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(54) **ADAPTIVE HYDRAULIC ACTUATOR CONTROL**

(57) A method (100) of controlling a hydraulic actuator (10) of a working equipment (1), such as a forestry crane or a loader crane, the working equipment comprising a movable arm (5) and said hydraulic actuator (10) for moving the movable arm (5), the method (100) comprising:

- providing (110), during a first time period (d1), a first electrical input (inp1) to an electromagnetic actuator (24) arranged to control a flow of hydraulic fluid to the

hydraulic actuator (10);

- obtaining (120) an electrical response (res1) that results from the first electrical input (inp1);

- determining (130) an adjustment value (adj1) based on the electrical response (res1) and the first electrical input (inp1); and

- applying (140), during a second time period (d2), the adjustment value (adj1) to a second electrical input (inp2) to the electromagnetic actuator (24).

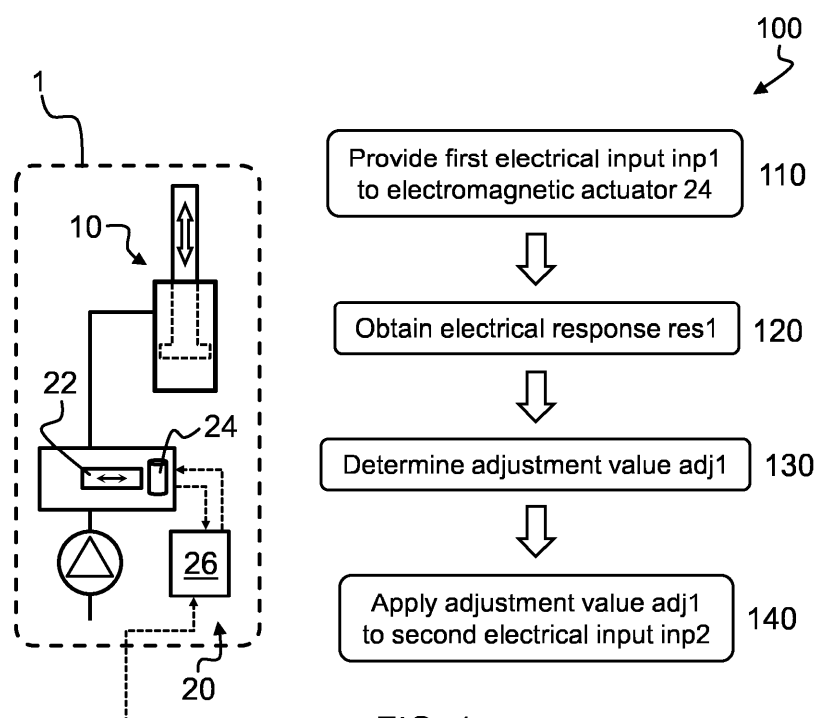


FIG. 1

Description

Technical field

[0001] The present disclosure generally pertains to controlling hydraulic actuators, and more in particular to a method of controlling a hydraulic actuator of a working equipment, and to a hydraulic valve assembly for controlling a working equipment.

Background

[0002] Working equipment, such as loader cranes, typically comprises a number of moving parts actuated by hydraulic actuators. During operation of the working equipment, an operator command is typically converted into an electrical input that drives a solenoid-operated valve, which controls a flow of hydraulic fluid to the actuator.

[0003] One challenge is to convert the operator input to a correct electrical input, e.g. due to variations in the resistance of the solenoid. The patent publication US20050211936A1 is based on feedback control that continuously estimates the solenoid resistance and adjust a voltage setpoint accordingly. A current compensation function comprises a first processing stage that produces a proportional term, a second processing stage that produces a feed forward term, and a third processing stage that produces a derivative term.

[0004] Even though existing solutions generally perform satisfactorily, there remains room for improvement, particularly with regard to achieving stable, precise, and consistent control of hydraulic actuators.

Summary

[0005] Objects of the present invention involve improving prior-art hydraulic actuator control, in particular with respect to efficiency, reliability, and accuracy. Improved efficiency may relate to enhanced operator performance, reduced energy consumption, and decreased mechanical wear.

[0006] The invention is exemplified through the embodiments disclosed herein. In accordance with one aspect, the present disclosure provides a method of controlling a hydraulic actuator of a working equipment, such as a forestry crane or machine or a loader crane. The working equipment comprises a movable arm and said hydraulic actuator for moving the movable arm. The method comprises providing, during a first time period, a first electrical input to an electromagnetic actuator arranged to control a flow of hydraulic fluid to the hydraulic actuator, obtaining an electrical response that results from the first electrical input, determining an adjustment value based on the electrical response and the first electrical input, and applying, during a second time period, the adjustment value to a second electrical input to the electromagnetic actuator.

