(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 4 230 809 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
23.08.2023 Bulletin 2023/34

(21) Application number: **22157274.6**

(22) Date of filing: **17.02.2022**

(51) International Patent Classification (IPC):
E02F 9/22 *(2006.01)*

(52) Cooperative Patent Classification (CPC):
E02F 9/2228; E02F 3/3414; E02F 3/432; E02F 9/2203; E02F 9/2235

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

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(54) HYDRAULIC CONTROL SYSTEM FOR A MACHINE, MACHINE AND METHOD FOR CONTROLLING BOOM AND ATTACHMENT MOVEMENTS OF A MACHINE

(57) The invention relates to a hydraulic control system (24) for a machine (1), wherein the machine has a hydraulic pump (22), a tank (26), at least one boom hydraulic cylinder (12) and at least one attachment hydraulic cylinder (14), comprising an attachment directional control valve (30) configured to be connected to the hydraulic pump (22) and to piston and rod sides (17, 19) of the at least one attachment hydraulic cylinder (14); a lowering manifold (40) configured to be connected to piston and rod sides (16, 18) of the at least one boom hydraulic cylinder (12); a pressure sensor (48) configured to detect a pressure value of hydraulic fluid and configure to be connected to the piston side (16) of the at least one boom hydraulic cylinder; and a control device (36) configured to control the attachment directional control valve and the lowering manifold and configured to receive the pressure value; wherein, when the hydraulic control system (24) is connected to the hydraulic pump (22), the at least one boom hydraulic cylinder (12) and the at least one attachment hydraulic cylinder (14), the control device is configured, during a return movement state: to determine, based on the pressure value, a meter-out flow rate of the flow of hydraulic fluid from the piston side (16) of the boom hydraulic cylinder to the rod side (18) of the boom hydraulic cylinder, and to control the attachment directional control valve (30), such that hydraulic fluid from the hydraulic pump (22) is directed into the piston side (17) or the rod side (19) of the attachment hydraulic cylinder (14), wherein a position of a spool of the attachment directional control valve is controlled based on said meter-out flow rate.

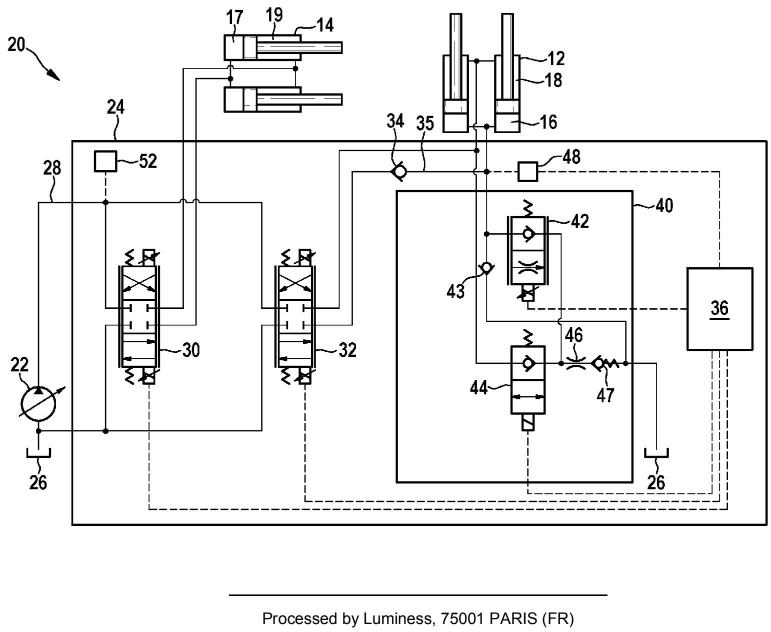

Fig. 2

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Description

[0001] The present invention relates to a hydraulic control system, a machine and a method as well as a control device and a computer program for performing the method.

Background

[0002] Hydraulically operated machines for loading or unloading bulk material, such as a wheel loader, a skid steer loader or a backhoe loader (or any other machine with equivalent kinematics), have a pivotable boom to which an attachment, e.g. a bucket, is attached in a rotatable manner. During a typical loading cycle, rotational movements of both the boom and the attachment are performed in response to control signals from a user interface. The actuation of respective hydraulic cylinders causes the rotational movements of the boom and of the attachment, wherein directional control valves direct the flow of hydraulic fluid to and from the hydraulic cylinders. A hydraulic pump is used to supply and pressurize the hydraulic fluid.

Summary

[0003] According to the invention, a hydraulic control system, a machine and a method for controlling boom and attachment movements of a machine as well as a control device and a computer program for performing the method with the features of the independent claims are proposed. Advantageous embodiments form the subject matter of the dependent claims and of the subsequent description.

[0004] The present invention relates to a hydraulic control system for a machine, the machine having a hydraulic pump, a tank for hydraulic fluid, at least one boom hydraulic cylinder for effecting movement of a boom of the machine, and at least one attachment hydraulic cylinder, for effecting (rotational) movement of an attachment of the machine, the attachment being attached to a free end of the boom. According to the invention a lowering manifold (i.e. an arrangement of hydraulic valves and hydraulic lines connecting them internally) is controlled to determine, during a "return movement state", a meter-out flow rate of the flow of hydraulic fluid from the piston side of the boom hydraulic cylinder. This flow is due to the weight of the boom (and attachment), which puts a load onto the boom hydraulic cylinder, when the boom is in an elevated position (gravity lowering). At the same time hydraulic fluid from the hydraulic pump is directed to the at least one attachment hydraulic cylinder, leading to synchronized movements of the boom and the attachment (without using the pump flow rate for the movement of the boom cylinder(s)).

[0005] More specifically, the hydraulic control system comprises an attachment directional control valve configured to be connected to the hydraulic pump and to piston and rod sides of the at least one attachment hydraulic cylinder. That is, when connected, the rotational movement of the attachment, which is actuated by the at least one attachment hydraulic cylinder, is controlled through the attachment directional control valve.

[0006] Further, the lowering manifold included in the hydraulic control system is configured to be connected to piston and rod sides of the at least one boom hydraulic cylinder and having a tank port that is configured to be connected to the tank. A pressure sensor is provided that is configured to detect a (piston side) pressure value of hydraulic fluid and configured to be connected to the piston side of the at least one boom hydraulic cylinder. The pressure value in combination with known/controlled cross-section of orifices of the lowering manifold allows to calculate a flow rate (meter-out flow rate) of hydraulic fluid from the piston side of the at least one boom hydraulic cylinder.

[0007] The hydraulic control system includes a control device configured to control the attachment directional control valve and the lowering manifold and configured to receive the pressure value. Wherein, when the hydraulic control system is connected to the hydraulic pump, the tank, the at least one boom hydraulic cylinder and the at least one attachment hydraulic cylinder, the control device, during a return movement state, is configured to:

- determine, based on the pressure value, a meter-out flow rate of the flow of hydraulic fluid released from the piston side of the boom hydraulic cylinder,
- control the attachment directional control valve, such that hydraulic fluid from the hydraulic pump is directed into the piston side or the rod side of the attachment hydraulic cylinder, wherein a position of a spool of the attachment directional control valve is controlled based on said (determined) meter-out flow rate. In particular, by controlling the position of the spool of the attachment directional control valve the flow rates of hydraulic fluid are controlled to one side of the at least one attachment hydraulic cylinder (either piston side or rod side, depending on whether the machine has "parallel" or "Z type" kinematics) and from the other side of the at least one attachment hydraulic cylinder.

[0008] That "the hydraulic control system is connected to the hydraulic pump, the at least one boom hydraulic cylinder and the at least one attachment hydraulic cylinder" is to be understood in the sense that the attachment directional control valve is connected to the hydraulic pump and to the piston and rod sides of the at least one attachment hydraulic cylinder, the lowering manifold is connected to the piston and rod sides of the at least one boom hydraulic cylinder, and the pressure sensor is connected to the piston side of the at least one boom hydraulic cylinder. Typically, the hydraulic control system has ports, which can be connected (over hydraulic lines) to corresponding ports of the hydraulic cylinders, the hydraulic pump and a tank for hydraulic fluid.

