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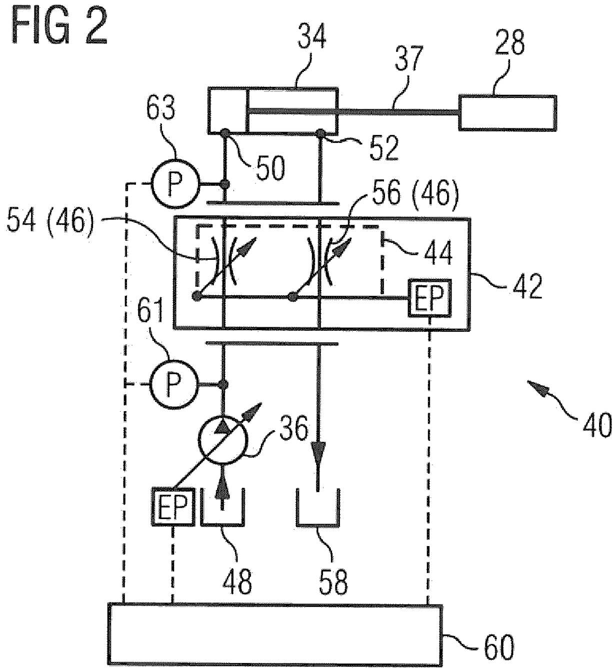
(54) **CONTROLLING AN ELECTRIC PROPORTIONAL VALVE**

(57) A method for controlling an electric proportional valve (42) of a hydraulic excavator attachment (28) is disclosed. The electric proportional valve (42) is controllable based on an electric input to the electric proportional valve (42). The electric proportional valve (42) is connected to a hydraulic actuator (34) for actuating the hydraulic excavator attachment (28) and to a hydraulic pump (36) for providing a flow of hydraulic fluid to the electric proportional valve (42). The method comprises operating the hydraulic pump (36) at a desired flow rate depending on the hydraulic excavator attachment (28); setting a desired pressure differential (Δp) over the electric proportional valve (42); determining an actual pressure differential (Δp') over the electric proportional valve (42); determining a pressure deviation (Δp - Δp') between the desired pressure differential (Δp) and the actual pressure differential (Δp'); and operating the electric proportional valve (42) such that the actual pressure differential (Δp') approaches the desired pressure differential (Δp).

FIG 2



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Description

Technical Field

[0001] The present disclosure generally relates to an electric proportional valve and in particular to an electric proportional valve of a hydraulic excavator attachment.

Background

[0002] Hydraulic excavators use hydraulic pumps to provide a certain flow of hydraulic fluid to a so-called auxiliary valve. The auxiliary valve controls operation of components of the hydraulic excavator such as a bucket, a grapple or other hydraulic excavator attachments. When the hydraulic pump and the valve are controlled electrically, the required flow to be provided to the auxiliary valve is calculated based on an expected spool position of the valve to meet a certain margin pressure across the valve. When the flow of hydraulic fluid is provided to the valve at the required margin pressure, the hydraulic attachment can be operated as desired.

[0003] The present disclosure is directed, at least in part, to improving or overcoming one or more aspects of prior systems.

Summary of the Disclosure

[0004] According to one aspect of the present disclosure, a method for controlling an electric proportional valve of a hydraulic excavator attachment is disclosed. The electric proportional valve is controllable based on an electric input to the electric proportional valve. The electric proportional valve is connected to a hydraulic actuator for actuating the hydraulic excavator attachment and to a hydraulic pump for providing a flow of hydraulic fluid to the electric proportional valve. The method comprises operating the hydraulic pump at a desired flow rate depending on the hydraulic excavator attachment; setting a desired pressure differential over the electric proportional valve; determining an actual pressure differential over the electric proportional valve; determining a pressure deviation between the desired pressure differential and the actual pressure differential; and operating the electric proportional valve such that the actual pressure differential approaches the desired pressure differential.

[0005] According to another aspect of the present disclosure, a hydraulic excavator attachment of a hydraulic excavator is disclosed. The hydraulic excavator includes a hydraulic pump configured to provide a flow of hydraulic fluid to the hydraulic excavator attachment. The hydraulic excavator attachment comprises a hydraulic actuator configured to actuate the hydraulic excavator attachment; an electric proportional valve fluidly connected to the hydraulic actuator and connectable the hydraulic pump; and a control unit electrically connected to the electric proportional valve and connectable to the hydraulic pump. The control unit is configured to perform the method as exemplarily disclosed herein.

[0006] According to another aspect of the present disclosure, a hydraulic excavator is disclosed. The hydraulic excavator comprises a hydraulic pump configured to provide a flow of hydraulic fluid; and a hydraulic excavator attachment as exemplarily disclosed herein, wherein the electric proportional valve is fluidly connected to the hydraulic pump and the control unit is electrically connected to the hydraulic pump.

[0007] Other features and aspects of this disclosure will be apparent from the following description and the accompanying drawings.

Brief Description of the Drawings

[0008] The accompanying drawings, which are incorporated herein and constitute a part of the specification, illustrate exemplary embodiments of the disclosure and, together with the description, serve to explain the principles of the disclosure. In the drawings:

Fig. 1 shows an exemplary hydraulic excavator with a hydraulic excavator attachment;

Fig. 2 shows an exemplary control system for controlling an electric proportional valve of the hydraulic excavator;

Fig. 3 shows another exemplary control system for controlling an electric proportional valve of the hydraulic excavator; and

Fig. 4 shows an exemplary calibration characteristic of an exemplary electric proportional valve.