[0007] Advantages may involve ensured stable, precise, and predictable control of the movable arm. Moreover, ensured smooth control and improved feel of the working equipment control may lead to time savings and increased efficiency. Because there is no change in control of the movable arm during the first time period - the adjustment value is applied to a second electrical input, subsequent to the first electrical input - an operator may experience consistent behaviour of the working equipment during each operator action or command. The operator may thereby experience less fatigue and maintain a high focus during a working day.

[0008] Applying the adjustment value during a subsequent or second electrical input entails that the precision may be maintained or enhanced stepwise in between operator commands during a working day. Earlier solutions, see e.g. US20050211936A1, instead using continuous feedback, such as PI or PID control, could suffer from vibration caused by noise in measured values, potentially leading to overshoots and unpredictable speed in the movements of the movable arm. By contrast, the present method may detect moments in which an operator holds an operator interface device lever steady (even briefly) and during such moments collect reliable data for calculating the adjustment value. Once an operator command ends and the lever returns to its neutral position, the determined adjustment value may improve the accuracy of subsequent operator commands.

[0009] As compared to solutions similar to the one disclosed in US20050211936A1, the present disclosure may ensure precise and reliable control independently of the lever deflection angle and the rate of lever deflection. Moreover, the avoidance of vibration may lead to reduced energy consumption and mechanical wear.

[0010] By operator command is meant that the operator actuates or manoeuvres the operator interface device, e.g. deflects or tilts a lever or a joystick or pushes a button, to achieve a desired movement of the movable arm. A first operator command may define the first time period, and a second operator command may define the second time period. An operator command may typically last from half a second to ten seconds. A single operator command may comprise different lever deflections, e.g. that the operator starts by moving the lever to a first angle for starting the movement that the command is addressing in a relatively slow speed and then increasing the lever angle from the first angle to a second angle to further increase the speed of the movement that the command is addressing from the initial relatively slow speed. A work task, such as lifting a load from the ground and placing it onto a vehicle on which the working equipment arrangement is mounted, may typically comprise several discrete operator commands.

[0011] A working equipment typically comprises a number of hydraulic actuators and associated electromagnetic actuators. Multiple hydraulic actuators and

electromagnetic actuators can be individually adapted using the present method. Moreover, no separate test signal or similar is required, the same input that drives the electromagnetic actuator may also be used to determine the adjustment value.

[0012] The first electrical input may be referred to as a first electrical input signal. The electrical response may be referred to as an electrical response signal. The second electrical input may be referred to as a second electrical input signal. The electrical response that results from the first electrical input may be referred to as a first electrical response, or an electrical response signal, or a first electrical response signal.

[0013] Optionally, the method comprises selecting a set of first electrical inputs during the first time period, which set satisfies a predetermined first validity criterion. The method may involve monitoring the first electrical input and selecting a set of first electrical inputs. Typically, the first electrical input comprises a plurality of discrete first electrical inputs separated in time. For example, the selected set of first electrical inputs may be 3 to 10 discrete first electrical inputs. The validity criterion can be defined in a number of ways, for instance based on the desired accuracy and the available computational capacity.

[0014] Optionally, the set of first electrical inputs satisfies the predetermined first validity criterion if a statistical deviation of the set of first electrical inputs is below a first deviation threshold. Thus, the method may involve calculating the corresponding statistical deviation and comparing the calculated statistical deviation to a first deviation threshold.

[0015] Optionally, the method comprises assessing whether a set of electrical responses that result from or correspond to the set of first electrical inputs satisfies a predetermined second validity criterion. Thus, a high accuracy may be ensured by monitoring not only the first electrical inputs but also the electrical responses. An electrical response that results from the first electrical input may be referred to as a first electrical response. Analogously, the set of electrical responses that result from or correspond to the set of first electrical inputs may be referred to as the first set of electrical responses.

[0016] Optionally, the set of electrical responses satisfies the predetermined second validity criterion if a statistical deviation of the set of electrical responses is below a second deviation threshold. The first and second deviation thresholds may be equal, meaning that the same validity criterion must be fulfilled by both the set of first electrical inputs and the corresponding set of electrical responses.

[0017] Optionally, determining an adjustment value based on the electrical response and the first electrical input comprises calculating a standard deviation of the difference between the electrical response and the first electrical input. Thus, determining the adjustment may comprise evaluating a standard deviation of the differ-

ence between the electrical response and the first electrical input. The method may comprise determining an adjustment value based on the electrical response and the first electrical input, only if the standard deviation of said difference is below a standard variation threshold.