[0009] The term "return movement state" (or "return movement phase") means an operational state during which the boom is lowered and preferably an activation signal, e.g. from a user interface, is present. The control device is preferably configured to determine whether the boom is lowered and optionally whether an activation signal is present, and, when the boom is lowered and optionally the activation signal is present, to determine that the return movement state is present. The lowering of the boom may for example be determined based on an input signal from a user interface (e.g. a joystick) or based on sensor measurements (e.g. from angle sensors attached to arm elements of the boom). The activation signal may be determined based on an activation signal from a user interface (e.g. a button or switch). For example, the "return movement state" can be controlled in three ways: Fully manual, wherein the user of the machine driver can modulate the operating speed of either boom and attachment cylinders with the joystick; Automatic without position sensors, wherein once selected the boom and attachment movements are managed by the controller with logics that allow to adjust the attachment cylinder once the boom arm is completely lowered, the movements can be stopped at any time by moving the joystick handle; and Automatic with position sensors, wherein once selected the boom and attachment movements are managed by the controller with logics that allow continuous adjustment of the attachment cylinder to keep the desired position through all the lowering movement of the boom, the movements can be stopped at any time by moving the joystick handle.

[0010] Unless stated otherwise (or obvious from the context, e.g. connections to/from the control device by signal/control lines), the term "connected" as used herein generally relates to a fluid connection, i.e. to a connection by fluid lines, specifically by lines for hydraulic fluid (hydraulic lines).

[0011] The control of the spool position of the attachment directional control valve based on the meter-out flow rate results in the synchronized rotational movements. In order to determine the spool position a predetermined mapping (e.g. in form of a function or a table) may be used, which assigns to each value of the meter-out flow rate a corresponding spool position. Based on the controlled meter-out flow of the boom hydraulic cylinders (for example, based on the comparison between input signal to proportional valve (see below) and the pressure value of the piston side of the boom hydraulic cylinders), it is possible to determine the meter-out flow out of the boom hydraulic cylinders during the lowering and consequently manage the flow to be sent to the attachment hydraulic cylinders to keep the desired position.

[0012] Whether the attachment directional control valve is controlled to direct hydraulic fluid from the hydraulic pump into the rod side or into the piston side of the at least one attachment hydraulic cylinder is predetermined. Specifically, it depends on the machine and the arrangement of the attachment hydraulic cylinder in relation to the attachment rotational movement. For example, for a skid steer loader having "parallel" kinematics as shown in figure 1, the hydraulic fluid is preferably directed into the rod side of the attachment hydraulic cylinders. On the other hand, for a wheel loader having "Z type" kinematics, the hydraulic fluid is preferably directed into the piston side of the attachment hydraulic cylinders.

[0013] Preferably, the lowering manifold comprises a (leak free) proportional valve having an adjustable orifice and having a first and a second port, wherein the first port is configured to be connected to the piston side of the at least one boom hydraulic cylinder; wherein the control device is configured to control a cross-section of the adjustable orifice of the proportional valve; and wherein the control device is configured to determine the meter-out flow rate based on the pressure value and the cross-section (more precisely cross-sectional area) of the adjustable orifice of the proportional valve. This structure of the lowering manifold is particularly easy to implement. The proportional valve is preferably an electro-proportional valve. The leak freeness is ensured on the side of the proportional valve connected to the piston side of the boom hydraulic cylinder.

[0014] More preferably, the lowering manifold comprises an out flow orifice connected between the second port and the tank port; and the control device is configured to determine the meter-out flow rate based on the pressure value, the cross-section of the adjustable orifice of the proportional valve, and a known cross-section (cross-sectional area) of the out flow orifice. This allows a precise estimation of the meter-out flow rate, as the flow rate can be calculated from the pressure drop and the cross-section of the orifices. The estimation is possible, since the pressure drop across the out flow orifice is related to the amount (out flow rate) of hydraulic fluid coming from the proportional valve. The "out flow orifice" is arranged downstream from the proportional valve and the hydraulic fluid flows through the out flow orifice towards the tank port and therefrom to the tank. For convenience, the expression that hydraulic fluid is directed towards or flows to the tank (or similar) will also be used in the description; this is to be understood in the sense that hydraulic fluid is directed towards or flows to the tank port and therefrom to the tank (when the tank is connected). Generally (without being mentioned explicitly in each case), hydraulic connections of the hydraulic control system to other hydraulic components (tank, hydraulic cylinders, ...) are typically achieved through respective ports for fluidic connection of hydraulic lines connected with those components.

[0015] Preferably, the lowering manifold comprises a check valve with fixed pre-load connected between the second port and the tank port, wherein, if the out flow orifice is present, the check valve with fixed pre-load is connected in series (in particular downstream) with the out flow orifice, and wherein the control device is configured to determine the meter-out flow rate based additionally on the pre-load of the check valve with fixed pre-load.

[0016] Preferably, the control device is configured to, during the return movement state, control the lowering manifold to allow hydraulic fluid to flow from the piston side of the boom hydraulic cylinder to the rod side of the boom hydraulic cylinder. This implementation allows to regenerate hydraulic fluid released from the piston side of the boom hydraulic cylinder for filling the rod side of the boom hydraulic cylinder, such that less or no hydraulic fluid has to be directed toward the rod side of the boom hydraulic cylinder through the boom directional control valve. As no (or at least less) pump to the rod side of the boom hydraulic cylinders is required, the flow of hydraulic fluid from the hydraulic pump does not have to be split between the two movements, both movements can be performed faster. This means more or less the same boom lowering performance at any engine speed of an engine driving the hydraulic pump.

[0017] Preferably, the lowering manifold comprises an on-off valve having a third and a fourth port, wherein the third port is configured to be connected to the rod side of the at least one boom hydraulic cylinder and wherein the fourth port is connected to the second port (by a hydraulic line); wherein the control device is configured to control the on-off-valve. In particular, during the return movement state, the control device is configured to control the on-off-valve to switch to an on state. Accordingly, regeneration of hydraulic fluid is achieved.

[0018] Preferably, the control device is configured to determine the return movement state based on a boom lowering control signal and/or an activation signal from a user interface. The boom lowering signal is more preferably determined by means of a user interface (e.g. HMI, Human Machine Interface, device such as a joystick). For example, when loading bulk material from the ground onto a truck, after unloading a bucket of bulk material onto the truck, the boom is lowered based on a user interaction, such as a movement of a joystick into a certain direction.

[0019] Preferably, the hydraulic control system further comprises a boom directional control valve configured to be connected to the hydraulic pump and to piston and rod sides of the at least one boom hydraulic cylinder, wherein the control device is configured to control the boom directional control valve, and wherein, when the boom directional control valve is connected to the hydraulic pump and to piston and rod sides of the at least one boom hydraulic cylinder, during the return movement state, the control device is configured to control the boom directional control valve to be in a neutral position. This allows to have the whole pump flow to manage the movement of the attachment mounted to the boom.

[0020] Preferably, a check valve is arranged in a hydraulic line connecting the boom directional control valve with the piston side of the at least one boom hydraulic cylinder, such that flow (and/or leakage) of hydraulic fluid from the piston side of the at least one boom hydraulic cylinder to the boom directional control valve is prevented. The check valve ensures that no hydraulic fluid flows or leaks from the piston side of the at least one boom hydraulic cylinder to the boom directional control valve and from there into the tank. Alternatively, also preferably, the boom directional control valve can be controlled to be in a state, in which flow of hydraulic fluid from the piston side of the at least one boom hydraulic cylinder to the tank is blocked and in which flow of hydraulic fluid from the hydraulic pump to the rod side of the at least one boom hydraulic cylinder is allowed (e.g. the boom directional control valve has a corresponding spool allowing a corresponding control position); specifically during a "machine lift state", whereas during the "return movement state" the spool of the boom directional control valve stays in a neutral position. Both embodiments allow the control of the lowering speed of the boom arm through only the lowering manifold. The check valve also ensures zero leak on the boom cylinder/s when the machine is inactive.

