hydraulic system 108 may include fluid components such as, for example, hydraulic actuators or cylinders, tanks, valves, accumulators, orifices and other suitable components for producing a pressurized flow of hydraulic fluid. Hydraulic system 108 may further comprise fluid sources, for example, one or more tanks and/or a reservoir 112, and one or more hydraulic pumps, which may include variable displacement pumps, fixed displacement pumps, variable delivery pumps or other suitable pressurizing systems. The hydraulic pumps may be drivably connected to engine 102, or may be indirectly connected to engine 102 via a gear mechanism or the like. It is also contemplated that hydraulic system 108 may include multiple sources of pressurized fluid interconnected to provide hydraulic fluid for hydraulic system 108.

[0019] Hydraulic system 108 may include a plurality of hydraulic actuators, for example, hydraulic actuators

120A, 120B for operating a boom of machine 100, a hydraulic actuator 122 for operating a stick of machine 100, a hydraulic actuator 124 for operating a bucket of machine 100, one or more hydraulic motors 130A, 130B (see Fig. 2) for operating a swing mechanism of machine 100, and a hydraulic motor 126 associated with a left propel drive and a hydraulic motor 128 associated with a right propel drive (see Fig. 2) of propelling machine 100. It should be appreciated that, in other embodiments, different numbers of hydraulic motors and/or hydraulic actuators may be provided for the different hydraulic circuits.

[0020] Hydraulic system 108 further includes a system 116 for providing hydraulic power to actuators 120A, 120B, 122, 124 and motors 126, 128, 130A, 130B, which will be described in more detail below.

[0021] Machine 100 also includes a control unit 114 suitable for controlling hydraulic system 108 and other components of machine 100. Control unit 114 may be operatively connected to input device 106 and may be adapted to receive an input from an operator indicative of a desired movement (or a desired velocity) of machine 100 or an implement of machine 100, and thus may determine a power demand associated with each hydraulic actuator or motor of hydraulic system 108 for performing the desired movements.

[0022] Control unit 114 may include one or more control modules (for example, ECMs, ECUs, etc.). The one or more control modules may include processing units, a memory, sensor interfaces and/or control interfaces for receiving and transmitting signals. The processing units may represent one or more logic and/or processing components used by the system according to the present disclosure to perform various communications, control and/or diagnostic functions. The one or more control modules may communicate to each other and to other components within and interfacing control unit 114 using any appropriate communication mechanisms, for example, a CAN bus.

[0023] Further, the processing units may be adapted to execute instructions, for example, from a storage device such as a memory. The one or more control modules may each be responsible for executing software code for system 116 and/or other components of machine 100. The processing units may include, for example, one or more general purpose processing units and/or special purpose units (for example, ASICs, FPGAs, etc.). In some embodiments, the functionality of the processing units may be embodied in an integrated microprocessor or microcontroller, including an integrated CPU, a memory, and one or more peripherals. The control modules of control unit 114 will be described in more detail below.

[0024] Referring now to Fig. 2, an exemplary embodiment of the system 116 for providing hydraulic power to a plurality of hydraulic circuits is shown in more detail. In the exemplary embodiment shown in Fig. 2, machine 100 includes a plurality of hydraulic circuits 160, 162, 166, 168, 170.

[0025] Hydraulic circuit 160 includes a hydraulic motor 126 associated with a left propel drive of machine 100. Hydraulic motor 126 is configured to receive a flow of hydraulic fluid to power a left propel drive of machine 100 in a known manner.

[0026] Hydraulic circuit 162 includes a hydraulic motor 128 associated with a right propel drive of machine 100. Hydraulic motor 128 is configured to receive a flow of hydraulic fluid to power a right propel drive of machine 100 in a known manner.

[0027] Hydraulic circuit 164 includes hydraulic motors 130A, 130B configured to drive a swing mechanism of machine 100. Hydraulic motors 130A, 130B are configured in a known manner to receive hydraulic fluid to effect swinging of, for example, operator cab 104 and the implement system of machine 100 about a vertical axis of machine 100.

[0028] Hydraulic circuit 166 includes a pair of actuators 120A, 120B associated with the boom of machine 100. Actuators 120A, 120B are configured to receive hydraulic fluid to raise or lower the boom of machine 100 in a known manner. Actuators 120A, 120B may be embodied as hydraulic cylinders including a piston and a piston rod reciprocating within the piston as schematically shown in Fig. 2. When an operator operates input device 106 to raise or lower the boom of machine 100, the signal received from input device 106 may be converted into a required hydraulic flow for actuators 120A, 120B by control unit 114. The required hydraulic flow results in actuators 120A, 120B moving the boom of machine 100 with the commanded velocity. It should be appreciated that, while two actuators 120A, 120B are shown in Figs. 1 and 2, a different number of actuators may be included in hydraulic circuit 166 in other embodiments according to the present disclosure. In the exemplary embodiment shown in Fig. 2, a float valve 156 is associated with hydraulic circuit 166 for operating the boom of machine 100 in a known manner. It should be appreciated that float valve 156 may be omitted in other embodiments in accordance with the present disclosure.

[0029] Hydraulic circuit 168 includes actuators 122A, 122B associated with the stick of machine 100. Actuators 122A, 122B are configured to receive hydraulic fluid to raise or lower the stick of machine 100 in correspondence to an operation of input device 106 by an operator. Actuators 122A, 122B are configured substantially similar to actuators 120A, 120B. It should be appreciated that hydraulic circuit 168 may include a different number of actuators, for example, a single actuator 122 as shown in Fig. 1, or more than two actuators. It should be appreciated that, in some embodiments, a float valve (not shown) may be associated with hydraulic circuit 168.

[0030] Hydraulic circuit 170 includes actuators 124A, 124B associated with the bucket of machine 100 and configured to move the bucket in response to a corresponding command input by an operator via input device 106. It should again be appreciated that any appropriate number of actuators may be included in hydraulic circuit

170, and that in some embodiments a float valve (not shown) may be associated with hydraulic circuit 170.

[0031] Each of hydraulic circuits 160-170 is configured to receive a required flow of hydraulic fluid from system 116. System 116 includes a plurality of hydraulic pumps 132, 134, 136, 138, 140A, 140B, a plurality of control valves 142, 144, 146A, 146B, 150A, 150B, 152A, 152B, 154A, 154B, a plurality of hydraulic lines fluidly connecting the various components of system 116, and a plurality of pressure sensors (not shown) for detecting pressure within system 116. Control valves 150A, 152A, 154A may form a first group of control valves 148A, and control valves 150B, 152B, 154B may form a second group of control valves 148B.

[0032] Hydraulic pump 132 is fluidly connected to reservoir 112 and is configured to draw hydraulic fluid from reservoir 112 and supply a flow of hydraulic fluid to control valve 142. Hydraulic pump 134 is configured to draw hydraulic fluid from reservoir 112 and supply the hydraulic fluid to control valve 150A and, via a bypass line, to control valve 152A. As shown in Fig. 2, hydraulic pump 134 is further configured to supply hydraulic fluid to control valve 154A when control valves 150A and 152A are operated accordingly.

[0033] Hydraulic pump 136 is configured to draw hydraulic fluid from reservoir 112 and provide the hydraulic fluid to control valve 144. Hydraulic pump 138 is configured to draw hydraulic fluid from reservoir 112 and provide the hydraulic fluid to control valve 150B, and, when control valves 150B and 152B are operated accordingly, to control valves 152B and 154B.

[0034] Hydraulic pump 140A is configured to draw hydraulic fluid from reservoir 112 and supply the hydraulic fluid to control valve 146A. Hydraulic pump 140B is configured to draw hydraulic fluid from reservoir 112 and provide the hydraulic fluid to control valve 146B.

[0035] Hydraulic pumps 132-140B are configured to be driven by engine 102. In some embodiments, hydraulic pumps 132-140B may be variable displacement pumps and may be configured to be operated with engine 102 running at a desired engine speed. In some embodiments, hydraulic pumps 132-140B may have the same configuration, i.e. the same maximum available displacement.