[0018] Optionally, the method comprises calculating the adjustment value based on the first electrical input and the electrical response that results from the first electrical input.

[0019] Optionally, the method comprises monitoring the first electrical input and selecting a set of first discrete electrical inputs. Each discrete first electrical input may be compared to some, e.g. one to three, preceding first electrical inputs to select a set of first discrete electrical inputs that may be used for determining the adjustment value.

[0020] Optionally, the set of first electrical inputs are selected if they represent a substantially constant magnitude for a certain duration, such as at least 1/10 second. In other words, for example, if the operator steadily actuates the operator interface device for a certain duration, the method may determine the adjustment value. Said duration may e.g. be at least 1/10 second, at least 1/5 second, or at least 1/2 second.

[0021] Optionally, the method comprises identifying an end of the first electrical input. Once the first electrical input has ended, the method may comprise determining the adjustment value and applying it to a second electrical input. Typically, the first and second electrical inputs are separated in time.

[0022] Optionally, the method comprises identifying an end of the first time period. The method may comprise identifying an end of the first time period when the first electrical input ceases to cause a flow of hydraulic fluid to the hydraulic actuator. The method may comprise identifying an end of the first time period when the first electrical input no longer causes a flow of hydraulic fluid to the hydraulic actuator.

[0023] Optionally, the method comprises applying the adjustment value to the second electrical input only if there is a predetermined time threshold between the second electrical input and the first electrical input. Thereby, the first and second electrical inputs may be reliably distinguished from one another. The operator is not to experience any alteration in control of the working equipment during an active time period. The predetermined time threshold may for example be at least 100 milliseconds, at least 250 milliseconds, or at least 500 milliseconds.

[0024] Optionally, the method comprises determining an adjustment value based on the electrical response and the first electrical input, only if a variation of the electrical response is below a response variation threshold and a variation of the first electrical input is below an input variation threshold.

[0025] Optionally, the method comprises receiving a first command and providing the first electrical input based on the first command, then receiving a, sepa-

rate, second command and providing the second electrical input based on the second command and based on the adjustment value. Optionally, if no adjustment value has been determined from the first time period, a neutral adjustment value may be used. The neutral adjustment value may be configured so as not to influence the second electrical input.

[0026] Optionally, providing the first electrical input comprises providing a pulse width modulated input. An advantage may be that a direct-current power source, for instance a battery, efficiently may drive the electromagnetic actuator. Moreover, the same input that generates actuator movement can be used to determine the adjustment value.

[0027] Optionally, obtaining the electrical response comprises detecting an electrical quantity indicative of a current through the electromagnetic actuator, such as by measuring a voltage across a resistor in a return path. This may be a relatively simple, reliable, and accurate way of obtaining the electrical response.

[0028] Optionally, providing a first electrical input comprises providing the first electrical input based on an estimated resistance of the electromagnetic actuator, and the adjustment value is applied to the second electrical input to adjust that estimated resistance. This may effectively compensate for temperature-dependent changes in the electrical resistance of the electromagnetic actuator. Advantageously, the present disclosure allows for using a constant resistance during the first time period. Then, during the second time period, the same or an adjusted constant resistance is used. The resistance of the electromagnetic actuator used during the first time period may be referred to as a first resistance or first estimated resistance. The resistance of the electromagnetic actuator used during the second time period may be referred to as a second resistance or a second estimated resistance or an adjusted resistance. The method may comprise adjusting or calibrating the resistance of the electromagnetic actuator by means of the adjustment value. Thus, optionally, providing a first electrical input comprises providing the first electrical input based on a first estimated resistance of the electromagnetic actuator, and the adjustment value may after the first time period be applied to the first estimated resistance to obtain a second estimated resistance, which is then used when providing a second electrical input.

[0029] Optionally, the first command corresponds to a first desired movement of the movable arm or a section thereof, the second command corresponds to a second desired movement of the movable arm or a section thereof, and the adjustment value is determined only if the first desired movement remains constant for at least 1/10 second. Optionally, the adjustment value is determined only if the first desired movement remains constant for at least 1/5 second, or at least 1/2 second. As an alternative to not determining an adjustment value, a preceding or a neutral adjustment value

may be used.