[0021] A machine according to the invention comprises a boom rotatable mounted on a chassis of the machine, wherein rotational movement of the boom is effected by at least one boom hydraulic cylinder, an attachment rotatable mounted at (to) a free end of the boom, wherein rotational movement of the attachment is effected by at least one attachment hydraulic cylinder; a hydraulic pump; and a hydraulic control system according to anyone of the preceding claims, wherein the attachment directional control valve is connected to the hydraulic pump and to piston and rod sides of the at least one attachment hydraulic cylinder, the lowering manifold is connected to piston and rod sides of the at least one boom hydraulic cylinder, and the pressure sensor is connected to the piston side of the at least one boom hydraulic cylinder. Preferably, the machine is a compact wheel loader, or a skid steer loader, wherein more preferably the attachment is a bucket. Using the hydraulic control system in a machine facilitates to speed up loading cycles of the machine.

[0022] Further advantages and embodiments of the invention will become apparent from the description and the appended figures.

[0023] The invention is shown schematically in the figures on the basis of exemplary embodiments and will be described in the following, with reference to the figures.

Short Description of the Figures

[0024]

Figure 1 shows a perspective view of an exemplary machine in which the method and system according to the invention can be implemented.

Figure 2 shows a hydraulic system including a hydraulic control system according to the invention.

Figure 3 illustrates pressure differences across various valves or orifices.

Figure 4 shows the connection of a load sense line between a directional control valve and a hydraulic pump.

Figure 5 shows a flow diagram of a method according to an embodiment of the invention.

Detailed Description

[0025] Figure 1 shows a perspective view of a machine 1. The machine is a skid steer loader, for example. The machine 1 has a boom 2 (which comprises two arms, one on each side of the machine) and an attachment (tool), namely a bucket 4. The boom 2 (also denoted as "boom arm") is attached to a chassis 6 of the machine in a pivotable manner; i.e. pivotable (rotatable) around an axis 8. The bucket 4 is attached to a free end of the boom 2 (i.e. the end of the boom opposite to the end of the boom that is attached to the chassis) in a rotatable manner around an axis (not visible in the perspective view of figure 1).

[0026] The rotational movements of the boom 2 and the bucket 4 around the respective axes are effected by hydraulic cylinders 12, 14. Particularly, the rotational movement of the boom 2 relative to the chassis 6 is effected by actuation of boom hydraulic cylinders 12 (only one visible in the perspective view of figure 1), and the rotational movement of the bucket 4 relative to the boom 2 is effected by actuation of attachment (bucket) hydraulic cylinders 14. The flow of hydraulic fluid to and from the hydraulic cylinders is controlled by a hydraulic control system. The pressure of the hydraulic fluid is provided by a hydraulic pump.

[0027] While the machine shown in figure 1 has two boom hydraulic cylinders and two attachment hydraulic cylinders, in general other numbers of hydraulic cylinders actuating the boom and the attachment are possible. Although the skid steer loader shown in Fig. 1 has a boom with two arms the invention may be used for machines having a boom with only one arm (or any other number of arms), in which case only one boom hydraulic cylinder 12 may be present, or any other number of boom hydraulic cylinders as the movement of a single arm of a boom may be effected by more than one boom hydraulic cylinder. Likewise, the movement of the attachment may be effected by different number of attachment hydraulic cylinders (e.g. one attachment hydraulic cylinder). For simplicity, in the plural "hydraulic cylinders" is used. This should be understood in the sense that only one boom and/or only one attachment hydraulic cylinder may be included in the machine.

[0028] Figure 2 shows a hydraulic system 20 including a hydraulic pump 22, a hydraulic control system 24, hydraulic cylinders 12, 14, and a control device 36, such as an electronic control device. The hydraulic system 20 can be included in a machine, such as the skid steer loader shown in figure 1, having a boom and an attachment that are hydraulically operated. Although a pair of boom hydraulic cylinders 12 and a pair of attachment hydraulic cylinders 14 are shown in figure 2, the hydraulic control system 24 may be used for machines having other numbers of boom hydraulic cylinders and/or attachment hydraulic cylinders. It should be highlighted that generally the hydraulic control system 24 can comprise more than the two the number of working spools can be higher than the two (directional control valves 30, 32) shown in Fig. 2. For example, there may be one or more additional slices to operate additional auxiliary functions

[0029] The hydraulic pump 22 is preferably a variable displacement hydraulic pump, i.e. its conveyed flow is variable. Use of a hydraulic pump having a fixed displacement is also possible, in which case the flow coming from the pump is controlled by directional valves (not shown). The conveyed flow can be controlled by means of a load sense line (not shown in Fig. 2; cf. Fig. 3), for example. Typically, load sensing valves may be used in the hydraulic system. The hydraulic pump 22 is arranged to pump hydraulic fluid form a tank 26 into a (pressurized) hydraulic line 28 that is connected to the pump. That is, the hydraulic pump pressurizes the hydraulic fluid in hydraulic line 28. Further, a preferred pressure sensor 52 is shown, which measures the pressure of the hydraulic fluid on the hydraulic line 28. The pressure value measure by pressure sensor 52 may be transmitted to control device 36 (signal line not shown).

[0030] The hydraulic cylinders are boom hydraulic cylinders 12 and attachment hydraulic cylinders 14, such as shown in figure 1. Ports connected to supply lines allow the flow of hydraulic fluid to and from cavities on each side of a piston of each of the hydraulic cylinders. These sides or cavities are denoted as "rod side" 18, 19 of the hydraulic cylinders (i.e. the side of the piston, on which the piston is connected to a rod of the hydraulic cylinder) and "piston side" 16, 17 of the hydraulic cylinders (i.e. the side of the piston opposite to the rod side).

[0031] The hydraulic control system 24 comprises an attachment directional control valve 30 configured to selectively control (according to spool positions) the flow of hydraulic fluid from the hydraulic pump 22 (i.e. from the hydraulic line 28) to each of the piston and rod sides of the attachment hydraulic cylinders 14 and the (return) flow of hydraulic fluid from each of the piston and rod sides of the attachment hydraulic cylinders 14 back to the tank 26. It should be noted that throughout the application the expression "to the tank" more specifically means "to a port configured to be connected to the tank", as the tank 26 itself is typically not part of the hydraulic control system 24.

[0032] The hydraulic control system 24 further comprises a boom directional control valve 32 configured to selectively control the flow of hydraulic fluid from the hydraulic pump 22 (i.e. from the hydraulic line 28) to each of the piston and rod sides of the boom hydraulic cylinders 12 and the (return) flow of hydraulic fluid from the rod side 18 of the boom hydraulic cylinders 12 back to the tank 26. A check valve 34 is arranged in a hydraulic line 35 connecting the boom directional control valve 32 with the piston side 16 of the boom hydraulic cylinders 12. The check valve 34 prevents flow of hydraulic fluid from the piston side 16 of the boom hydraulic cylinders 12 to come back to the boom directional control valve 32 and from there back to the tank 26. On the other hand, the check valve 34 allows flow of hydraulic fluid from the boom directional control valve 32 to the piston side 16 of the boom hydraulic cylinders 12. As alternative to the check valve 34 (leak free solution) it is also possible to use a boom directional control valve having a special spool with a different circuit (blocked connection between the piston side of the boom cylinder 16 and the tank 26 during the lowering). As explained before, during normal boom lowering the boom spool must stay in neutral position and only when machine lifting is needed the boom spool must be operated.