[0036] Control valve 142 is configured to receive hydraulic fluid from hydraulic pump 132 at a first port P. In the exemplary embodiment shown in Fig. 2, control valve 142 is an open center valve. In a first position, control valve 142 is configured to supply the hydraulic fluid received at port P to hydraulic circuit 160 via a port B and receive a return flow of hydraulic fluid from hydraulic circuit 160 at a port A. The return flow of hydraulic fluid is directed to a tank via a port T when control valve 142 is in the first position. The tank may be fluidly connected to reservoir 112, or the hydraulic fluid may be directly returned to reservoir 112 from port T. In a second position, control valve 142 is configured to supply the hydraulic fluid received at port P to hydraulic circuit 160 via port A, and receive a return flow of hydraulic fluid from hydraulic circuit 160 at port B. The return flow of hydraulic fluid may be returned to the tank or reservoir 112 via port T. In a third position, i.e. a center position of control valve 142, the hydraulic fluid received at port P is supplied to control valve 154A via a hydraulic line connecting control valves 142 and 154A. Depending on the operation of control valves 154A and 152A, the hydraulic fluid received at port P may also be supplied to control valves 152A and 150A.

[0037] It should be appreciated that control valve 142 may also be operated to be in an intermediate position between, for example, the first and third positions. In this case, part of the hydraulic fluid supplied to control valve 142 is supplied to hydraulic circuit 160, and part of the hydraulic fluid supplied to control valve 142 is supplied to control valve 154A. As will be described below, however, in the exemplary embodiment of system 116 according to the present disclosure, control valve 142 is generally operated to be in one of the first to third positions. Accordingly, control valve 142 (and also control valves 144-154B) is primarily used for routing the flow to one of hydraulic circuits 160-170 and/or for controlling the direction of the flow into the associated hydraulic circuit.

[0038] Control valve 144 has a similar configuration to control valve 142, such that a detailed description of the same will be omitted. Control valve 144 is configured to receive hydraulic fluid from hydraulic pump 136 at port P, supply the received hydraulic fluid to hydraulic circuit 162 in a first and second position, and, in its center position, supply the received hydraulic fluid to control valves 154B, 152B and 150B via corresponding hydraulic lines, as shown in Fig. 2.

[0039] Control valve 146A has a similar configuration to control valves 142 and 144 and is configured to receive hydraulic fluid from hydraulic pump 140A at port P, supply the received hydraulic fluid to hydraulic circuit 164 in a first position and a second position, respectively, and supply the received hydraulic fluid to control valves 150A, 152A and 154A in its center position. In the same manner, control valve 146B is configured to supply hydraulic fluid received at port P to hydraulic circuit 164 in a first position and in a second position, respectively, and to supply the received hydraulic fluid to control valves 154B, 152B and 150B in its center position.

[0040] In the exemplary embodiment described herein, control valve 150A is also an open center valve. Control valve 150A is configured to receive hydraulic fluid from hydraulic pump 134 and from control valve 146A via a port P1 of first group of control valves 148A. Further, control valve 150A is configured to receive hydraulic fluid from control valve 142 via a port P2 of first group of control valves 148A and control valves 152A and 154A when they are in their center position.

[0041] In a first position, control valve 150A may supply the hydraulic fluid received from P1 and P2 of first group of control valves 148A to hydraulic circuit 166 via a first port A of first group of control valves 148A, receive a return flow of hydraulic fluid from hydraulic circuit 166 via a first port B of first group of control valves 148A, and supply the returned hydraulic fluid to a tank via a port T of first group of control valves 148A.

[0042] In a second position, control valve 150A may receive hydraulic fluid from control valve 152A, and may supply the received hydraulic fluid to the associated tank via a port C2 of first group of control valves 148A. It should be noted that, in other embodiments, control valve 150A may receive flow from control valve 152A in the second position and supply the hydraulic fluid to hydraulic circuit 166. In other words, control valve 150A may have a similar configuration to control valves 152A and 154A described below. Further, control valve 150A may receive hydraulic fluid from hydraulic pump 134 and supply the received hydraulic fluid to hydraulic circuit 166 via first port B of first group of control valves 148A, receive a return flow of hydraulic fluid from hydraulic circuit 166 via first port A of first group of control valves 148A, and supply the returned hydraulic fluid to the tank via port T of first group of control valves 148A.

[0043] In a third position, control valve 150A may receive hydraulic fluid from hydraulic pump 134 and supply the received hydraulic fluid to control valve 152A. Likewise, control valve 150A may receive hydraulic fluid from control valve 152A and supply the same to the tank via port C2 of first group of valves 148A.

[0044] Control valve 152A is an open center valve and is configured to receive hydraulic fluid from control valve 150A, hydraulic pump 134 via port P1 of first group of control valves 148A, and control valve 154A.

[0045] In a first position, control valve 152A may receive hydraulic fluid from hydraulic pump 134 via port P1 of first group of control valves 148A and from control valve 154A via associated check valves, and may supply the received hydraulic fluid to hydraulic circuit 168 via a second port A of first group of control valves 148A. In the first position, control valve 152A may receive a return flow of hydraulic fluid from hydraulic circuit 166 via a second port B of first group of control valves 148A. Further, control valve 152A may return the received return flow to the associated tank via port T of first group of control valves 148A.

[0046] In a second position, control valve 152A may receive a flow of hydraulic fluid from hydraulic pump 134 and control valve 154A via the associated check valves, and provide the received flow to hydraulic circuit 168 via second port B of first group of control valves 148A. Further, control valve 152A is configured to receive a return flow of hydraulic fluid from hydraulic circuit 168 via second port A of first group of control valves 148A, and direct the received returned flow to the tank via port T of first group of control valves 148A.

[0047] In a third position, i.e. the center position, control valve 152A is configured to receive hydraulic fluid from hydraulic pump 134 via port P1 and first control valve 150A, and pass the same to control valve 154A of first group of control valves 148A. Further, in the third position, control valve 152A is configured to receive a flow of hydraulic fluid from hydraulic pump 132 via port P2 and control valve 154A of first group of control valves 148A, and pass the same to control valve 150A.

[0048] Control valve 154A, in a first position, is configured to receive hydraulic fluid from control valve 152A and control valve 142 via associated check valves, and provide the received flow to hydraulic circuit 170 via a third port A of first group of control valves 148A. In addition, in the first position, control valve 154A is configured to receive a return flow of hydraulic fluid from hydraulic circuit 170 via a third port B of first group of control valves 148A, and direct the received return flow to an associated tank via port T of first group of control valves 148A.

[0049] In a second position, control valve 154A is configured to receive hydraulic fluid from control valve 152A and control valve 142 via the associated check valves, and provide the received flow to hydraulic circuit 170 via third port B of first group of control valves 148A. Similarly, control valve 154A is configured to receive a return flow from hydraulic circuit 170 via third port A of first group of control valves 148A. Further, control valve 154A is configured to direct the received return flow to the associated tank via port T of first group of control valves 148A.

[0050] In a third position, i.e. the center position, control valve 154A is configured to receive a flow of hydraulic fluid from control valve 152A and direct the received flow to the associated tank via port C1 of first group of control valves 148A. In addition, control valve 154A is configured to receive a flow of hydraulic fluid from control valve 142 via port P2 of first group of control valves 148A and pass the same to control valve 152A.

[0051] Control valves 150B, 152B and 154B of second group of control valves 148B have a similar configuration to control valves 150A, 152A, 154A such that a detailed description will be omitted. As is readily apparent from Fig. 2, control valve 150B is configured to supply hydraulic fluid to hydraulic circuit 166, control valve 152B is configured to supply hydraulic fluid to hydraulic circuit 168, and control valve 154B is configured to supply hydraulic fluid to hydraulic circuit 170. Control valve 150B is configured to receive hydraulic fluid from hydraulic pump 138 via a port P2 of second group of control valves 148B and from control valve 152B. Control valve 152B is configured to receive hydraulic fluid from hydraulic pump 136 via control valve 144 and a port P1 of second group of control valves 148B, and from hydraulic pump 140B via control valve 146B and port P1 of second group of control valves 148B. Further, control valve 152B is configured to receive hydraulic fluid from control valves 150B and 154B when they are in their center positions. Control valve 154B is configured to receive hydraulic fluid from hydraulic pumps 140B and 136 via control valves 146B and 144 and port P1 of second group of control valves 148B. Further, control valve 154B is configured to receive hydraulic fluid from hydraulic pump 138 when control valves 150B and 152B are in their center positions.