[0030] As has been mentioned, the same electrical input that drives the electromagnetic actuator by means of the hydraulic fluid flow may be used to determine the adjustment value. However, the present method may comprise providing a first electrical input to the electromagnetic actuator arranged to control a flow of hydraulic fluid to the hydraulic actuator, wherein the first electrical input is of a magnitude that does not cause hydraulic fluid flow to the hydraulic actuator. Such a first electrical input, being of a magnitude that does not cause hydraulic fluid flow to the hydraulic actuator, may be referred to as an initial electrical input signal. Advantages involve that the adjustment value may be determined without hydraulic fluid flow to the hydraulic actuator, i.e. without a movement of the movable arm. The initial electrical input signal may e.g. be beneficial for selecting an estimated resistance of the electromagnetic actuator during start-up of the working equipment. Typically, the method will involve both first electrical inputs of magnitudes that do not cause hydraulic fluid flow to the hydraulic actuator, and first electrical inputs of magnitudes that do cause hydraulic fluid flow to the hydraulic actuator.

[0031] In accordance with a general aspect, the present disclosure provides a method of controlling a hydraulic actuator of a working equipment that comprises a movable arm and said hydraulic actuator for moving the movable arm. The method comprises providing an electrical input to an electromagnetic actuator arranged to control a flow of hydraulic fluid to the hydraulic actuator, obtaining an electrical response that results from the electrical input, determining an adjustment value based on the electrical response and the electrical input, and applying the adjustment value to a subsequent electrical input to the electromagnetic actuator. Thus, for example, the aforementioned first electrical input may simply be referred to as electrical input and the aforementioned second electrical input may be referred to as subsequent electrical input. Advantages and further possible features correspond to those of the above aspect.

[0032] In accordance with another aspect, the present disclosure provides a computer program product comprising instructions which, when executed by a processor in or connected to a working equipment, cause the processor to carry out the methods described herein.

[0033] In accordance with another aspect, the present disclosure provides a non-transitory computer-readable medium storing instructions which, when executed by a processor in or connected to a working equipment, cause the processor to carry out the methods described herein.

[0034] In accordance with another aspect, the present disclosure provides a hydraulic valve assembly for controlling a working equipment, such as a forestry crane or a loader crane, that comprises a movable arm

and a hydraulic actuator for moving the movable arm. The hydraulic valve assembly comprises a valve spool for controlling a flow of hydraulic fluid to the hydraulic actuator, an electromagnetic actuator for moving the valve spool, and a controller configured to provide a first electrical input to the electromagnetic actuator, obtain an electrical response resulting from the first electrical input, determine an adjustment value based on the electrical response and the first electrical input, and apply the adjustment value to a second electrical input to the electromagnetic actuator.

[0035] In accordance with another aspect, the present disclosure provides a control system for controlling a working equipment, such as a forestry crane or a loader crane, that comprises a movable arm and a hydraulic actuator for moving the movable arm. The working equipment comprising a hydraulic valve assembly that comprises a valve spool for controlling a flow of hydraulic fluid to the hydraulic actuator and an electromagnetic actuator for moving the valve spool. The control system is configured to provide a first electrical input to the electromagnetic actuator, obtain an electrical response resulting from the first electrical input, determine an adjustment value based on the electrical response and the first electrical input, and apply the adjustment value to a second electrical input to the electromagnetic actuator.

[0036] In accordance with another aspect, the present disclosure provides a vehicle-mountable working equipment comprising the control system or the hydraulic valve assembly. In accordance with another aspect, the present disclosure provides a forestry crane comprising the control system or the hydraulic valve assembly. The vehicle may typically be a truck, such as a timber truck.

[0037] Further advantages and associated advantageous features of the invention are disclosed in the following description and defined in the dependent claims.

Brief description of the drawings

[0038]

Figure 1 schematically illustrates a hydraulic valve assembly for controlling a working equipment with a hydraulic actuator, as well as a method of controlling the hydraulic actuator.

Figure 2 shows an example of the working equipment schematically illustrated in figure 1, in the form of a vehicle-mountable forestry crane.

Figure 3 is a schematic diagram illustrating the hydraulic valve assembly of figure 1.

Figures 4a-4c illustrate, with reference to the method and the assembly of figure 1, commands, elec-

trical inputs, electrical responses, and an adjustment value, as respective functions of time.

Detailed description

[0039] Exemplifying embodiments of the methods and apparatuses will now be described in detail with references to the appended figures. A general inventive concept of the present disclosure is to use an adjustment value obtained from an electrical input and a resulting electrical response to adjust a subsequent electrical input. In other words, to adjust or modify a control input based on a relationship between a previous control input and its resulting response.

[0040] Referring initially to figures 1 to 3, a method 100 of controlling a hydraulic actuator 10 of a working equipment 1 is disclosed. As shown in figure 2, the working equipment 1 may be a forestry crane mounted to a partly depicted timber truck.