Detailed Description

[0009] The following is a detailed description of exemplary embodiments of the present disclosure. The exemplary embodiments described therein and illustrated in the drawings 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 patent protection. Rather, the scope of patent protection shall be defined by the appended claims.

[0010] The present disclosure is based in part on the realization that electric proportional valves that are connected to a hydraulic actuator for operating a hydraulic excavator attachment are subjected to flow forces. The term "electric proportional valve" as used herein refers to a high-pressure circuit electric proportional valve being controllable by an electric input provided to an electric proportional pressure reducing valve that is configured to control a pilot pressure of hydraulic fluid for moving a spool of the high-pressure circuit electric proportional between different positions.

[0011] The present disclosure is further based in part on the realization that these flow forces may reposition the valve spool such that a spool position different from the expected spool position occurs.

[0012] The present disclosure is further based in part on the realization that the repositioning of the spool is mainly caused by a return flow of hydraulic fluid from the hydraulic actuator to the tank. As the return flow of hydraulic fluid depends on the type of hydraulic actuator used, and as the type of hydraulic actuator used depends on the type of hydraulic excavator attachment to be controlled by the electric proportional valve, the flow forces acting on the spool vary depending on the hydraulic excavator attachment. As a result, the "correct" position of the spool is unknown.

[0013] The present disclosure is further based in part on the realization that a repositioned spool results in an "incorrect" pressure margin, i.e. an incorrect pressure differential across the electric proportional valve, which may have adverse effects on the operation of the hydraulic excavator attachment. For example, if the margin pressure is too low, the hydraulic excavator attachment may fail to operate.

[0014] The present disclosure is further based in part on the realization that the incorrect pressure margin can be corrected by offsetting the position of the spool until the actual pressure differential approaches the correct (desired) pressure differential. Or in other words, the electric proportional valve is recalibrated so that the actual pressure margin that is measured equals the desired pressure margin that is set independent of the type of hydraulic actuator attached.

[0015] The present disclosure is further based in part on the realization that for some hydraulic excavator attachments such as a grapple, the flow of hydraulic fluid needs to be sent to the hydraulic actuator within a very short time frame of some seconds or even some tenths of a second. Hence, it was realized that recalibrating the electric proportional valve - or offsetting the spool position - cannot be achieved by conventional feedback loop strategies which would exceed the very short time frame. Instead, it was realized that a feed forward command is necessary.

[0016] The present disclosure is further based in part on the realization that a procedure for offsetting the spool position is performed by determining an actual pressure differential over the electric proportional valve, comparing the actual pressure differential (actual margin pressure) with a desired pressure differential (desired margin pressure) and associating the determined pressure deviation with an electric input value (electric input offset value) that is necessary to reposition the spool accordingly.

[0017] Referring now to the drawings, Fig. 1 shows an exemplary hydraulic excavator 10. Hydraulic excavator 10 includes an undercarriage 12 with ground engaging elements such as wheels 14 or tracks. Hydraulic excavator 10 further includes an uppercarriage 16 rotatably connected to undercarriage 12. Uppercarriage 16 includes an internal combustion engine 18 powering hydraulic excavator 10 and an operator cabin 20 for operating hydraulic excavator 10. Uppercarriage 16 further includes an implement 22. Implement 22 includes a boom 24 connected to uppercarriage 16 and a stick 26 connected to boom 24. Stick 26 is further connected to a hydraulic excavator attachment 28. As exemplarily shown in Fig. 1, hydraulic excavator attachment 28 is a grapple. Other hydraulic excavator attachments 28 are, for example, a milling drum, a pulverizer etc. In order to operate hydraulic excavator attachment 28, operator cabin 20 includes one or more attachment actuation operator elements 21, such as a joystick or a slider.

[0018] Hydraulic excavator 10 further includes various hydraulic actuators for controlling various components of hydraulic excavator 10. For example, hydraulic excavator 10 includes as a boom actuator 30 for moving boom 24 relative to uppercarriage 16 and a stick actuator 32 for moving stick 26 relative to boom 24. Hydraulic excavator 10 further includes a hydraulic excavator attachment actuator 34 (short: hydraulic actuator 34) for actuating hydraulic excavator attachment 28. When hydraulic excavator attachment 28 is a grapple, as shown in Fig. 1, hydraulic actuator 34 controls, for example, an opening and closing motion of the grapple. Of course, hydraulic actuator 34 may control other and more complex motions depending on the type of hydraulic excavator attachment 28 used. Depending on the type of hydraulic excavator attachment 28 used, hydraulic actuator 34 may be a cylindrical actuator including a hydraulic cylinder, or may be an electric motor.

[0019] Hydraulic excavator 10 further includes a hydraulic pump 36 powered by internal combustion engine 18. Hydraulic pump 36 is a calibrated pump and configured to provide a desired flow rate of hydraulic fluid to the hydraulic actuators such as hydraulic actuator 34. A tank (item 48 in Fig. 2) is connected to hydraulic pump 36. Tank 48 acts as a source of hydraulic fluid.

[0020] Referring now to Fig. 2, an exemplary control system 40 for controlling an electric proportional valve 42 is shown. As can be seen, control system 40 includes hydraulic pump 36, hydraulic actuator 34 connected to hydraulic pump 36 and hydraulic excavator attachment 28 (schematically illustrated by a box) connected to hydraulic actuator 34. In the example shown, hydraulic excavator attachment 28 and hydraulic actuator 34 are connected via a rod 37. In the example shown, hydraulic actuator 34 is a cylinder-type hydraulic actuator 34.