[0052] It should be appreciated that, while two groups of control valves 148A and 148B are shown in the exemplary embodiment, in other embodiments, different groups of control valves may be used, depending on the configuration of hydraulic circuits 166, 168, 170. For example, only a single group of control valves may be present, or each group of control valves may include a reduced number of control valves. For example, in case hydraulic circuits 168,170 each include only a single hydraulic actuator, one of control valves 152A, 152B and one of control valves 154A, 154B may be omitted. It should be appreciated that hydraulic pumps 132-140B may then be fluidly connected to the remaining control valves in an appropriate manner, or that some of hydraulic pumps 132-140B may be omitted.

[0053] It will be readily understood from Fig. 2 that the exemplary embodiment of system 116 allows associating each of hydraulic pumps 132, 134, 136, 138, 140A, 140B with one of hydraulic circuits 160-170 by corresponding operation of control valves 142, 144, 146A, 146B, 150A, 150B, 152A, 152B, 154A, 154B. In the exemplary embodiment shown in Fig. 2, each hydraulic pump may be selectively assigned with one of at least three different hydraulic circuits. In other embodiments, different hydraulic pumps may be selectively associated with different numbers of hydraulic circuits. In the exemplary embodiment shown in Fig. 2, hydraulic pump 132 may be exclusively associated with hydraulic circuit 160 when control valve 142 is in its first or second position. In addition, when control valve 142 is in its third position, i.e. its center position, hydraulic pump 132 may be associated with one of hydraulic circuits 166, 168, 170, depending on the operation of first group of control valves 148A. For example, hydraulic pump 132 may be exclusively associated with hydraulic circuit 168 by controlling control valve 154A to its third position, i.e. its center position, and controlling control valve 152A to either its first position or its second position. A corresponding association of the remaining hydraulic pumps 134, 136, 138, 140A, 140B with two different hydraulic circuits will be readily apparent from the exemplary embodiment shown in Fig. 2.

[0054] It will be appreciated that many different modifications may be made to the fluid connections and valve arrangements shown in Fig. 2 without departing from the teachings of the present disclosure. It is contemplated that other control valves and other appropriate fluid connections may be used to allow associating each of hydraulic pumps 132-140B with one of hydraulic circuits 160-170. Further, the number of hydraulic pumps, the number of hydraulic circuits, and the number of control valves may be different in other embodiments, as appropriate. In general, the present disclosure allows exclusively associating at least some of a plurality of hydraulic pumps with one of a plurality of hydraulic circuits. This may results in at least a substantial reduction of flow sharing between the hydraulic circuits, resulting in an overall reduction or elimination of pressure drop losses in the associated hydraulic system.

[0055] Control unit 114 is operatively connected to input device 106, the plurality of hydraulic pumps 132, 134, 136, 138, 140A, 140B and the plurality of control valves 142, 144, 146A, 146B, 150A, 150B, 152A, 152B, 154A, 154B. Further, control unit 114 may be operatively connected to a plurality of sensors 180 (see Fig. 3) associated with hydraulic system 108, in particular, system 116. Sensors 180 may include any known sensors such as pressure sensors, temperature sensors, and the like. In particular, sensors 180 may include pressure sensors configured to detect a pressure in hydraulic system 108, for example, at various locations within hydraulic circuits 160-170and in hydraulic lines fluidly connecting the plurality of control valves 142-150B to the plurality of hydraulic pumps 132-140B and the plurality of hydraulic circuits 160-170.

[0056] According to the present disclosure, control unit 114 is configured to determine a hydraulic flow required by each of the plurality of hydraulic circuits 160-170 when an operator operates input device 106 to effect movement of machine 100 and/or its implements with a commanded velocity. Control unit 114 is further configured to determine a number of hydraulic pumps to be associated with each of the plurality of hydraulic circuits based on the hydraulic flow required by hydraulic circuits 160-170. In a next step, control unit 114 is configured to operate control valves 142-154B to associate the determined number of hydraulic pumps with each of the plurality of hydraulic circuits 160-170. In particular, control unit 114 is configured to operate control valves 142-154B such that each hydraulic pump 132-140B is exclusively associated with one of hydraulic circuits 160-170 to supply the same with hydraulic fluid, without at the same time supplying hydraulic fluid to any of the other hydraulic circuits. It should be appreciated that the particular hardware configuration used for system 116 may determine which hydraulic pump may be associated with which hydraulic circuit. Further, control unit 114 is configured to operate the plurality of hydraulic pumps 132-140B to supply the required hydraulic flow to each of the plurality of hydraulic circuits 160-170. In some exemplary embodiments, each hydraulic pump 132-140B may be a variable displacement pump, and control unit 114 may be configured to control the displacement of each variable displacement pump to provide the required hydraulic flow to the associated hydraulic circuit.

[0057] In some exemplary embodiments, control unit 114 may further be configured to determine a total hydraulic flow required by the plurality of hydraulic circuits 160-170, and to proportionally reduce the flow to be supplied to each hydraulic circuit when the required total flow exceeds a maximum available flow from the plurality of hydraulic pumps 132-140B.

[0058] In addition, according to some exemplary embodiments of the present disclosure, control unit 114 may further be configured to determine a number of active hydraulic circuits requiring hydraulic flow, associate one hydraulic pump 132-140B with each active hydraulic circuit, and calculate a flow ratio value for a select number of active hydraulic circuits. The flow ratio value may be defined by the number of hydraulic pumps associated with the respective active hydraulic circuit times the average maximum available flow from each hydraulic pump associated with the active hydraulic circuit divided by the required hydraulic flow of the active circuit. It is contemplated that, in other embodiments, different flow ratios may be calculated and used for distributing the hydraulic pumps to the active circuits, as appropriate. It should be appreciated that, in some embodiments, each hydraulic pump 132-140B may be a variable displacement pump having the same configuration, i.e. the same maximum displacement. In other embodiments, however, the plurality of hydraulic pumps 132-140B may have different configurations, and control unit 114 may be configured to calculate an average maximum available flow for the associated hydraulic pumps.

[0059] Further, control unit 114 may be configured to associate one of the remaining hydraulic pumps 132-140B with the active hydraulic circuit having the lowest flow ratio value. Then, control unit 114 may repeat the steps of calculating the flow ratio value for the active hydraulic circuits and continue to associate the remaining hydraulic pumps one by one to the circuit having the lowest flow ratio value until all hydraulic pumps are associated with one of the active hydraulic circuits or until each active hydraulic circuit has a flow ratio value equal to or greater than, for example, one. In some embodiments, other values than one may be used for this determination.

[0060] In some embodiments, control unit 114 may be configured to prioritize one or more of hydraulic circuits 160-170. In other words, control unit 114 may be configured to associate at least one hydraulic pump to each of the prioritized hydraulic circuits when they require hydraulic power. For example, control unit 114 may be configured to prioritize hydraulic circuits 160, 162 associated with the left propel drive and the right propel drive, respectively, of machine 100, and/or hydraulic circuit 164 associated with swing motors 130A and 130B of machine 100. For example, when an operator operates input device 106 to swing cab 104, control unit 114 may associate hydraulic pumps 140A and 140B exclusively with hydraulic circuit 164 regardless of the amount of hydraulic flow required by hydraulic circuit 164. Of the remaining hydraulic pumps 132, 134, 136, 138, control unit 114 may then associate one with each of the remaining active hydraulic circuits. For example, when an operator operates input device 106 to move the boom and the stick of machine 100 at maximum velocity while performing a swing movement of machine 100, control unit 114 may associate, for example, hydraulic pump 134 with hydraulic circuit 166 by operating control valve 150A, and may associate hydraulic pump 136 with hydraulic circuit 168 by operating control valve 152B. Then, control unit 114 may calculate the flow ratio values for hydraulic circuits 166, 168. Control unit 114 may determine the one of hydraulic circuits 166, 168 having the lowest flow ratio value, and may associate one additional hydraulic pump with the hydraulic circuit having the lowest flow ratio value. For example, control unit 114 may associate hydraulic pump 132 with hydraulic circuit 166. Next, control unit 114 may recalculate the flow ratio values for hydraulic circuits 166, 168, and may associate remaining hydraulic pump 138 with the hydraulic circuit having the lowest flow ratio value, for example, hydraulic circuit 168. It should be appreciated that many different combinations of active hydraulic circuits and many different priorities of the hydraulic circuits are possible and are intended to be covered by the present disclosure.