[0033] The attachment (bucket) and boom directional control valves 30, 32 are provided with actuators and are actuated, for example, electro-magnetically and/or electro-pneumatically, electro-hydraulically (e.g. utilizing PWM-controlled pressure reduction valves; PWM: pulse width modulation), and/or simply hydraulically with low pressure pilot signals. Spool positions are controlled by the actuators in order to adjust the cross-section (more specifically the area thereof) of orifices of the attachment and boom directional control valves 30, 32 in order to control flow rates of hydraulic fluid through the attachment and boom directional control valves 30, 32. The actuators are connected with the (preferably electronic) control device 36 by electric control lines (only some shown as dashed lines in the figure). For some or all of the control lines it is possible to use pneumatic and/or hydraulic control lines instead of electric control lines. A wireless control is also possible.

[0034] While not shown in figure 2, each of the attachment and boom directional control valves 30, 32 may be provided as or included in a load sense directional control valve. That is, there may be provided load sense lines and corresponding valves that are connected to a load sense line connected to the hydraulic pump.

[0035] The hydraulic control system 24 further comprises a lowering manifold 40, which is connected to the piston side 16 and rod sides 18 of the boom hydraulic cylinders 12. The lowering manifold 40 includes a proportional valve 42 (adjustable throttle valve; preferably electro-proportional throttle valve) connected to the piston side 16 of the boom hydraulic cylinders 12. A cross-section of an orifice of the proportional valve 42 (also denoted as piston side proportional valve or piston side valve) is adjustable according to a control signal. The control signal is typically an electric control signal provided by the control device 36. The proportional valve 42 is actuated (and therefore proportionally adjusted) electro-magnetically and/or electro-pneumatically and/or electro-hydraulically based on the control signal, or hydraulically through a connection with an electro-proportional pilot valve mounted on line.

[0036] The lowering manifold 40 further includes an on-off valve 44 (also denoted as rod side on-off valve) which is connected to the rod side 18 of the boom hydraulic cylinders 12. The on-off valve 44 is controllable to switch on or off a fluidic connection between the proportional valve 42 and the rod side 18 of the boom hydraulic cylinders 12. That is, the on-off valve 44 is connecting the meter-out flow downstream the proportional valve 42 to the rod side 18 of the boom cylinders 12.

[0037] Specifically, the proportional valve 42 and the on-off valve 44 each have two ports, wherein the ports of the proportional valve 42 are denoted as a first port and a second port and the ports of the on-off valve 44 are denoted as a third port and a fourth port. The first port (of the proportional valve 42) is connected to the piston side 16 of the boom hydraulic cylinders 12, the third port (of the on-off valve 44) is connected to the rod side 18 of the boom hydraulic cylinders 12, and the second port (of the proportional valve 42) and the fourth port (of the on-off valve 44) are connected with each other.

[0038] The second and fourth ports are further connected with an inlet of an out flow orifice 46 (throttle valve) having a known cross-section (i.e. cross-sectional area). An outlet of the out flow orifice 46 in turn is connected to the tank 26 (more specifically, to the tank port configured to be connect to the tank), such that hydraulic fluid from the second port (or fourth port) is able to flow through the out flow orifice 46 into the tank 26. Optionally, instead of or additionally to the out flow orifice 46 a check valve with fixed pre-load 47 may be present; cf. below. Although the tank is shown within the hydraulic control system 24, it is generally not a part of the hydraulic control system; rather the manifold includes a tank port that is configured to be connected to the tank. Formulated differently, the out flow orifice 46 is connected (arranged) between the second port and the tank port.

[0039] When the proportional valve 42 is controlled to allow flow of hydraulic fluid from the first port to the second port (wherein the cross-section of the orifice of the proportional valve 42 is adjusted), the control device is configured to calculate the meter-out flow based on the pressure value detected by pressure sensor 48 and to control the proportional valve 42, such that a lowering speed of the boom can be controlled. Additionally, the control device is configured to control the attachment directional control valve 30, such that a synchronized movement of the attachment (e.g. bucket) with the lowering of the boom is achieved.

[0040] Additionally, when the proportional valve 42 is controlled to allow flow of hydraulic fluid from the first port to the second port (wherein the cross-section of the orifice of the proportional valve 42 is adjusted) and when the on-off valve 44 is in an on state (i.e. allowing flow of hydraulic fluid from the fourth to the third port; also called energized), hydraulic fluid is able to flow from the piston side 16 of the boom hydraulic cylinders 12 to the rod side

18 of the boom hydraulic cylinders 12. Therefore, when an external force, i.e. due to gravity, compresses the boom hydraulic cylinders 12, hydraulic fluid from the piston side 16 flows through the proportional valve 42 and (due to the back pressure provided by the out flow orifice 46 and/or check valve with fixed pre-load 47, see below) through the on-off valve 44 into the rod side 18. That is, the hydraulic fluid is "regenerated" to fill the piston side of the boom hydraulic cylinders, particularly cavitation is prevented. A flow of hydraulic towards the boom directional valve 32 is prevented by the check valve 34.

[0041] The lowering manifold 40 preferably further includes a check valve 43, connected to the piston side 16 of the boom hydraulic cylinders 12 and to the outlet of the out flow orifice 46 (and/or check valve with fixed pre-load 47), such that flow of hydraulic fluid from the outlet of the out flow orifice 46 to the piston side 16 of the boom hydraulic cylinders 12 is allowed while flow of hydraulic fluid from the piston side 16 of the boom hydraulic cylinders 12 to the outlet of the out flow orifice 46 is prevented. Formulated differently, the check valve 43 is connected to the piston side 16 of the boom hydraulic cylinders 12 and to the tank port (without further restrictions to minimize pressure loss when the flow is moving between the tank and the piston side 16 of the boom hydraulic cylinders.

[0042] A pressure sensor 48 is arranged to measure the pressure (also denoted as piston side pressure) of the hydraulic fluid on the piston side 16 of the boom hydraulic cylinders 12. The detected value of the piston side pressure is transmitted to the control device 36. The value of the piston side pressure together with the cross-section (more specifically the area thereof) of the orifice of the proportional valve 42 and the known cross-section (more specifically the area thereof) of the out flow orifice 46 allows to determine (calculate) the flow rate (meter-out flow rate) of hydraulic fluid from the piston side 16 into the rod side 18 of the boom hydraulic cylinders 12. The cross-section of the orifice of the proportional valve 42 is known as it is adjusted according to the control signal. The meter-out flow rate may be measured as volume flow, e.g. in l/min (litres per minute). The meter-out flow rate is determined (calculated) by the control device 36, for example. Instead of a single control device, more than one control device may be used, such as a control device for generating the control signals for the actuators combined with a control device for determining the meter-out flow rate.

[0043] According to other embodiments, in addition or as an alternative to the out flow orifice 46 a check valve with fixed pre-load 47 can be arranged in the connection between the second port and the tank port. The check valve with fixed pre-load is arranged in a direction, such that flow from the tank port to the second port is prevented and flow from the second port to the tank port is allowed, when the pressure difference (or the corresponding force) across the check valve with fixed pre-load exceeds the pre-load. If both out flow orifice and check valve with fixed pre-load are present, they are arranged in series. In the determination of the meter-out flow rate the know fixed pre-load should be taken into account. Similar to the out flow orifice, a back pressure is achieved due to the pre-load, such that hydraulic fluid flows through the on-off valve 44 to the rod side 18 of the boom hydraulic cylinder 12. In any case the check valve 43 (if present), connected to the piston side 16 of the boom hydraulic cylinders 12 and to the tank port is directly connected to the tank port, i.e. downstream the out flow orifice 46 and/or the check valve with fixed pre-load 47.