[0021] Control system 40 further includes electric proportional valve 42 interconnected between hydraulic pump 36 and hydraulic actuator 34. Electric proportional valve 42 is configured to control a flow of hydraulic fluid between hydraulic pump 36 and hydraulic actuator 34 as will be explained.

[0022] Electric proportional valve 42 includes a spool 44 movable between different positions based on an electric input provided to electric proportional valve 42.

Spool 44 includes two metering orifices 46 arranged on spool 44. A first metering orifice (meter-out orifice 54) is connected to a bottom side 50 of hydraulic actuator 34. A second metering orifice (meter-in orifice 56) is connected to a rod side 52 of hydraulic actuator 34. Both metering orifices 46 are shaped such that a cross-sectional area of metering orifices 46 changes in dependence of a position of spool 44. As mentioned, the position of spool 44 depends on an electric input provided to electric proportional valve 42 (indicated by the "EP" box). Hence, upon applying a certain electric input value to electric proportional valve 42, a position of spool 44 changes, which in turn changes the cross-sectional area of metering orifices 46, which in turn changes a pressure differential (margin pressure) across electric proportional valve 42. As an example, spool 44 may be a rod and metering orifices 46 may be circumferential notches arranged on a circumferential face of the rod.

[0023] Referring now to the hydraulic circuit of Fig. 2 in more detail. Hydraulic fluid provided by tank 48 flows through hydraulic pump 36, through meter-out orifice 54 and from there to bottom side 50 of hydraulic actuator 34. Likewise, hydraulic fluid flows from rod side 52 of hydraulic actuator 34 through meter-in orifice 56 and from there to a discharge tank 58. Discharge tank 58 and tank 48 may be the same tank or may be different tanks. The flow of hydraulic fluid from hydraulic pump 36 to bottom side 50 is called supply flow. The flow of hydraulic fluid from rod side 52 to discharge tank 58 is called return flow. Depending on the flow rate ratio of supply flow to return flow, hydraulic actuator 34 may be termed a "cylinder-type hydraulic actuator" or a "rotating-type hydraulic actuator". In a rotating-type hydraulic actuator 34, the flow rate ratio of supply flow to return flow is 1:1. In a cylinder-type hydraulic actuator 34, the flow rate ratio of supply flow to return flow has values other than 1:1, for example, 1:2 or 1:4. Examples of hydraulic excavator attachments 28 that require a cylinder-type hydraulic actuator 34 are pulverizers or grapples. Examples of hydraulic excavator attachments 28 that require a rotating-type hydraulic actuator 34 are compactors or milling drums.

[0024] Control system 40 further includes a control unit 60. Control unit 60 controls electric proportional valve 42 and hydraulic pump 36 as indicated schematically in Fig. 2 by the dashed lines connecting control unit 60 to "EP" boxes of electric proportional valve 42 and hydraulic pump 36. Control unit 60 controls, among other operations, for example, a position of spool 44 and/or a flow rate of hydraulic pump 36.

[0025] Control system 40 further includes a first pressure sensor 61 arranged downstream of hydraulic pump 36 and upstream of electric proportional valve 42. Control system 40 further includes a second pressure sensor 63 arranged downstream of electric proportional valve 42 and upstream of hydraulic actuator 34. First and second pressures sensors 61, 63 are both connected to control unit 60 as indicated by the dashed lines. Control unit 60 may, for example, measure the pressure differential or margin pressure over electric proportional valve 42.

[0026] Referring now to Fig. 3, another exemplary control system 40 is shown. Compared to Fig. 2, electric proportional valve 42 is a four-connection three-port electric proportional valve 42. Such an electric proportional valve is also known as 4/3 electric proportional valve. In other examples, the electric proportional valve may be a 7/3 electric proportional valve.

[0027] In the example of Fig. 3, electric proportional valve 42 includes a first position 62, a second position 64 and a third position 66. In first position 62, hydraulic pump 36 provides hydraulic fluid via first orifice 54 to bottom side 50. Thus, in first position 62, hydraulic fluid flows from rod side 52 via second orifice 56 to discharge tank 58. In second position 64, hydraulic pump 36 provides hydraulic fluid via second orifice 56 to rod side 52. Thus, in second position 64, hydraulic fluid flows from bottom side 50 via first orifice 54 to discharge tank 58. In third position 66, hydraulic pump 36 and discharge tank 58 are both disconnected from hydraulic actuator 34.

[0028] As can be seen in Fig. 3, electric proportional valve 42 is biased towards third position 66, whereas first and second positions 62, 64 can be electrically controlled by control unit 60 (indicated by the dashed lines between "EP" boxes and control unit 60). Hence, upon applying a certain electric input value to electric proportional valve 42, spool 44 is moved a certain distance from third position 66 towards first position 62 or from third position 66 towards second position 64. Because first and second orifices 54, 56 are arranged on spool 44, changing the spool position between first and second positions 62, 64, also changes a cross-sectional area of first and second orifices 54, 56 thereby changing a pressure differential across electric proportional valve 42. As can be further seen, a shuttle valve 59 is interconnected between the line connecting bottom side 50 to electric proportional valve 42 and the line connecting rod side 52 to electric proportional valve 42. Shuttle valve 59 is further connected to second pressure sensor 63. Thus, second pressure sensor 63 always measures the highest pressure of the pressures present in the lines connecting bottom side 50 and rod side 52 to electric proportional valve 42. The pressure measured by second pressure sensor 63 may also be called load sense pressure.