[0061] Turning now to Fig. 3, a configuration of control unit 114 and its control modules is shown in more detail. In the exemplary embodiment described herein, control unit 114 includes a signal conditioning module 200, a required flow calculation module 202, an overrunning load control module 204, a pump flow modifier module 206, a maximum allowed flow calculation module 208, a pump allocation module 210, a spool area calculation module 212, a pump pressure control module 214, a valve allocation module 216, a spool modulation module 220, a pump displacement control module 218, a load limit control module 222, and a pump modulation module 224. Each of modules 200-224 may be implemented in software, for example, as a Matlab/Simulink program implemented in control unit 114, or may alternatively be implemented in a separate control unit or as a separate hardware circuitry.

[0062] Signal conditioning module 200 is configured to receive an input from input device 106 and from the plurality of sensors 180 associated with hydraulic system 108 or machine 100. Signal conditioning module 200 is further configured to process the received inputs in a known manner and to provide the processed inputs to the modules requiring said inputs, for example, modules 202, 204,206,210,212,214,216,220,222.

[0063] Required flow calculation module 202 is configured to receive an input from signal conditioning module 200 and from overrunning load control module 204. Required flow calculation module 202 may further be configured to obtain one or more tunable parameters relating to the operation of machine 100 from an external control system (not shown), which may be set in advance to regulate operation of machine 100, in particular, system 116. In some embodiments, required flow calculation module may also receive said parameters from an operator operating an additional input device provided on machine 100 during operation of the same.

[0064] Required flow calculation module 202 is configured to calculate a maximum available flow from a desired engine speed setting of engine 102 to determine a maximum velocity for the hydraulic actuators and motors of hydraulic circuits 160-170. Further, required flow calculation module 202 is configured to determine the minimum of the velocity commanded by the operator and the maximum velocity calculated based on the desired engine speed setting. Required flow calculation module 202 then outputs the determined velocity and flow to overrunning load control module 204 and pump flow modifier module 206.

[0065] Overrunning load control module is configured to receive an output of signal conditioning module 200 relating to the plurality of sensors 180 associated with hydraulic system 108, and may determine the hydraulic circuits in which an overrunning load condition is present by monitoring the received pressures and the direction of travel of the associated hydraulic actuator commanded by the operator. For example, overrunning load control module may receive pressure values indicating the hydraulic pressures in hydraulic circuit 166 associated with the boom of machine 100, and determine that an overrunning load condition is present in hydraulic circuit 166, for example, when the boom of machine 100 is lowered due to gravity and not due to a flow of hydraulic fluid from one of hydraulic pumps 132-140B. Further, overrunning load control module 204 is configured to receive a commanded circuit velocity for the hydraulic circuit from required flow calculation module 202 and to determine the required flow of hydraulic fluid from a corresponding actuator to an associated tank to maintain the commanded circuit velocity. In addition, overrunning load control module 204 is configured to set an overrunning load flag for each hydraulic circuit 160-170 depending on whether an overrunning load condition is determined for the hydraulic circuit. Overrunning load control module 204 is configured to output the result of the overrunning load control determination to pump flow modifier module 206, pump allocation module 210, pump pressure control module 214, spool area calculation module 212, and valve allocation module 216.

[0066] Pump flow modifier module 206 is configured to receive the result of the required flow calculation from required flow calculation module 202, the operating status of input device 106 from signal conditioning module 200 and the result of the overrunning load control determination from overrunning load control module 204. When an overrunning load condition is detected for one of hydraulic circuits 160-170, pump flow modifier module 206 is configured to modify the pump flow command for the corresponding hydraulic circuit to reduce the same by an appropriate factor. In some exemplary embodiments, each hydraulic circuit may be associated with a different factor, which may be set in advance on the basis of various considerations concerning operation of machine 100. For example, pump flow modifier module 206 may be configured to reduce the desired pump flow for hydraulic circuit 166 associated with the boom of machine 100 by about 50% or by about 100%, for example, to account for the presence of float valve 156 or a makeup flow when an overrunning load condition is detected for hydraulic circuit 166, i.e. when the boom of machine 100 is lowered due to gravity. It is contemplated that a corresponding pump flow modification may also be performed for other ones of hydraulic circuits 160-170, if appropriate. Pump flow modifier module 206 is further configured to output the (modified) pump flow command to maximum allowed flow calculation module 208.

[0067] Maximum allowed flow calculation module 208 is configured to determine the total required flow for all hydraulic circuits 160-170 and compare the same to the total maximum available flow. If the total required flow is greater than the total maximum available flow, maximum allowed flow calculation module 208 is configured to reduce the flow to each hydraulic circuit 160-170 proportionally such that the maximum available total flow is not exceeded. Further, maximum allowed flow calculation module 208 is configured to determine the number of hydraulic pumps required for each hydraulic circuit 160-170, and output the number of pumps required for each circuit, as well as the allocated flow for each circuit to pump allocation module 210, pump pressure control module 214 and pump displacement control module 218.

[0068] Pump allocation module 210 receives the output from maximum allowed flow calculation module 208 and assigns the number of pumps to the hydraulic circuits 160-170 to maintain the commanded velocity ratios for the corresponding hydraulic circuits. Pump allocation module 210 may be configured to prioritize one or more of hydraulic circuits 160-170 when assigning the hydraulic pumps 132-140B to hydraulic circuits 160-170. In the exemplary embodiment described herein, pump allocation module 210 prioritizes hydraulic circuits 160, 162 associated with the left and right propel drives of machine 100, respectively, and hydraulic circuit 164 associated with the swing movement of machine 100. When one of the prioritized hydraulic circuits requires hydraulic flow, at least one hydraulic pump is associated with each of the prioritized circuits. In the exemplary embodiment described herein, both hydraulic pumps 140A and 140B are associated with hydraulic circuit 164 when a swing movement of machine 100 is to be performed. It should be appreciated, however, that in other embodiments, different priorities may be implemented.

[0069] Pump allocation module 210 is further configured to output information on which hydraulic pump is to be associated with which hydraulic circuit to spool area calculation module 212, pump pressure control module 214, valve allocation module 216 and pump displacement control module 218.

[0070] Pump pressure control module 214 receives the outputs from pump allocation module 210 and maximum allowed flow calculation module 208. In addition, pump pressure control module 214 receives an output from signal conditioning module 200 relating to the pressures within hydraulic system 108. Pump pressure control module 214 is configured to modulate the pump displacement, i.e. the flow provided by the corresponding hydraulic pump, for the pumps associated with a hydraulic circuit for which an overrunning load condition is detected. For these hydraulic pumps, a proportional-integral control or a PID control or any other appropriate control is implemented to control the flow command for the respective pumps. This control is provided to minimize the pressure drop across the pump-to-cylinder orifice, as this area is not being directly controlled during the overrunning load control. Pump pressure control module 214 is further configured to output the (modified) flow command for each hydraulic circuit to pump displacement control module 218.

[0071] Pump displacement control module 218 is configured to calculate a displacement command for hydraulic pumps 132-140B based on the received flow command from pump pressure control module 214. In addition, pump displacement control module 218 is configured to receive the number of pumps and the identity of the pumps to be associated with each hydraulic circuit from pump allocation module 210. Pump displacement control module 218 is configured to calculate the displacement command for each hydraulic pump 132-140B and output the same to load limit control module 222.