[0044] The check valve with fixed pre-load is advantageous in situations with a low meter-out flow rate, in order to generate a high enough back pressure to cross the on-off valve 44 and fill the rod side 18 of the boom hydraulic cylinders 12. This is illustrated in figure 3, which shows exemplary pressure differences across the out flow orifice 46, the check valve with fixed pre-load 47, and the on-off valve 44. In figure 3 the pressure difference Δp (e.g. measured in bar) of the respective valves is shown as function of the flow rate Q (e.g. measured in lpm, litre per minute) across the valve. Line 60 illustrates the pressure difference across the out flow orifice 46, line 62 illustrates the pressure difference across the on-off valve 44, and line 64 illustrates the pressure difference across the check valve with fixed pre-load 47. As can be seen, at relative low flow rates Q the check valve with fixed pre-load 47 generate enough back pressure (corresponding to the pressure difference) to cross on-off valve 44 (line 64 > line 62); at relative high flow rates Q the out flow orifice 46 generates enough back pressure to cross on-off valve 44 (line 60 > line 62). Depending on actual flow rates occurring in a machine, in which the hydraulic control system is used, the appropriate implementation of the lowering manifold can be chosen.

[0045] The control device 36 controls the attachment directional control valve 30 based on the meter-out flow rate, i.e. the position of the spool of the attachment directional control valve 30 is controlled based on the meter-out flow rate. More specifically, a flow of hydraulic fluid is directed through the attachment directional control valve 30 towards either the piston side or the rod side of the attachment hydraulic cylinders 14. The side (piston or rod side), into which the flow is directed, is predetermined, for example. As each spool position corresponds to a specific cross-section of an orifice (through which the flow is directed) of the attachment directional control valve 30, the cross-section of the orifice is controlled. Combining the information about calculated meter-out flow from boom lowering (through the proportional valve 42 and pressure sensor 48), the controller 36 can modulate the flow to be sent to the attachment hydraulic cylinders controlled by attachment directional control valve 30 in order to keep or reach the desired position or orientation. It is possible to determine a flow rate (denoted as attachment flow rate) of the flow of hydraulic fluid into the piston or rod side of the attachment hydraulic cylinders 14 based on this cross-section and the pressure drop across the attachment directional control valve 30. The pressure drop may be determined based on measurements of pressure sensors connected to the pressurized hydraulic line 28 (connected to the pump) and to a hydraulic line that connects the attachment directional control valve 30 with the piston or rod side. Alternatively, the pressure drop across the spool of attachment directional control valve 30, can be determined by a local pressure compensator on each spool of the directional control valve.

[0046] As result, a synchronized movement of the elements actuated by the hydraulic cylinders is achieved. For example, with reference to figure 1, the bucket 4 of the machine can be rotated in a synchronized manner with a lowering movement of the boom 2. The rotation of the bucket 4, which is caused by actuation of the attachment hydraulic cylinders 14, is performed automatically as controlled by the control device which controls the attachment hydraulic cylinders 14 based on the pressure value (measured by pressure sensor 48) and the calculated meter-out flow rate of the boom hydraulic cylinders. Due to the regeneration of hydraulic fluid by means of the lowering manifold, no power and pump flow is required for the lowering of the boom. This allows to completely use the power provided by the hydraulic pump for rotating the bucket. The power does not have to be divided between the bucket rotation and the lowering movement of the boom. As result, the speed, with which at a loading position can be arrived (i.e. a position where bulk material can be loaded onto the bucket), can be increased.

[0047] For example, in case of a compact wheel loader or a skid steer loader (such as in figure 1), on a control panel (having mechanical switches, e.g. on a joystick, or implemented on a touch screen) of the machine a switch can be provided which allows a user to turn on and off a return function (or return-to-dig function). When the return function is on and/or a specific button is pressed by the user and when a user signal or user interaction (e.g. a joystick movement in a certain direction) indicating a lowering of the boom is detected, the control device will, firstly (for lowering the boom), control the lowering manifold to regenerate hydraulic fluid from the piston side into the rod side of the boom hydraulic cylinders and, secondly, automatically (based on the meter-out flow rate) control the attachment directional control valve in order rotate the bucket from its unloading position into its loading position. A separate user signal or user interaction (e.g. a joystick movement in a different direction) for rotating the bucket is not necessary, facilitating the handling of the machine. When the return function is off, the user may control the boom and attachment movements independently.

[0048] The operating phase as described above (i.e., regeneration of hydraulic fluid, determination of the meter-out flow rate, synchronized movement of the attachment) is denoted as "return movement state". For example, the boom and the bucket are returned to a dig (loading) position from an unloading positon. The return movement state can be triggered in response to a boom lowering control signal, preferably a boom lowering control signal as indicated by a user signal, e.g. a certain movement of a user control element such as a joystick.

[0049] Apart from the return movement state other operating phases or operating states can be implemented by controlling (by the control device, based on control signals, e.g. from the user) the valves of the hydraulic control system 24 accordingly. For each state, the control device may be configured to determine whether the respective state is present based on a determined movement of the boom and/or attachment (e.g. based on a control signal from a user interface and/or based on sensor measurements, such as from pressure sensors, inertial motion units, position sensors, and/or angle sensors) and/or based on an activation signal for the respective state (e.g. from a user interface).

[0050] During an "up movement state" (that is a raising movement of the boom), the boom directional control valve 32 is controlled to allow flow of hydraulic fluid from the hydraulic pump (i.e. from hydraulic line 28) into the piston side 16 of the boom hydraulic cylinders 12, resulting in a rotational movement of the boom, such that the boom and therefore attachment are raised. Preferably, during the up movement state, the attachment directional control valve 30 is controlled to allow flow of hydraulic fluid from the hydraulic pump into the piston side 17 of the attachment hydraulic cylinders 14, resulting in a rotation of the attachment around the axis at the free end of the boom. During the up movement state, the proportional valve 42 and the on-off valve 44 are controlled to be in an off (closed) state, i.e. to not allow flow of hydraulic fluid. The flow to/from the boom hydraulic cylinders is managed by the spool of the boom directional control valve 32.

[0051] During a "float state", the proportional valve 42 and the on-off valve 44 are controlled to be in an on (fully open) state, i.e. to allow flow of hydraulic fluid. Thus, hydraulic fluid can freely flow between the piston and rod sides 16, 18 of the boom hydraulic cylinders 12, such that the attachment "floats" on the ground. The attachment and boom directional control valves 30, 32 are normally controlled to be in a neutral state. Specifically, the boom directional control valve 32 should stay in neutral position during the float state. The attachment directional control valve 30 is normally in neutral position during the float state, but if required it can be operated when in necessary to change the position of the bucket during the float state. In this way the boom arm will keep floating while the bucket position is adjusted. The float state can be implemented by the control device 36, when (after lowering the boom) it is determined that the pressure value (detected by pressure sensor 48) drops to the tank pressure level (when the attachment touches the ground). Activation via external input signals is possible any time. The flow through proportional valve 42 goes preferably from the cylinder side to tank, so when the flow has to go in the opposite direction (from tank to the hydraulic cylinders) the high pressure losses, needed to cross this valve, would not allow to completely fill the piston side of the boom hydraulic cylinders, the boom is lifted by the attachment because of the contact with uneven surface of the ground. To prevent this problem, check valve 43 can be included in the hydraulic control system, e.g. as part of the lowering manifold 40 (as shown).

[0052] During a "machine lift state", the proportional valve 42 is controlled to be in a throttle state (partially open) and the on-off valve 44 is controlled to be in the off state. The boom directional control valve 32 is controlled to allow flow of hydraulic fluid from the hydraulic pump (i.e. from hydraulic line 28) into the rod side 18 of the boom hydraulic cylinders 12, resulting in a rotational movement of the boom, such that the boom is lowered. When the absence of pressure on the piston side 16 of the boom hydraulic cylinders 12 is detected (e.g. by pressure sensor 48, indicating that the free end of the boom or the attachment has reached the ground) and the float state is not active and when the machine lift state is used, the machine (to which the boom is attached) will be lifted. The attachment directional control valve 30 is controlled to be in a neutral state. The float state and the machine lift state are not active at the same time. For example, the machine lift state is activated when the operator moves the joystick to the boom lowering direction. Accordingly, the boom lowering input from the joystick (intentionally made by the operator) will stop the float state and will activate the control of the boom spool of the boom directional control valve 32.