Industrial Applicability

[0029] In the following, a procedure for controlling electric proportional valve 42 is described in connection with Figs. 1 to 3 and Fig. 4. For illustration purposes, the control procedures described herein are disclosed with reference to structural elements disclosed in Figs. 1 to 3. However, one skilled in the art will appreciate that the respective steps of the control procedure can be performed on other embodiments as well.

[0030] The procedure is applicable to any electric proportional valve, for example, electric hydraulic valves.

Exemplary electric proportional valves suitable for the procedure are, for example, the electric proportional valves used in D-series or F-series hydraulic excavators manufactured by Caterpillar Inc. One skilled in the art will, however, acknowledge that the disclosed procedure may be applied to other machines using electric proportional valves as well.

[0031] In a first step, hydraulic pump 36 is operated at a desired flow rate depending on requirements of hydraulic excavator attachment 28. The desired flow rate depends on the type of hydraulic excavator attachment 28 to be used and on a position of attachment actuation operator element 21 (joystick, slider, etc.). For example, when hydraulic excavator attachment 28 is a work tool requiring a maximal flow rate of 100 liters per minute and the operator positions attachment actuation operator element 21 to 50%, a desired flow rate of 50% of the maximal flow rate is provided by hydraulic pump 36. Sticking to the above example of a maximal flow rate of 100 liters per minute and an attachment actuation operator element position of 50%, hydraulic pump 36 would be operated to provide a desired flow rate of 50 liters per minute.

[0032] In a next step, a desired pressure differential Δp over electric proportional valve 42 is set. Desired pressure differential Δp is a system based pressure differential. For example, desired pressure differential Δp is 25 bar.

[0033] Desired pressure differential Δp is set by positioning spool 44 based on a nominal electric input value. The nominal electric input value is provided by a nominal electric input map 400 (see Fig. 4). Nominal electric input map 400 is a function of the desired flow rate and provides nominal electric input values 402 (see Fig. 4) for electric proportional valve 42 so that the desired pressure differential Δp over electric proportional valve 42 would be achieved. In other words, spool 44 is positioned based on nominal electric input map 400 from which desired pressure differential Δp is expected. Nominal electric input map 400 is either preset by the manufacturer of electric proportional valve 42 or is adapted to hydraulic excavator attachment 28. Nominal electric input map 400 may depend, for example, on a flow rate ratio between bottom side 50 and rod side 52 of hydraulic actuator 34 or may further depend on the type of hydraulic actuator 34 such as a cylinder-type hydraulic actuator 34 or a rotating-type hydraulic excavator 34. Moreover, nominal electric input map 400 may be provided specifically for meter-out orifice 54 and meter-in orifice 56. A typical nominal electric input value provided by nominal electric input map 400 is in a range between about 200 mA and about 800 mA. Control unit 60 can readily access nominal electric input map 400 to control electric proportional valve 42.

[0034] In a next step, an actual pressure differential $\Delta p'$ over electric proportional valve 42 is determined. Actual pressure differential $\Delta p'$ is measured by control unit 60 from readings of first and second pressure sensors 61, 63.

[0035] As long as a position of attachment actuation operator element 21 does not change, the desired flow rate to be provided by hydraulic pump 36 remains constant. As the desired flow rate, however, requires a certain spool position for electric proportional valve 42 to provide the desired pressure differential Δp, the actual pressure differential $\Delta p'$ is only determined for a "steady" position of attachment actuation operator element 21. The procedure therefore monitors the position of attachment actuation operator element 21 over a period of time, calculates a position mean and a position variation and determines the actual pressure differential $\Delta p'$ only, when the position variation is below a threshold value of the position mean. For example, the position is monitored over a period of time between about 0.1 s and about 0.5 s, and the desired pressure differential is set only when the position variation is below $\pm 1\%$ to $\pm 5\%$ of the position mean. Preferably, the position is monitored over a period of time of about 0.2 seconds and the threshold value is about $\pm 2\%$ of the position mean.

[0036] From the determined actual pressure differential $\Delta p'$ and the set desired pressure differential Δp, a pressure deviation $\Delta p - \Delta p'$ is determined.

[0037] In a next step, electric proportional valve 42 is controlled such that the actual pressure differential $\Delta p'$ approaches the desired pressure differential Δp. In other words, a position of spool 44 is controlled so that the determined pressure deviation $\Delta p - \Delta p'$ approaches a value of about zero. Control of electric proportional valve 42 is now explained in more detail with respect to Fig. 4.

[0038] Fig. 4 shows an exemplary calibration characteristic of electric proportional valve 42. On the horizontal axis 200, values of attachment actuation operator element 21 are plotted. As mentioned, these values are associated with a desired flow rate of hydraulic fluid to hydraulic actuator 34. For example, for a desired flow rate of 100 liters per minute, a value of 50% corresponds to 50 liters per minute. On the vertical axis 300, electric input values for electric proportional valve 42 are plotted. Nominal electric input map 400 is schematically illustrates as a linear function. In other examples, the nominal electric input map 400 may have other shapes as well.