[0072] Load limit control module 222 is configured to perform a load limit control of hydraulic pumps 132-140B on the basis of the displacement command from pump displacement control module 218 to maintain a desired engine speed of engine 102 under overload conditions by reducing the displacement command for hydraulic pumps 132-140B, if necessary. Further, load limit control module 222 may be configured to maintain the ratios of the displacement of hydraulic pumps 132-140B after reducing the same. Load limit control module 222 may then output the pump displacement commands to pump modulation module 224. Pump modulation module 224 is configured to calculate the appropriate current commands for hydraulic pumps 132-140B to adjust the displacement of each hydraulic pump 132-140B to provide the required flow to hydraulic circuits 160-170.

[0073] Spool area calculation module 212 configured to receive an input from overrunning load control module 204, pump allocation module 210 and signal conditioning module 200. Spool area calculation module 212 is configured to maintain the commanded circuit velocity when the velocity of the corresponding actuator is not controlled by the pump flow, but by gravity. In particular, spool area calculation module 212 is configured to calculate an opening area associated with a corresponding hydraulic circuit which is necessary to maintain the desired cylinder velocity at the measured load pressure. Further, spool area calculation module 212 is configured to consider the number of control valves which are fluidly connected between the corresponding actuator and the associated tank or reservoir. Spool area calculation module 212 is configured to provide the calculated opening areas to valve allocation module 216. For example, spool area calculation module 212 may determine that one or both of control valves 152A, 152B associated with hydraulic circuit 168 should be operated to be in an intermediate position to regulate the flow of hydraulic fluid from actuators 122A, 122B to the corresponding tank in order to maintain the commanded velocity of actuators 122A, 122B. While this results in some flow sharing between different hydraulic circuits, it should be appreciated that this effect only occurs to some extent when one or more of hydraulic circuits 160-170 are operating under an overrunning load condition. The control valves associated with the circuits for which no overrunning load condition is detected, however, are operated to be in one of their three limiting positions, i.e. to exclusively provide the hydraulic flow to only one of hydraulic circuits 160-170.

[0074] Valve allocation module 216 receives the inputs from overrunning load control module 204, spool area calculation module 212, pump allocation module 210 and signal conditioning module 200 and is configured to determine the required operation of control valves 142-154A to provide the required flow from the associated hydraulic pumps 132-140B to hydraulic circuits 160-170. Further, valve allocation module 216 is configured to determine the required operation of the control valves 142-154B associated with the hydraulic circuits for which an overrunning load condition is detected. Valve allocation module 216 is configured to output the control commands for effecting the required operations of the control valves to spool modulation module 220.

[0075] Spool modulation module 220 is configured to calculate a current command for each control valve 142-154B on the basis of the control commands received from valve allocation module 216. Spool modulation module 220 may then output the current commands for control valves 142-154B to actuate each of control valves 142-154B to be in the required position.

[0076] While an exemplary embodiment of the present disclosure has been described with reference to Figs. 1-3, those of ordinary skill in the art will appreciate that many modifications may be made to the system and method described herein. For example, it should be appreciated that the number of hydraulic circuits 160-170, the number of hydraulic pumps 132-140B, and the number of control valves 142-154B may be different in other systems according to the present disclosure. Similarly, the number of priority hydraulic circuits may vary in other embodiments. In some embodiments, no priority circuits may be present. Further, it should be appreciated that, in some embodiments, not all hydraulic pumps may be configured to be selectively associated with different hydraulic circuits. For example, a subset of hydraulic pumps may be dedicated pumps fixedly associated with a specific hydraulic circuit. Further, it should be appreciated that the hydraulic circuit may include a different number of hydraulic actuators and/or motors than described herein. The present disclosure is not intended to be limited to systems which include both hydraulic motors and hydraulic actuators, e.g. hydraulic cylinders. The present disclosure may also be applied to systems in which only hydraulic actuators or only hydraulic motors are present.

[0077] While in the exemplary embodiment described herein open center valves have been used, it should be appreciated that other types of control valves may be used in a system according to the present disclosure.

The necessary modifications to allow association of the hydraulic pumps with one of the hydraulic circuits will be readily apparent to the skilled person. Further, it should be appreciated that not all of modules 200-224 associated with control unit 114 must be present in each embodiment according to the present disclosure. For example, an overrunning load control as described herein may be omitted when such a control is not necessary. If appropriate, other modules of control unit 114 may also be omitted in other embodiments, when they are not required for the association of the hydraulic pumps to the hydraulic circuits.

Industrial Applicability

[0078] The industrial applicability of the systems and methods for providing hydraulic power to a plurality of hydraulic circuits of a machine described herein will be readily appreciated from the foregoing discussion. One exemplary machine suited to the disclosure is an excavator. Similarly, the systems and methods described can be adapted to a large variety of machines and tasks. For example, backhoe loaders, compactors, feller bunchers, forest machines, industrial loaders, skid steer loaders, wheel loaders and many other machines can benefit from the systems and methods described herein.

[0079] In accordance with some embodiments, a method of operating a machine including a plurality of hydraulic circuits, a plurality of hydraulic pumps and a plurality of control valves comprises the steps of determining a hydraulic flow required by each of the plurality of hydraulic circuits, determining a number of hydraulic pumps to be associated with each of the plurality of hydraulic circuits based on the hydraulic flow required by the plurality of hydraulic circuits, operating the plurality of control valves to associate the determined number of hydraulic pumps exclusively with each of the plurality of hydraulic circuits, and operating the plurality of hydraulic pumps to supply the required hydraulic flow to each of the plurality of hydraulic circuits.

[0080] An exemplary embodiment of the control performed by control unit 114 will be described in the following with reference to the drawings.

[0081] When an operator operates input device 106 to effect movement of machine 100 and/or to actuate one or more of hydraulic actuators 120A-124B, signal conditioning module 200 receives the corresponding operator input. Signal conditioning module 200 then outputs a corresponding signal to required flow calculation module 202 and to overrunning load control module 204.

[0082] Required flow calculation module 202 calculates commanded velocities and the flow required by each hydraulic circuit 160-170 to effect the desired movement of machine 100 and/or actuators 120A-124B. Overrunning load control module 204 performs an overrunning load control. Depending on the overrunning load flag set for each hydraulic circuit 160-170, pump flow modifier module 206 modifies the pump flow command for each hydraulic circuit. The modified pump flow is output to maximum allowed flow calculation module 208. The maximum allowed flow calculation module 208 determines whether the total required flow is greater than a maximum allowable flow. If this is the case, maximum allowed flow calculation module 208 proportionally reduces the flow to be supplied to each hydraulic circuit 160-170. Maximum allowed flow calculation module 208 then outputs the flow to be supplied to each hydraulic circuit 160-170 and the number of pumps allocated for each hydraulic circuit 160-170 to pump allocation module 210 and to pump pressure control module 214. Pump allocation module 210 may then determine which pump is to be associated with which circuit. Pump pressure control module 214, which is active for circuits with an overrunning load condition, modifies the flow command for the corresponding circuits to minimize the pressure drop across the pump to cylinder spool of the circuit. The (modified) flow from pump pressure control module 214 is input to pump displacement control module 218 to calculate the displacement of each pump also based on the information from pump allocation module 210. The displacement commands are output to load limit control module 222. Load limit control module 222 may reduce the commanded pump displacement to maintain a desired engine speed by reducing each pump displacement command while maintaining a ratio of pump displacements for hydraulic pumps 132-140B. Load limit control module 222 then outputs the displacement commands to pump modulation module 224, and pump modulation module 224 outputs the corresponding current commands to each hydraulic pump 132-140B.

[0083] Spool area calculation module receives the inputs from overrunning load control module 204 and from pump allocation module 210 and determines the opening area for each circuit 160-170. As described above, in case no overrunning load conditions are detected, spool area calculation module will set the spool area for each circuit 160-170 to the maximum spool area, resulting in the reduction or elimination of flow sharing between different hydraulic circuits. In case an overrunning load condition is detected for one or more hydraulic circuits, the spool area for the associated circuits will be set to an intermediate value to maintain commanded velocities of the corresponding hydraulic actuators due to gravity. Spool area calculation module 212 then outputs the calculated spool areas for each circuit to valve allocation module 216, and valve allocation module 216 obtains command values for each control valve 142-154B and outputs the same to spool modulation module 220. Spool modulation module 220 generates appropriate current commands for control valves 142-154B and outputs the current commands to the same to obtain the desired association of hydraulic pumps 132-140B with hydraulic circuits 160-170.