[0053] Figure 4 shows the connection of a load sense line 50 to a directional control valve, such as the boom directional control valve 32 and the attachment directional control valve 30. Depending on the spool position of the directional control valve, the pressure sensed by the load sense line corresponds to the pressure of hydraulic fluid being directed towards the piston or rod sides of the respective hydraulic cylinder or the tank pressure. As illustrated, the load sense line 50 is further connected to a control input of the (variable displacement) hydraulic pump 22, such that the pump is controlled according to the pressure/load sensed by load sense line 50. As common in the art, the directional control valves 30, 32 are both connected to the same load sense line through one or more shuttle valves or check valves (not shown), such that the load sense line senses the highest pressure present at the directional control valves and the pump is controlled according to the highest pressure.

[0054] Additionally, the pressure sensor 52 is shown, which measures/detects the pressure (denoted as pump pressure value) of the hydraulic fluid on the hydraulic line 28 that is pressurised by the hydraulic pump 22. Amongst others, the pump pressure value may be used by the control device 36 to determine whether, during the lowering movement state, the attachment hydraulic cylinders reach full stroke, which leads to a pump pressure jump to the maximal value. Based on this determination, the control device can stop the (synchronized) movement of the attachment hydraulic cylinders while continuing the lowering of the boom. Once the boom/attachment touches the ground (which can be detected due to drop of the pressure value detected by pressure sensor 48), the control device can control the attachment directional control valve 30 to move the attachment until a required final (horizontal) position/orientation is reached.

[0055] Alternatively, in case one or more position sensors (e.g. accelerometers, angle sensor, stroke sensors, etc.) are present on the boom (or arm elements thereof and/or on the attachment), during the lowering movement state, the control device may control the attachment directional control valve 30 to move the attachment until the required final position/orientation is reached (detected by the position sensors), stop the movement of the attachment when the final position has been reached, and continue the lowering of the boom by controlling the lowering manifold accordingly.

[0056] Figure 5 shows a flow diagram of a method according to an embodiment of the invention. The diagram shortly illustrates the essential parts of the procedure as described in connection with figure 2. In preferred step 110 hydraulic fluid is directed to flow from the piston side to the rod side of the at least one boom hydraulic cylinder. In step 120 the (piston side) pressure and the meter-out flow rate of the hydraulic fluid flowing from the piston side to the tank and the rod side of the at least one boom hydraulic cylinder are determined. In step 130 a flow of hydraulic fluid from a hydraulic pump to the piston side or to a rod side of the at least one attachment hydraulic cylinder is controlled based on the determined meter-out flow rate.

Claims

1. A hydraulic control system (24) for a machine (1), wherein the machine has a hydraulic pump (22), a tank (26) for hydraulic fluid, at least one boom hydraulic cylinder (12) and at least one attachment hydraulic cylinder (14), comprising

    an attachment directional control valve (30) configured to be connected to the hydraulic pump (22) and to piston and rod sides (17, 19) of the at least one attachment hydraulic cylinder (14);
    a lowering manifold (40) configured to be connected to piston and rod sides (16, 18) of the at least one boom hydraulic cylinder (12) and having a tank port configured to be connected to the tank (26);
    a pressure sensor (48) configured to detect a pressure value of hydraulic fluid and configured to be connected to the piston side (16) of the at least one boom hydraulic cylinder; and
    a control device (36) configured to control the

attachment directional control valve and the lowering manifold and configured to receive the pressure value from the pressure sensor (48);
wherein, when the hydraulic control system (24) is connected to the hydraulic pump (22), the tank (26), the at least one boom hydraulic cylinder (12) and the at least one attachment hydraulic cylinder (14), the control device is configured to, during a return movement state:

- determine, based on the pressure value, a meter-out flow rate of the flow of hydraulic fluid released from the piston side (16) of the boom hydraulic cylinder,
- control the attachment directional control valve (30), such that hydraulic fluid from the hydraulic pump (22) is directed into the piston side (17) or the rod side (19) of the attachment hydraulic cylinder (14), wherein a position of a spool of the attachment directional control valve is controlled based on said meter-out flow rate.

2. The hydraulic control system according to claim 1, wherein the lowering manifold (40) comprises

a proportional valve (42) having an adjustable orifice and having a first and a second port, wherein the first port is configured to be connected to the piston side of the at least one boom hydraulic cylinder;
wherein the control device (36) is configured to control a cross-section of the adjustable orifice of the proportional valve; and
wherein the control device (36) is configured to determine said meter-out flow rate based on the pressure value and the cross-section of the adjustable orifice of the proportional valve (42).

3. The hydraulic control system according to claim 2, wherein the lowering manifold (40) comprises
an out flow orifice (46) connected between the second port and the tank port; and wherein the control device (36) is configured to determine said meter-out flow rate based on the pressure value, the cross-section of the adjustable orifice of the proportional valve (42), and a known cross-section of the out flow orifice (46).

4. The hydraulic control system according to claim 2 or 3, wherein the lowering manifold (40) comprises

a check valve with fixed pre-load 47) connected between the second port and the tank port;
wherein, if dependent on claim 3, the check valve with fixed pre-load (47) is connected in series with the out flow orifice (46); and
wherein the control device (36) is configured to determine said meter-out flow rate based additionally the pre-load of the check valve with fixed pre-load (47).

5. The hydraulic control system according to any one of claims 2 to 4, wherein the lowering manifold (40) comprises

an on-off valve (44) having a third and a fourth port, wherein the third port is configured to be connected to the rod side of the at least one boom hydraulic cylinder and wherein the fourth port is connected to the second port;
wherein the control device (36) is configured to control the on-off-valve (44).

6. The hydraulic control system according to anyone of the preceding claims, wherein the control device is configured to, during the return movement state, control the lowering manifold to allow hydraulic fluid to flow from the piston side (16) of the boom hydraulic cylinder (12) to the rod side (18) of the boom hydraulic cylinder.

7. The hydraulic control system according to anyone of the preceding claims, wherein the control device (36) is configured to determine the return movement state based on a boom lowering control signal and/or an activation signal from a user interface.

8. The hydraulic control system according to anyone of the preceding claims, further comprising a boom directional control valve (32) configured to be connected to the hydraulic pump and to piston and rod sides of the at least one boom hydraulic cylinder;

wherein the control device (36) is configured to control the boom directional control valve;
wherein, when the boom directional control valve (32) is connected to the hydraulic pump and to piston and rod sides of the at least one boom hydraulic cylinder, during the return movement state, the control device (36) is configured to control the boom directional control valve (32) to be in a neutral position.

9. The hydraulic control system according to claim 8,

wherein a check valve (34) is arranged in a hydraulic line (35) connecting the boom directional control valve with the piston side of the at least one boom hydraulic cylinder, such that flow of hydraulic fluid from the piston side (16) of the at least one boom hydraulic cylinder (12) to the boom directional control valve (32) is prevented; or
wherein the boom directional control valve (32) can be controlled to be in a state, in which flow

of hydraulic fluid from the piston side (16) of the at least one boom hydraulic cylinder (12) to the tank (26) is blocked and in which flow of hydraulic fluid from to hydraulic pump (22) to the rod side (18) of the at least one boom hydraulic cylinder (12) is allowed.

10. A machine (1) comprising

a boom (2) rotatable mounted on a chassis (6) of the machine, wherein rotational movement of the boom is effected by at least one boom hydraulic cylinder (12);
an attachment (4) rotatable mounted at a free end of the boom (2), wherein rotational movement of the attachment is effected by at least one attachment hydraulic cylinder (14);
a hydraulic pump (22); and
a hydraulic control system according to anyone of the preceding claims, wherein the attachment directional control valve is connected to the hydraulic pump and to piston and rod sides of the at least one attachment hydraulic cylinder, the lowering manifold is connected to piston and rod sides of the at least one boom hydraulic cylinder, and the pressure sensor is connected to the piston side of the at least one boom hydraulic cylinder.