[0039] To reposition spool 44, a map 410 of electric input values is provided. Map 410 is a function of preset pressure deviations $\Delta p - \Delta p'$ and provides the electric input values that are necessary to reposition spool 44 so that the actual pressure differential $\Delta p'$ approaches the desired pressure differential Δp. In other words, map 410 provides the electric input "offset" values 444 that are added to nominal electric input values 402 to recalibrate electric proportional valve 42. By adding electric input "offset" values to nominal electric input values 402, a new, recalibrated characteristic 420 for electric proportional valve 42 is obtained. By performing the steps of determining the actual pressure differential $\Delta p'$, determining the pressure deviation $\Delta p - \Delta p'$ and controlling electric proportional valve 42 multiple times, i.e. in multiple iterations, electric input "offset" values 444 will constantly adapt until the actual pressure differential Δp' has approached the determined pressure differential Δp. The final electric input "offset" values 444 thus obtained can then be stored as a so-called offset map. Control unit 60 has access to the offset map and adds the final electric input offset values 444 to nominal electric input values 402 in order to obtain the final characteristic. As a result, electric proportional valve 42 can be recalibrated and used with hydraulic excavator attachment 28.

[0040] The procedure can further store multiple offset maps, each offset map corresponding to a specific hydraulic excavator attachment 28. Thus, when hydraulic excavator attachment 28 is changed from a first hydraulic excavator attachment to a second hydraulic excavator attachment, control unit 60 reads the offset map and the nominal electric input map both corresponding to the second hydraulic excavator attachment and primes electric proportional valve 42 for use with the second hydraulic excavator attachment. In case, the electric input "offset" values are zero for the offset map of the second hydraulic excavator attachment, the procedure starts anew and obtains electric input "offset" values 444 from map 410 as explained above.

[0041] Map 410 is now explained in more detail. Map 410 includes a curve 430 that assigns electric input values to preset pressure deviations 440. Curve 430 has been determined from measurements in the field. To correctly reposition spool 44, the determined pressure deviation Δp - Δp' is compared with preset pressure deviations 440 provided in map 410. Then, the preset pressure deviation that is closest to the determined pressure deviation (marked by arrow 442) is chosen and the appropriate electric input "offset" value (marked by arrow 444) is added to nominal electric input value 402.

[0042] As can be seen, various maps 410 are provided for various preset positions 448 of attachment actuation operator element 21. Exemplarily, Fig. 4 shows a first map 450 for a position of 25% attachment actuation operator element 21, and a second map 460 for a position of 100% attachment actuation operator element 21. Exemplarily, in the first map 450, a positive electric input value (arrow 444 in first map 450) is obtained and in the second map 460, a negative electric input value (arrow 444 in second map 460) is obtained. As can be seen, curves 430 of first and second maps 450, 460 may not be the same. For example, curve 430 of first map 450 may constantly increase, whereas curve 430 of second map 460 may plateau for high pressure deviations. Thus, the same pressure deviations Δp - Δp' measured at different attachment actuation operator element positions, may result in different electric input values for electric proportional valve 42. Of course, curves 430 do not necessarily need to be different for different positions of attachment actuation operator element 2. Moreover, curves 430 may have other shapes than the ones shown in Fig. 4.

[0043] In case an actual position of attachment actuation operator element 21 does not correspond to any of the preset positions 448, the procedure compares the actual position with the preset positions 448 and selects the map 410 that corresponds to the preset position 448 closest to the actual position. In some embodiments, margins are provided around preset positions 448. In these embodiments, the map 410 is selected that corresponds to a preset position where the actual position falls within the margin of the preset position 448.

[0044] In some embodiments, maps 410 may also depend on a temperature and/or a viscosity of the hydraulic fluid. For this, control unit 60 may be connected to a temperature sensor and/or may have access to a viscosity-temperature-curve. By providing temperature dependent maps 410, recalibration of electric proportional valve 42 can become more reliable, because temperature effects of the hydraulic system can be taken into account.

[0045] Moreover, repositioning of spool 44 requires a certain time for the hydraulic system to settle, i.e. reach a steady state. The procedure therefore applies a waiting time before each time the actual pressure differential Δp' is determined. The waiting time depends on the iteration the procedure executes. For example, in the first iteration, a first waiting time is applied and in a second iteration and in further iterations, a second waiting time is applied. The first waiting time is in a range between about 0.5 seconds to about 1.0 seconds, preferably about 0.8 seconds. The second waiting time is in a range between about 1.5 seconds to about 3.0 seconds, preferably about 2 seconds. By applying a first waiting time below 2 seconds, electric proportional valves 42 can be recalibrated in a very short time frame so that hydraulic excavator attachments 28 operating in a very short time frame, such as a grapple, can be used with the recalibrated electric proportional valve 42. The second, longer waiting time, which can also be termed "settle time", allows the hydraulic system to achieve a steady state after spool 44 has been repositioned by the procedure.

[0046] The herein described control procedure for an electric proportional valve allows control and recalibration of electric proportional valves in an iterative feed forward command. By using the procedure disclosed herein, the electric proportional valve recalibrates itself in dependence of the desired flow rate at hand. As a result, the actual flow rate and the actual margin pressure are about 95% to about 105% of the desired flow rate and the desired margin pressure so that the hydraulic excavator attachments and the hydraulic excavator implements can be operated as desired. Moreover, in hydraulic systems with more than one hydraulic fluid consumers (multi-operation), the procedure allows an immediate and accurate flow sharing between the hydraulic fluid consumers.

[0047] Terms such as "about", "around", "approximately", or "substantially" as used herein when referring to a measurable value such as a parameter, an amount, a temporal duration, and the like, is meant to encompass variations of ±5% or less, more preferably ±1% or less, and still more preferably ±0.1% or less of and from the specified value, insofar as such variations are appropriate to perform in the disclosed invention. It is to be understood that the value to which the modifier "about" refers is itself also specifically, and preferably, disclosed. The recitation of numerical ranges by endpoints includes all numbers and fractions subsumed within the respective ranges, as well as the recited endpoints.