[0084] It will be appreciated that the foregoing description provides examples of the disclosed systems and methods. However, it is contemplated that other implementations of the disclosure may differ in detail from the foregoing examples. All references to the disclosure or examples thereof are intended to reference the particular example being discussed at that point and are not intended to imply any limitation as to the scope of disclosure more generally. All methods described herein may perform in any suitable order unless otherwise indicated herein or clearly contradicted by context.

[0085] Accordingly, this disclosure includes all modifications and equivalences of the subject-matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the disclosure unless otherwise indicated herein or clearly contradicted by context.

[0086] Although the preferred embodiments of this disclosure have been described herein, improvements and modifications may be incorporated without departing from the scope of the following claims.

Claims

1. A system (116) for providing hydraulic power to a plurality of hydraulic circuits (160, 162, 164, 166, 168, 170) of a machine (100), comprising:

    a plurality of hydraulic pumps (132, 134, 136, 138, 140A, 140B) for supplying the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170) with hydraulic fluid;
    a plurality of control valves (142, 144, 146A, 146B, 150A, 150B, 152A, 152B, 154A, 154B) operable to associate each of the plurality of hydraulic pumps (132, 134, 136, 138, 140A, 140B) with one of the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170) for supplying hydraulic fluid exclusively to the associated hydraulic circuit (160, 162, 164, 166, 168, 170); and
    a control unit (114) configured to:

        determine a hydraulic flow required by each of the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170);
        determine a number of hydraulic pumps (132, 134, 136, 138, 140A, 140B) to be associated with each of the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170) based on the hydraulic flows required by the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170);
        operate the plurality of control valves (142, 144, 146A, 146B, 150A, 150B, 152A, 152B, 154A, 154B) to exclusively associate the determined number of hydraulic pumps (132, 134, 136, 138, 140A, 140B) with each of the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170); and
        operate the plurality of hydraulic pumps (132, 134, 136, 138, 140A, 140B) to supply the required hydraulic flow to each of the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170).

2. The system of claim 1, wherein the control unit (114) is further configured to determine a total hydraulic flow required by the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170), and proportionally reduce the hydraulic flow to be supplied to each of the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170) when the required total hydraulic flow exceeds a maximum available hydraulic flow from the plurality of hydraulic pumps (132, 134, 136, 138, 140A, 140B).

3. The system of claim 1 or 2, wherein the control unit (114) is further configured to
    determine a number of active hydraulic circuits (160, 162, 164, 166, 168, 170) requiring a hydraulic flow,
    associate one hydraulic pump (132, 134, 136, 138, 140A, 140B) with each active hydraulic circuit (160, 162, 164, 166, 168, 170),
    calculate a flow ratio value for a select number of active hydraulic circuits (160, 162, 164, 166, 168, 170), the flow ratio value being defined by the number of hydraulic pumps (132, 134, 136, 138, 140A, 140B) associated with the active hydraulic circuit times the average maximum available flow from each hydraulic pump (132, 134, 136, 138, 140A, 140B) divided by the hydraulic flow required by the active circuit,
    associate one of the remaining hydraulic pumps (132, 134, 136, 138, 140A, 140B) with the active hydraulic circuit (160, 162, 164, 166, 168, 170) having the lowest flow ratio value, and
    repeat the steps of calculating the flow ratio values and associating one of the remaining hydraulic pumps (132, 134, 136, 138, 140A, 140B) until all hydraulic pumps are associated with one of the active hydraulic circuits (160, 162, 164, 166, 168, 170) or until each active hydraulic circuit has a flow ratio value equal to or greater than one.

4. The system of any one of claims 1 to 3, wherein the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170) includes at least one high priority hydraulic circuit (164), and the control unit (114) is configured to associate at least two hydraulic pumps (140A, 140B) with the at least one priority hydraulic circuit (164) when the at least one priority hydraulic circuit (164) requires a hydraulic flow.

5. The system of any one of claims 1 to 4, further comprising a plurality of sensors for detecting an overrunning load condition in one or more of the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170),

wherein the control unit (114) is configured to modify the hydraulic flow supplied to the one or more hydraulic circuits (160, 162, 164, 166, 168, 170) for which the overrunning load condition is detected.

6. The system of claim 5, wherein the control unit (114) is configured to modify the hydraulic flow by at least one of modifying a pump flow command for the associated hydraulic pumps (132, 134, 136, 138, 140A, 140B) and modifying an opening area of one or more control valves (142, 144, 146A, 146B, 150A, 150B, 152A, 152B, 154A, 154B) fluidly connecting the associated hydraulic pumps (132, 134, 136, 138, 140A, 140B) to the one or more hydraulic circuits (160, 162, 164, 166, 168, 170) for which the overrunning load condition is detected.

7. The system of any one of claims 1 to 6, wherein the control unit (114) is further configured to detect an overload condition of an engine (102) driving the plurality of hydraulic pumps (132, 134, 136, 138, 140A, 140B), and reduce the amount of flow provided by each of the plurality of hydraulic pumps (132, 134, 136, 138, 140A, 140B) while maintaining flow ratios of the flows provided by the plurality of hydraulic pumps (132, 134, 136, 138, 140A, 140B), to maintain a desired engine speed of the engine (102)

8. The system of any one of claims 1 to 7, wherein each of the plurality of hydraulic pumps (132, 134, 136, 138, 140A, 140B) is a variable displacement pump configured to supply a variable amount of hydraulic flow to the associated hydraulic circuit (160, 162, 164, 166, 168, 170).

9. The system of any one of claims 1 to 8 wherein each of the plurality of control valves (142, 144, 146A, 146B, 150A, 150B, 152A, 152B, 154A, 154B) is an open center valve configured to receive hydraulic fluid from one of the plurality of hydraulic pumps (132, 134, 136, 138, 140A, 140B) and supply the hydraulic fluid to one of the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170) in a first position and in a second position, and to supply the hydraulic fluid to at least one other hydraulic circuit (160, 162, 164, 166, 168, 170) in a third position.

10. A machine (100), comprising:

an engine (102);
a plurality of hydraulic pumps (132, 134, 136, 138, 140A, 140B) powered at least in part by the engine (102);
a plurality of hydraulic circuits (160, 162, 164, 166, 168, 170);
a plurality of control valves (142, 144, 146A, 146B, 150A, 150B, 152A, 152B, 154A, 154B) operable to associate each of the plurality of hydraulic pumps (132, 134, 136, 138, 140A, 140B) with one of the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170) for supplying hydraulic fluid exclusively to the associated hydraulic circuit (160, 162, 164, 166, 168, 170); and
a control unit (114) operatively connected the plurality of hydraulic pumps (132, 134, 136, 138, 140A, 140B) and the plurality of control valves (142, 144, 146A, 146B, 150A, 150B, 152A, 152B, 154A, 154B), the control unit (114) being configured to:

determine a hydraulic flow required by each of the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170);
determine a number of hydraulic pumps (132, 134, 136, 138, 140A, 140B) to be associated with each of the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170) based on the hydraulic flows required by the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170);
operate the plurality of control valves (142, 144, 146A, 146B, 150A, 150B, 152A, 152B, 154A, 154B) to exclusively associate the determined number of hydraulic pumps (132, 134, 136, 138, 140A, 140B) with each of the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170); and
operate the plurality of the hydraulic pumps (132, 134, 136, 138, 140A, 140B) to supply the required hydraulic flow to each of the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170).

11. The machine of claim 10, wherein the machine (100) is an excavator and the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170) includes a travel left circuit (160), a travel right circuit (162), a swing circuit (164) and one or more actuator circuits (166, 168, 170), and the plurality of hydraulic pumps (132, 134, 136, 138, 140A, 140B) includes at least one first hydraulic pump (140A, 140B) fluidly connectable to the swing circuit (164) and the one or more actuator circuits (166, 168, 170) via at least one first control valve (146A, 146B).