11. The machine according to claim 10, wherein the machine is a wheel loader or a skid steer loader; wherein preferably the attachment is a bucket.

12. A method for controlling boom and attachment rotational movements of a machine (1) having a boom (2) that is actuated by at least one boom hydraulic cylinder (12) and an attachment (4) that is actuated by at least one attachment hydraulic cylinder (14), wherein a hydraulic control system for a hydraulic fluid is configured to control flow of a hydraulic fluid to and from piston and rod sides of boom and attachment hydraulic cylinders; wherein during a return movement state, the method comprises

determining (120) a pressure and a meter-out flow rate of the hydraulic fluid flowing from the piston side to the rod side of the at least one boom hydraulic cylinder;
controlling (130) a flow of hydraulic fluid from a hydraulic pump to a piston side or to a rod side of the at least one attachment hydraulic cylinder based on said meter-out flow rate.

13. The method of claim 12, wherein a pressure sensor is used in order to detect the pressure.

14. A control device, configured to receive a signal indicating a pressure and configured to generate control signals for performing the method of claim 12.

15. A computer program that causes a control device to generate control signals for performing the method of claim 12, when executed by the control device.

16. A machine-readable storage medium, having stored thereon a computer program according to claim 15.

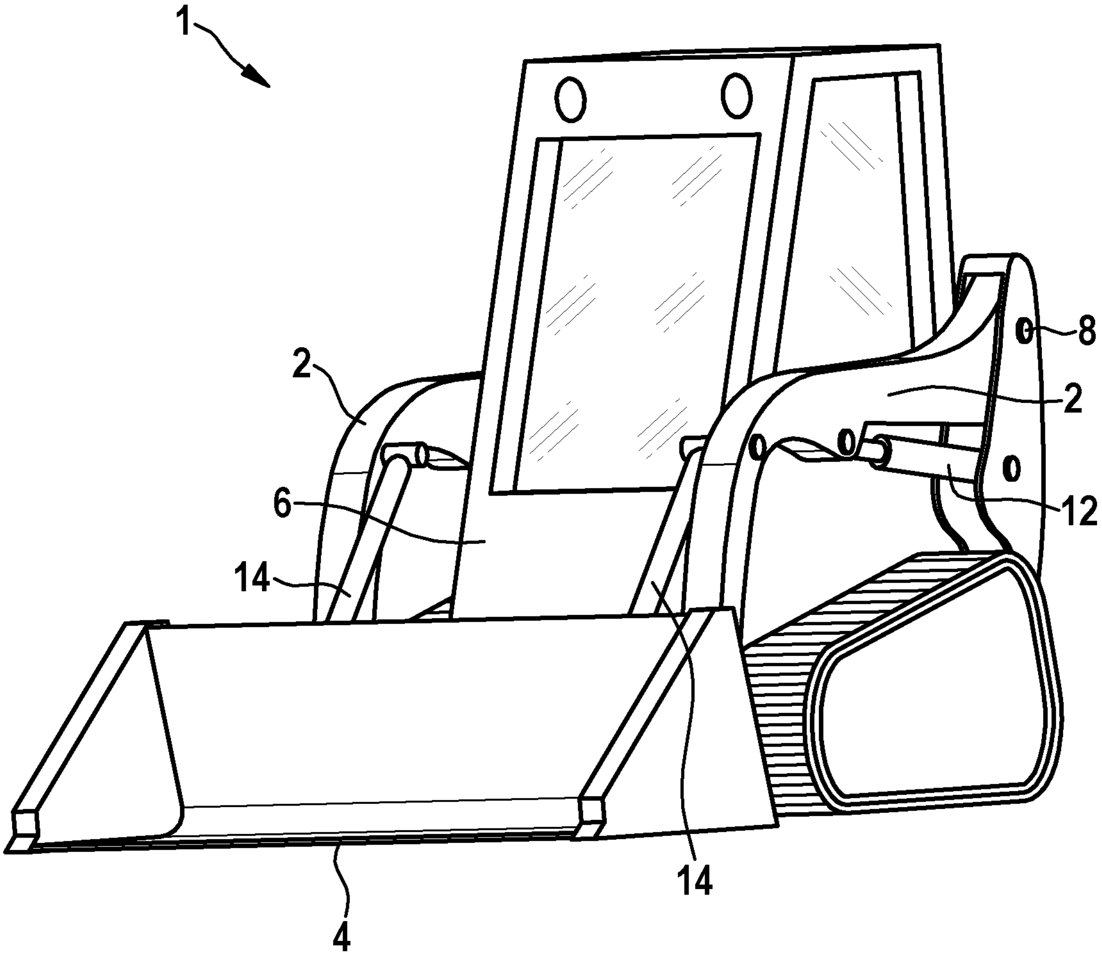

Fig. 1

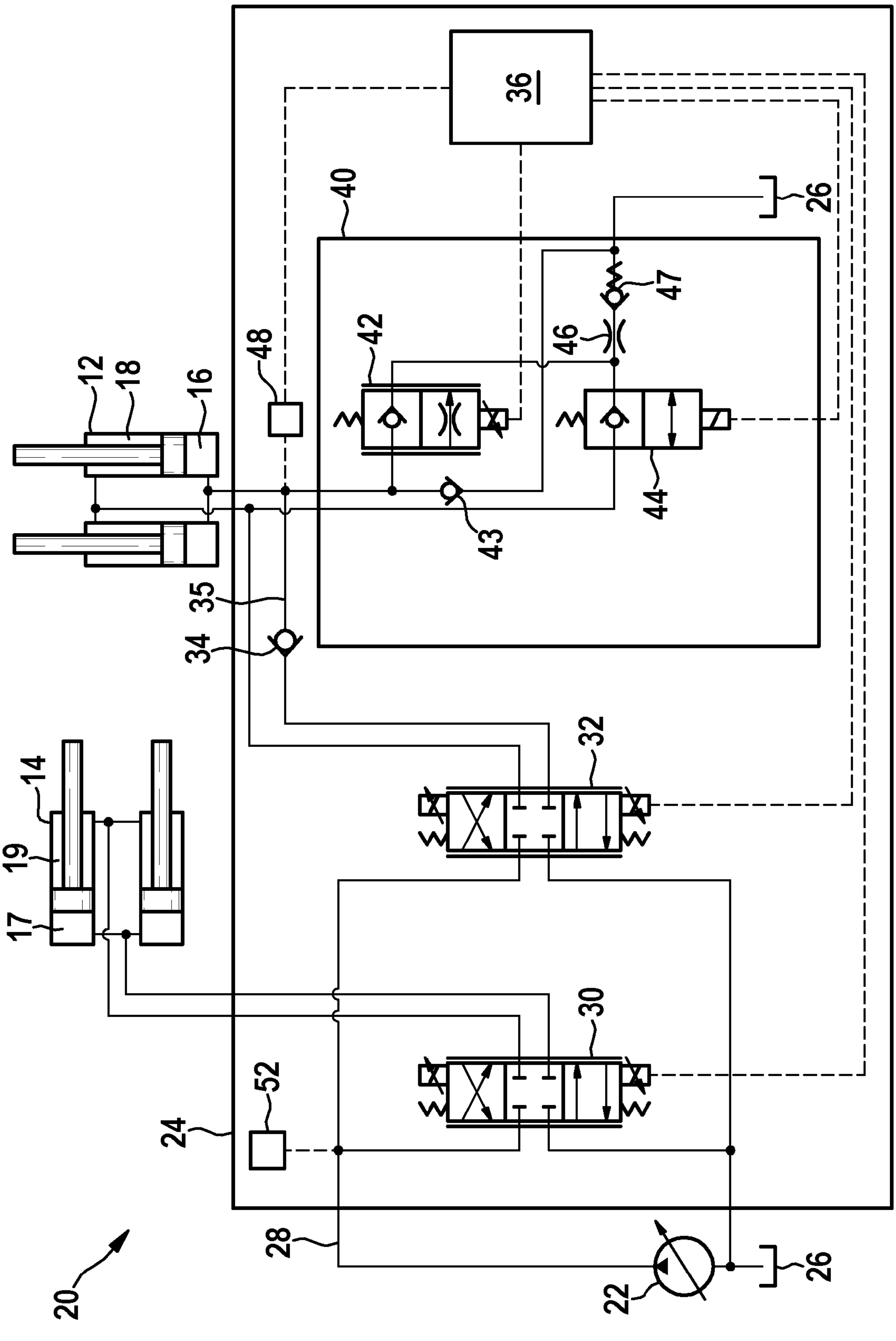
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Fig. 2