[0048] Although the preferred embodiments of this invention have been described herein, improvements and modifications may be incorporated without departing from the scope of the following claims.

Claims

1. A method for controlling an electric proportional valve (42) of a hydraulic excavator attachment (28), the electric proportional valve (42) being controllable based on an electric input to the electric proportional valve (42), being connected to a hydraulic actuator (34) for actuating the hydraulic excavator attachment (28) and being connected to a hydraulic pump (36) for providing a flow of hydraulic fluid to the electric proportional valve (42), the method comprising:

    operating the hydraulic pump (36) at a desired flow rate depending on the hydraulic excavator attachment (28);
    setting a desired pressure differential (Δp) over the electric proportional valve (42);
    determining an actual pressure differential (Δp') over the electric proportional valve (42);
    determining a pressure deviation (Δp - Δp') between the desired pressure differential (Δp) and the actual pressure differential (Δp'); and
    operating the electric proportional valve (42) such that the actual pressure differential (Δp') approaches the desired pressure differential (Δp).

2. The method of claim 1, wherein operating the electric proportional valve (42) further comprises:

    providing a map (410) of electric input values associated with the determined pressure deviation (Δp - Δp'); and
    setting an electric input value for the electric proportional valve (42) in dependence of the determined pressure deviation (Δp - Δp').

3. The method of claims 1 or 2, wherein setting an electric input value further comprises:

    comparing the determined pressure deviation (Δp - Δp') with preset pressure deviations (440) provided in the map (410); and
    selecting the electric input value (444) that corresponds to the preset pressure deviation (442) closest to the determined pressure deviation (Δp - Δp').

4. The method of claims 2 or 3, wherein the map (410) of electric input values depends on a temperature and/or a viscosity of the hydraulic fluid.

5. The method of any one of claims 2 to 4, wherein the desired flow rate is associated with a position of an attachment actuation operator element (21) and the map (410) of electric input values depends on the position of the attachment actuation operator element (21).

6. The method of claim 5, wherein the map (410) of electric input values is provided for preset positions (448) of the attachment actuation operator element (21) and the method further comprises:

    associating the position of the attachment actuation operator element (21) with an actual position;
    comparing the actual position with the preset positions (448); and
    selecting the map (450, 460) that corresponds to the preset position closest to the actual position.

7. The method of any one of claims 1 to 6 wherein operating the hydraulic pump (36) at a desired flow rate further comprises:

    associating the desired flow rate with a position of an attachment actuation operator element (21), and the method further comprising:

        monitoring the position of the attachment actuation operator element (21) over a period of time;
        calculating a position mean and a position variation; and
        performing the step of determining the actual pressure differential (Δp') only when the position variation is below a threshold value of the position mean.

8. The method of claim 7, wherein the time period is in a range between about 0.1 seconds and about 0.5 seconds and/or wherein the threshold value is in a range between about ±1% and about ±5%.

9. The method of any one of claims 1 to 8, wherein setting a desired pressure differential (Δp) further comprises:

    providing a nominal electric input map (400) including nominal electric input values (402) configured to achieve the desired pressure differential (Δp), the nominal electric input map (400) depending on a flow rate ratio between a supply flow of hydraulic fluid to the hydraulic actuator (34) and a return flow of hydraulic fluid from the hydraulic actuator (34).

10. The method of claim 9, wherein the nominal electric input map (400) depends on a type of hydraulic actuator (34) such as a rotating-type hydraulic actuator (34) wherein the flow rate ratio is 1:1, or a cylinder-type hydraulic actuator (34) wherein the flow rate ratio is unequal to 1:1.

11. The method of any one of claims 1 to 10, wherein the electric proportional valve (42) includes a spool (44) movable between different positions based on the electric input provided to the electric proportional valve (42) and the step of operating the electric proportional valve (42) further comprises:

positioning the spool (44) such that the actual pressure differential (Δp ’) approaches the desired pressure differential (Δp),
wherein positioning the spool (44) comprises:

changing a cross-sectional area of a metering orifice (46) arranged on the spool (44).

12. The method of any one of claims 1 to 11, further comprising:

applying a waiting time before the step of determining the actual pressure differential (Δp’).

13. The method of claim 12, wherein the steps of determining an actual pressure differential (Δp’), determining a pressure deviation (Δp - Δp’) and controlling the electric proportional valve (42) are performed for multiple iterations and the waiting time includes a first waiting time for the first iteration and a longer, second waiting time for the second iteration and the further iterations.

14. A hydraulic excavator attachment (28) of a hydraulic excavator (10), the hydraulic excavator (10) including a hydraulic pump (36) configured to provide a flow of hydraulic fluid to the hydraulic excavator attachment (28), the hydraulic excavator attachment (28) comprising:

a hydraulic actuator (34) configured to actuate the hydraulic excavator attachment (28);
an electric proportional valve (42) fluidly connected to the hydraulic actuator (34) and connectable to the hydraulic pump (36); and
a control unit (60) electrically connected to the electric proportional valve (42) and connectable to the hydraulic pump (36), wherein the control unit (60) is configured to perform the method of any one of claims 1 to 13.

15. A hydraulic excavator (10) comprising:

a hydraulic pump (36) configured to provide a flow of hydraulic fluid; and
a hydraulic excavator attachment (28) according to claim 14

wherein the electric proportional valve (42) is fluidly connected to the hydraulic pump (36) and the control unit (60) is electrically connected to the hydraulic pump (36).