12. The machine of claim 11, wherein the plurality of hydraulic pumps (132, 134, 136, 138, 140A, 140B) further includes:

a second hydraulic pump (132) fluidly connectable to the travel left circuit (160) and the one or more actuator circuits (166, 168, 170) via a second control valve (142);
a third hydraulic pump (132) fluidly connectable to the travel right circuit (162) and the one or more actuator circuits (166, 168, 170) via a third

control valve (144);
a fourth hydraulic pump (134) fluidly connectable to the one or more actuator circuits (166, 168, 170) via a set of fourth control valves (150A, 152A, 154A); and
a fifth hydraulic pump (138) fluidly connectable to the one or more actuator circuits (166, 168, 170) via a set of fifth control valves (150B, 152B, 154B).

13. The machine of claim 11 or 12, wherein the one or more actuator circuits (166, 168, 170) include a boom circuit (166), a stick circuit (168) and a bucket circuit (170).

14. A method of operating a machine (100) including a plurality of hydraulic circuits (160, 162, 164, 166, 168, 170), a plurality of hydraulic pumps (132, 134, 136, 138, 140A, 140B) for supplying the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170) with hydraulic fluid, and a plurality of control valves (142, 144, 146A, 146B, 150A, 150B, 152A, 152B, 154A, 154B) operable to exclusively associate each of the plurality of hydraulic pumps (132, 134, 136, 138, 140A, 140B) with one of the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170), the method comprising the steps of:

determining a hydraulic flow required by each of the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170);
determining a number of hydraulic pumps (132, 134, 136, 138, 140A, 140B) to be associated with each of the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170) based on the hydraulic flows required by the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170);
operating the plurality of control valves (142, 144, 146A, 146B, 150A, 150B, 152A, 152B, 154A, 154B) to exclusively associate the determined number of hydraulic pumps (132, 134, 136, 138, 140A, 140B) with each of the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170) for supplying a flow of hydraulic fluid exclusively to the associated hydraulic circuit (160, 162, 164, 166, 168, 170); and
operating the plurality of hydraulic pumps (132, 134, 136, 138, 140A, 140B) to supply the required hydraulic flow to each of the plurality of hydraulic circuits (160, 162, 164, 166, 168, 170).

15. A computer program comprising computer-executable instructions which, when executed by a computer, cause the computer to perform the steps of the method of claim 14.

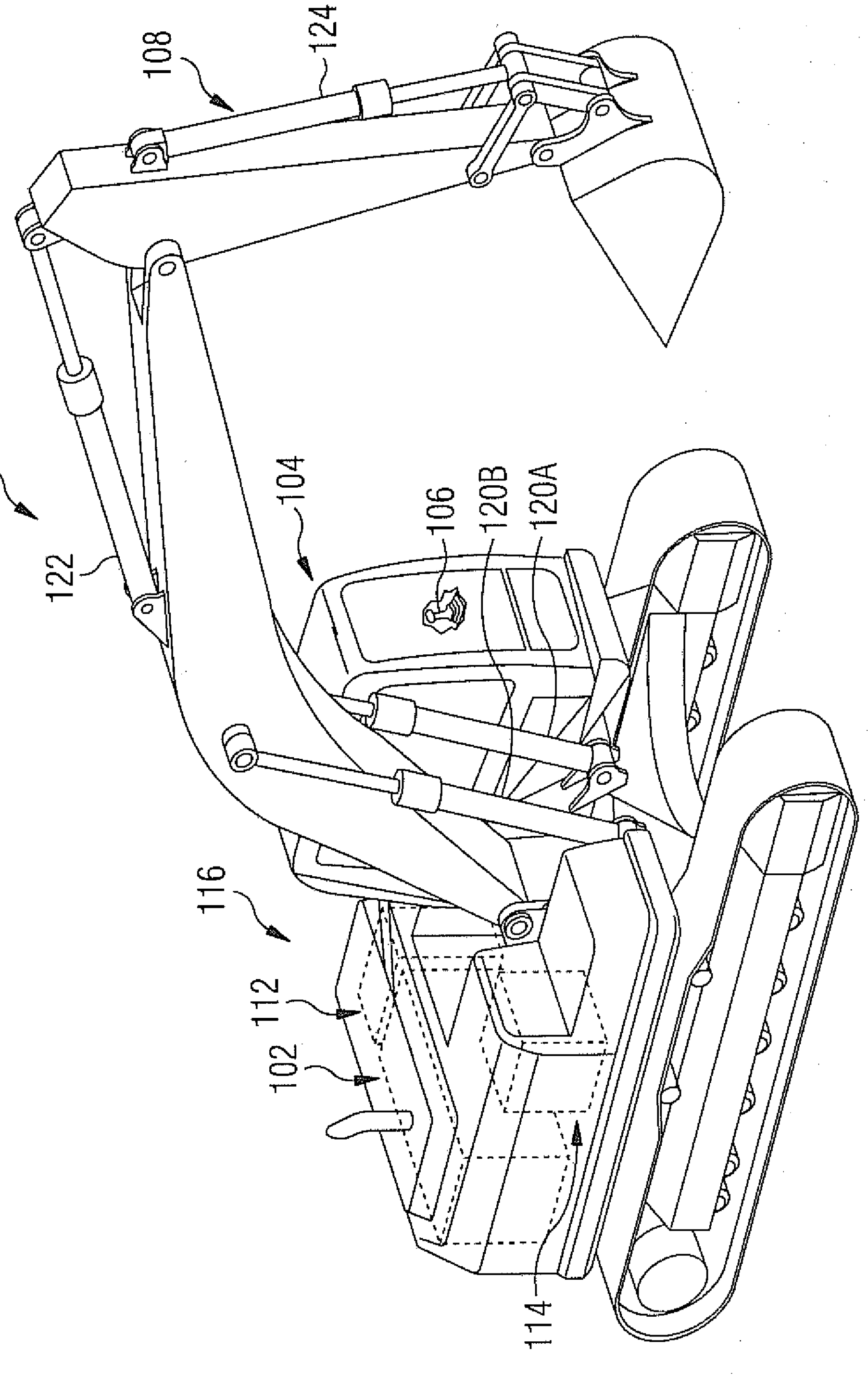
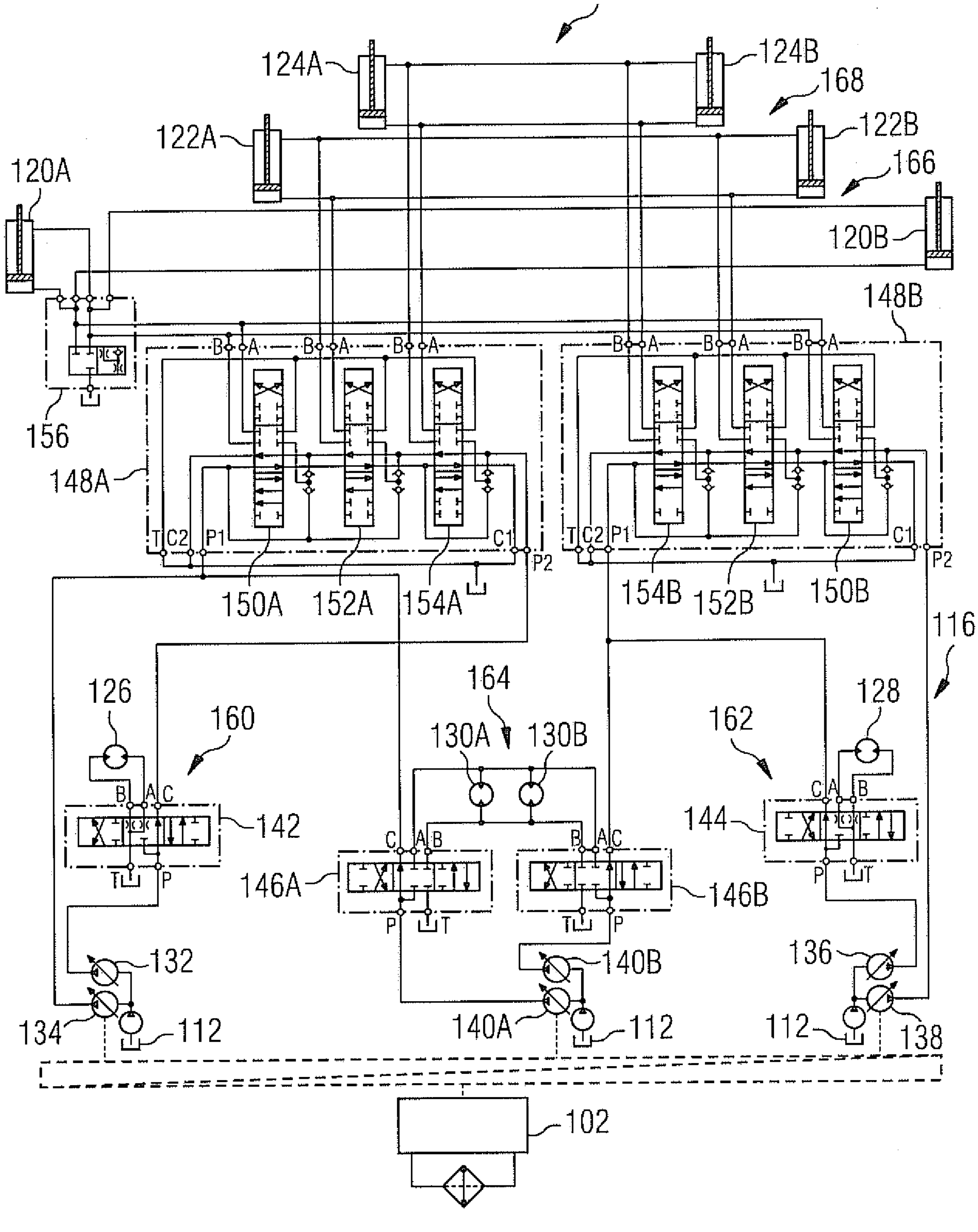