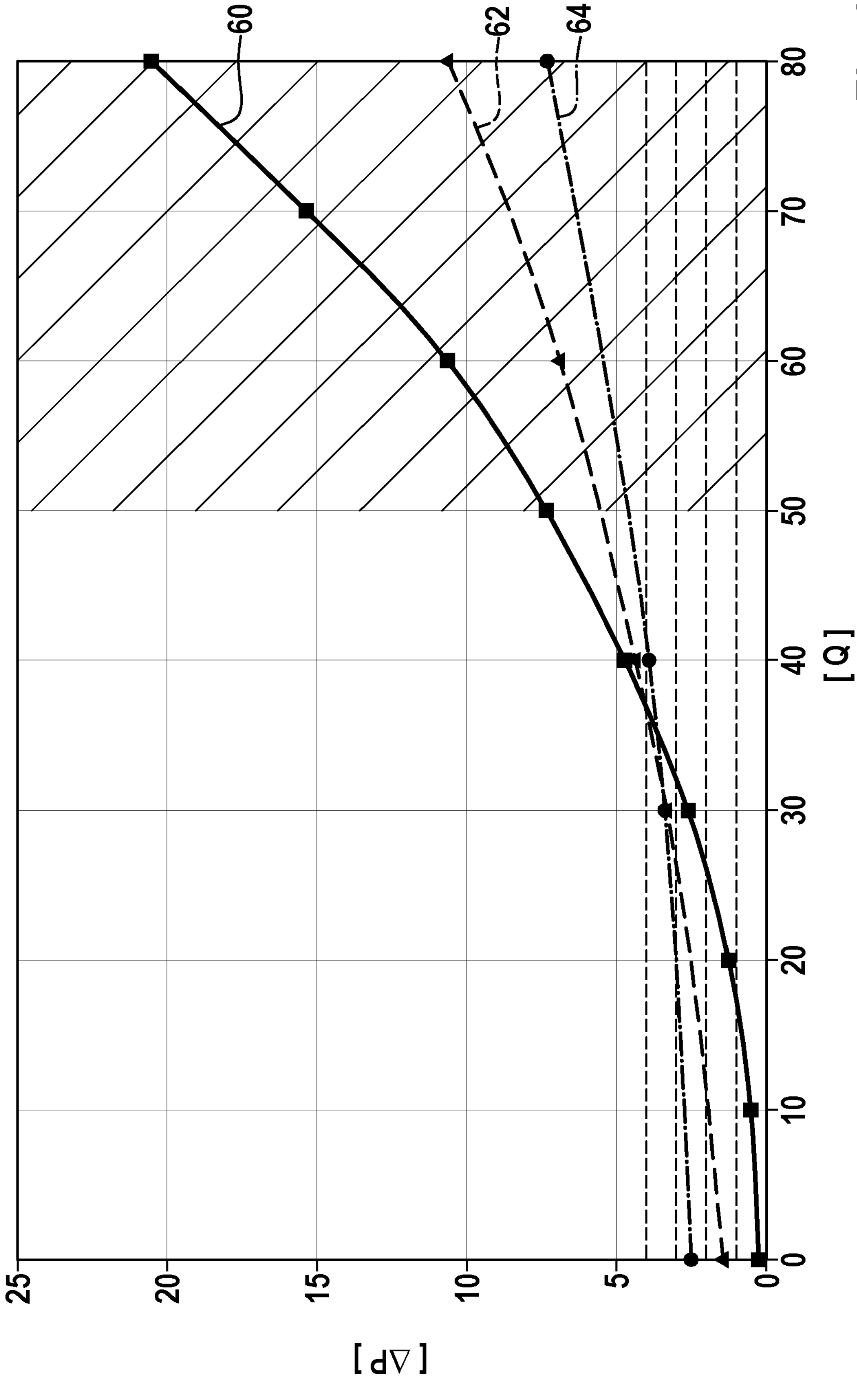

Fig. 3

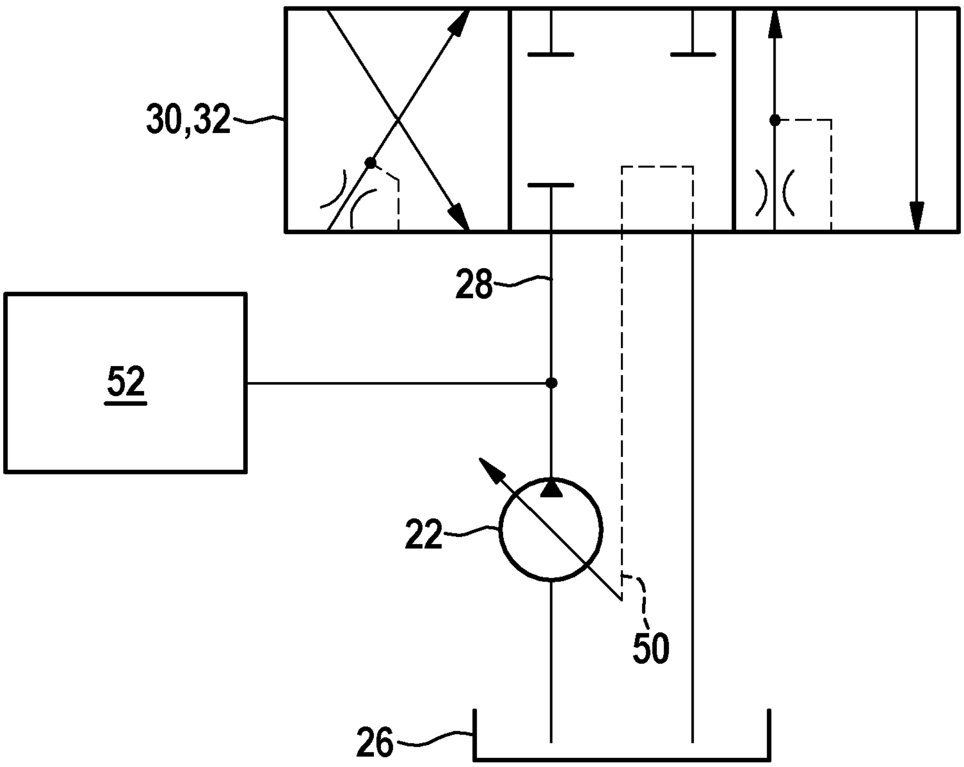

Fig. 4

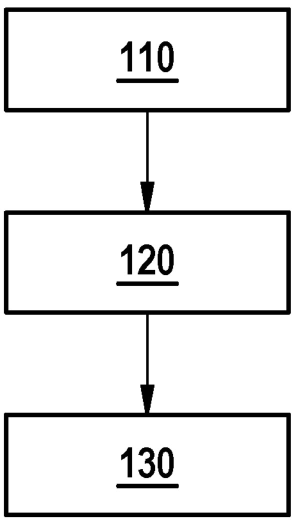

Fig. 5

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EUROPEAN SEARCH REPORT

Application Number
EP 22 15 7274

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E02F

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	4 August 2022	Dreyer, Christoph

CATEGORY OF CITED DOCUMENTS

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