FIG 1

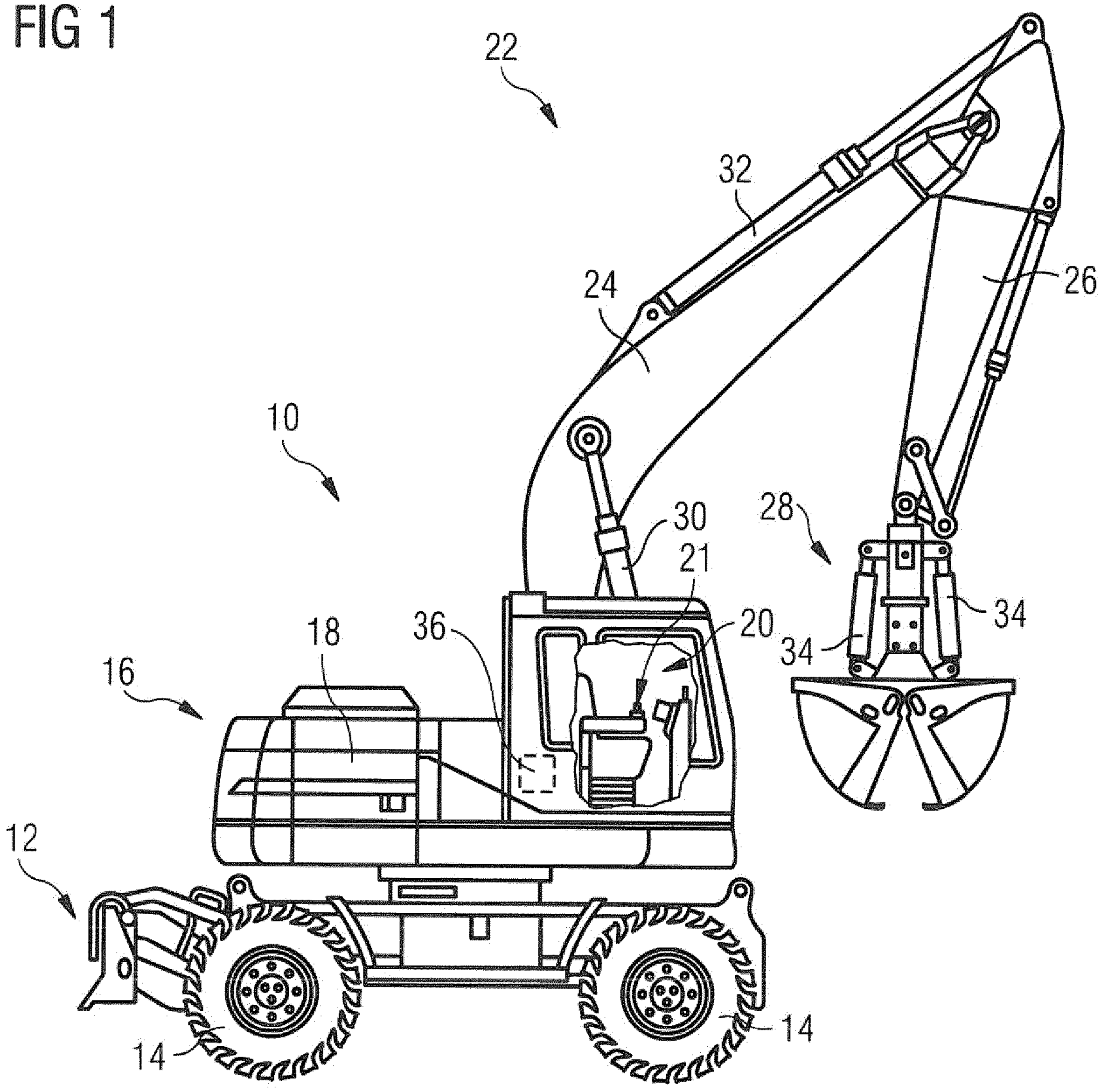

FIG 2

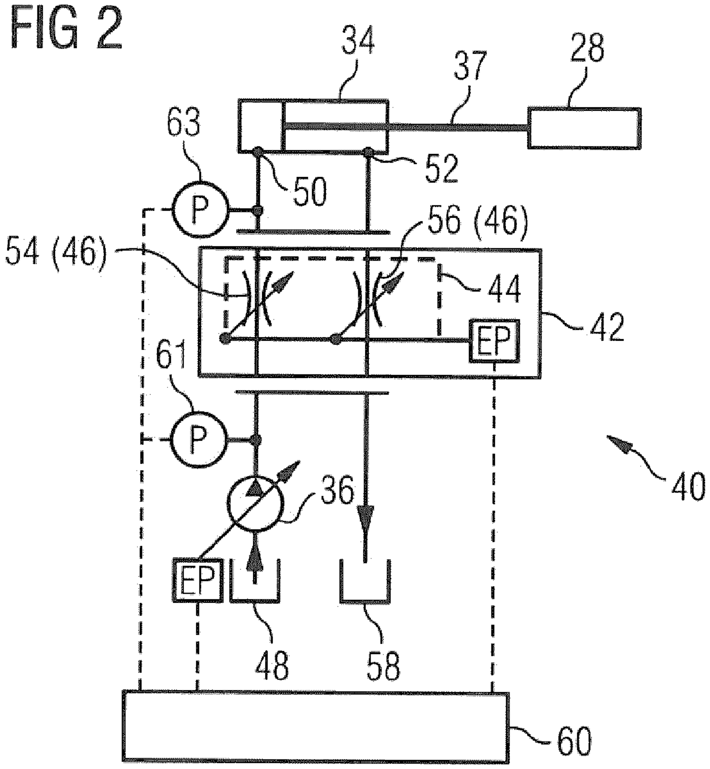
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FIG 3