FIG 1

FIG 2


170
124A
124B
168
122A
122B
166
120A
120B
148B
156
148A
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T C2 P1
C1
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150A
152A
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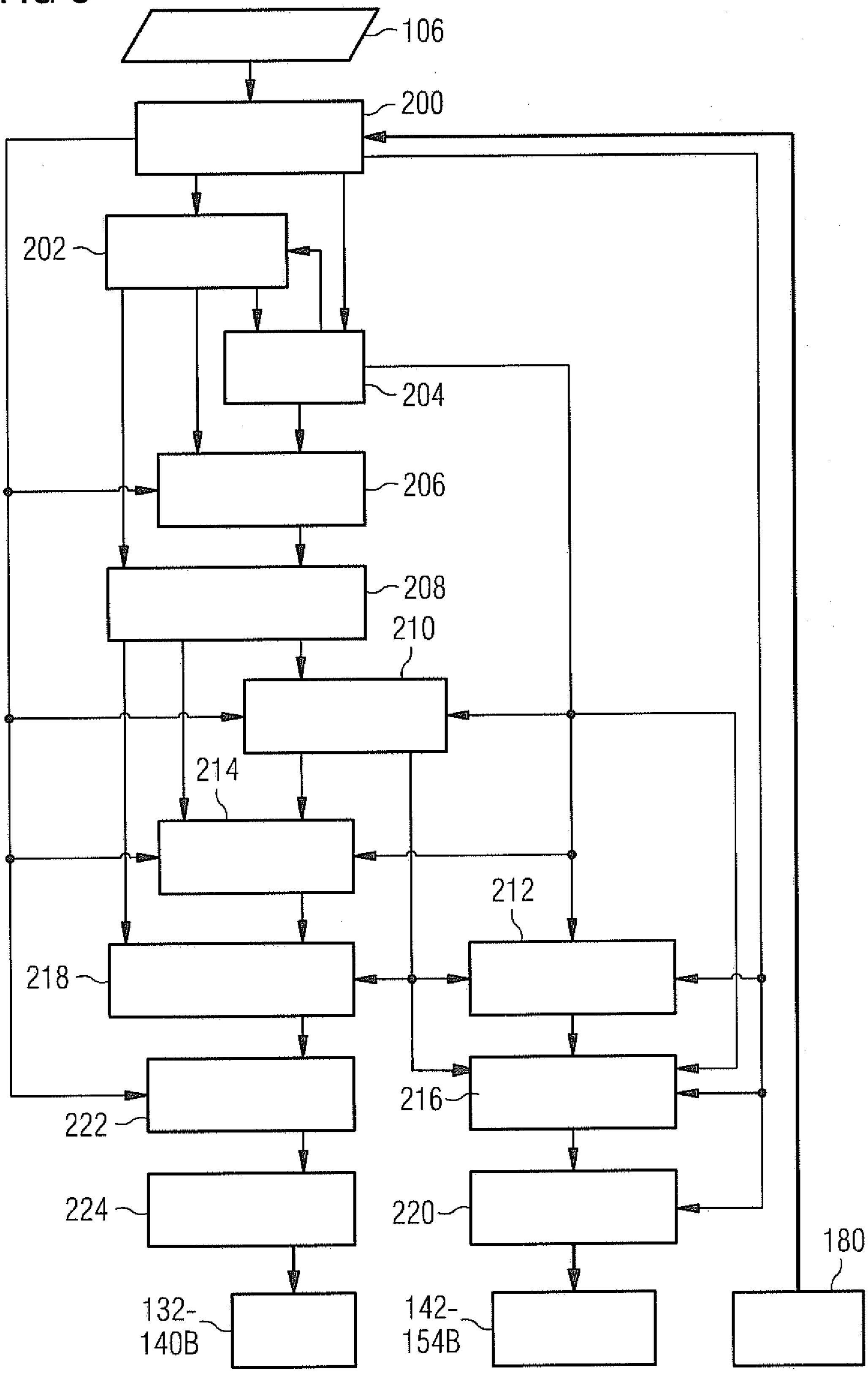
116
126
160
164
130A
130B
162
128
B A C
142
C A B
144
146A
146B
P T
132
136
134
112
140B
140A
138
102

FIG 3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140B
142-
154B

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EUROPEAN SEARCH REPORT

Application Number
EP 12 19 8269

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2012/233996 A1 (QUINNELL COREY K [US] ET AL) 20 September 2012 (2012-09-20)	1,2,4, 7-11, 13-15	INV. E02F9/22
A	* the whole document *	3,5,12	
X	JP S62 258026 A (KOBE STEEL LTD) 10 November 1987 (1987-11-10) * the whole document *	1	
A	US 5 940 997 A (TOYOOKA TSUKASA [JP] ET AL) 24 August 1999 (1999-08-24) * the whole document *	1	

TECHNICAL FIELDS SEARCHED (IPC)

E02F

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
Munich	17 May 2013	Laurer, Michael

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

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CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☐ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☒ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☐ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

☐ The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).

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LACK OF UNITY OF INVENTION SHEET B

Application Number
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The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1, 2, 7, 14, 15

are directed to the known system of claim 1 and suggests to distribute hydraulic flow when the demand exceeds a maximum available hydraulic flow of the pumps or an overload condition of an engine.

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2. claim: 3

is directed to the known system of claim 1 and suggests to distribute hydraulic flow among active hydraulic circuits with respect to the average maximum available hydraulic flow from the pumps.

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3. claim: 4

is directed to the known system of claim 1 and suggests to distribute hydraulic flow to a hydraulic circuit with priority to fulfill the required demands.

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4. claims: 5, 6

are directed to the known system of claim 1 and suggest to influence hydraulic flow to a circuit with an overrunning load condition.

---

5. claim: 8

is directed to the known system of claim 1 and suggests to use variable displacement hydraulic pumps for supplying fluid.

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6. claim: 9

is directed to the known system of claim 1 and suggests to use open center control valves.

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7. claims: 10-13

is directed to the known machine of claim 10 and suggests specific actuators of an excavator and its hydraulic circuits.

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 12 19 8269

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

17-05-2013

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82