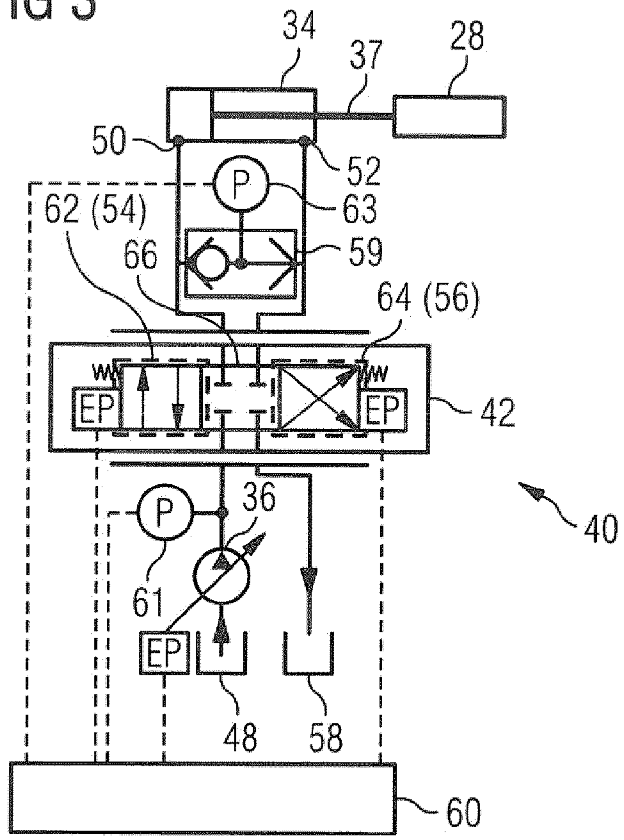
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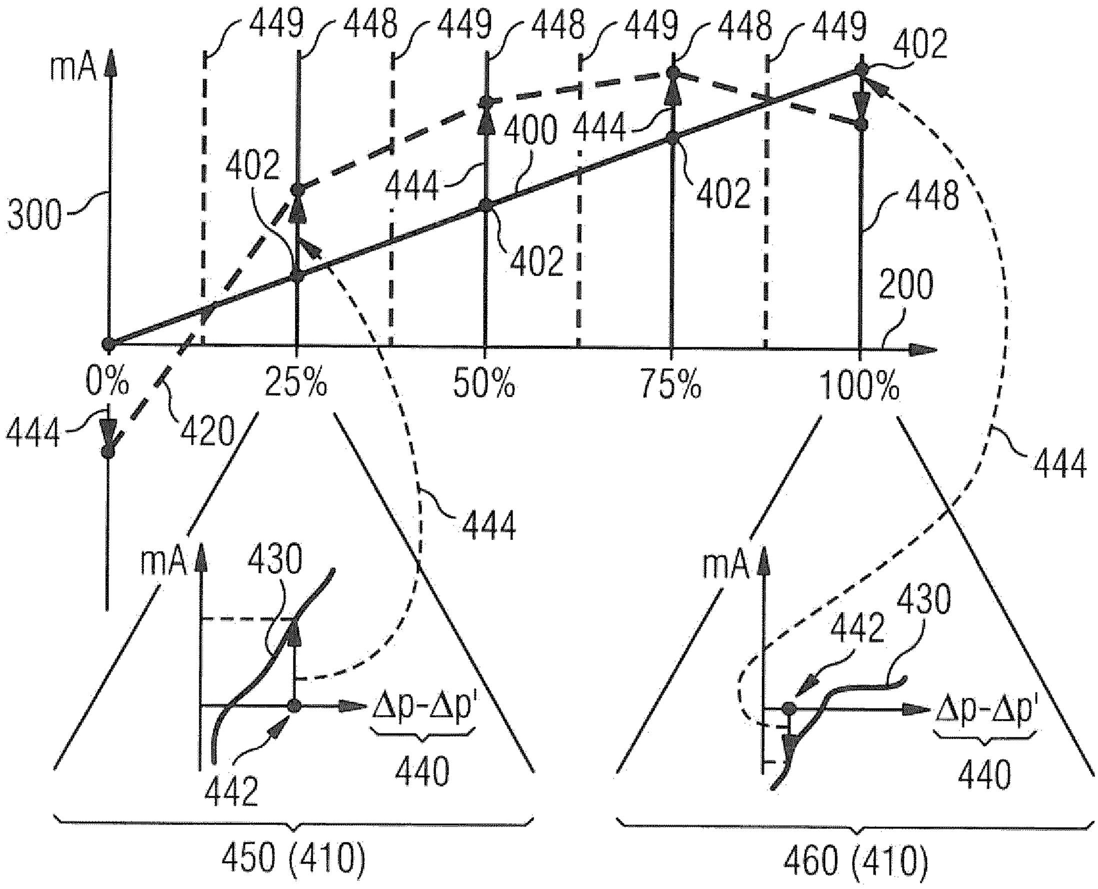
FIG 4



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430
Δp-Δp'
440
460 (410)

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EUROPEAN SEARCH REPORT

Application Number
EP 16 16 9558

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E02F
F15B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	24 October 2016	Ferrien, Yann

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