[0041] The working equipment 1 comprises a movable arm 5 and the hydraulic actuator 10 for moving the movable arm 5. Referring to figure 2, the movable arm 5 may comprise a plurality of arm sections, pivot joints or telescopic connections joining the arm sections, a set of hydraulic actuators 10 for operating movements of the arm sections, and a load manipulator (here exemplified as a grapple) for engaging the undepicted load (here typically a log) during the load handling. As shown in figures 1 and 2, the present hydraulic actuators 10 are hydraulic cylinders. An operator interface device 7, adapted to be manoeuvred by an operator to achieve a desired movement of the movable arm, is shown in figures 2, 3 and 4a. The operator interface device 7 may comprise a lever and/or joystick to control the movements of the movable arm 5.

[0042] Moreover, the working equipment 1 typically comprises or is connectable to a hydraulic pump, shown at the bottom left in figure 1. The pump is in fluid connection with a hydraulic actuator 10 via a hydraulic valve assembly 20 that controls the flow of hydraulic fluid from the pump and an undepicted fluid tank to the hydraulic actuator. The illustrations of figures 1 and 3 are simplified to convey the principles of the present disclosure. In a typical realization of the invention, there are a plurality of double-acting hydraulic actuators 10 (see figure 2), each connected to at least two hydraulic valve assemblies 20.

[0043] In more detail, referring still to figures 1 and 3, the hydraulic valve assembly 20 comprises a valve spool 22 for controlling a flow of hydraulic fluid to the input of the hydraulic actuator 10 and electromagnetic actuator 24 for moving the valve spool 22. There is a controller 26 configured to provide a first electrical input inp1 to the electromagnetic actuator 24, more precisely to a solenoid of the electromagnetic actuator 24. There controller 26 is configured to provide a first electrical input inp1 to the solenoid of the electromagnetic actuator 24 to control the position of the valve spool 22 which

in turn controls the flow of hydraulic fluid, as is known per se.

[0044] The controller 26 may typically control one or more switching elements 28, such as field-effect transistors (FETs), to generate a pulse width modulated voltage (PWM, 24 V or 0 V) that is applied to the electromagnetic actuator 24, see figure 3. In figure 1, no switching elements 28 are illustrated, but merely the controller 26. It is to be apprehended that the controller 26 and the switching elements 28, if the latter are required, may be provided as separate or integral components.

[0045] Referring especially to the flowchart to the right in figure 1 and to figures 4a-c, the controller 26 is configured to obtain an electrical response res1 that results from the first electrical input inp1. In the present examples, obtaining the electrical response res1 may comprise detecting an electrical quantity indicative of a current through the electromagnetic actuator 24, more precisely by measuring a voltage across a resistor R that is connected on a return path from the electromagnetic actuator 24. Figure 3 illustrates such a resistor, and an amplifier A configured to facilitate measurement by the controller 26 of the voltage across the resistor R. To reduce losses, the resistor R is preferably a low-ohmic resistor, such as one having a resistance of less than 0.5 ohm.

[0046] Figure 4a illustrates a first command during a first time period d1 and a second command during a subsequent second time period d2. The dots of figures 4a and 4b indicate PWM pulses or sample values of the controller 26. The individual dots are connected by straight lines that show the progression. The horizontally aligned dots before, between, and after the first and second time periods d1, d2 represent periods without any command.

[0047] As is best understood from figure 4b, the controller 26 is configured to determine an adjustment value adj1 based on the electrical response res1 and the first electrical input inp1. For example, the electrical response res1 may be subtracted from the first electrical input inp1 to obtain an error. The adjustment value adj1 may be the error divided by the first electrical input inp1.

[0048] Figures 4a and 4b show that the first electrical input inp1 that results from the first command runs behind, typically by a few tens of milliseconds up to approximately 50 milliseconds, the first command. The (first) electrical response res1 that results from the first electrical input inp1 in turn runs behind, typically by a few tens of milliseconds up to approximately 50 milliseconds, the first electrical input inp1.

[0049] Referring to figures 3 and 4b, the controller 26 is configured to apply the adjustment value adj1 to a second electrical input inp2 to the electromagnetic actuator 24. Figure 4b shows that the electrical response res2 that results from the second electrical input inp2 is very close to the second electrical input inp2. Thus, the

adjustment value adj1 has served to correct the control of the hydraulic actuator 10. Stated in other words, the control of the hydraulic actuator has been calibrated.

[0050] Thus, referring to the flowchart to the right in figure 1, figure 3, and to figures 4a-c, the present method 100 comprises providing, during a first time period d1, a first electrical input inp1 to an electromagnetic actuator 24 arranged to control a flow of hydraulic fluid to the hydraulic actuator 10; obtaining an electrical response res1 that results from the first electrical input inp1; determining an adjustment value adj1 based on the electrical response res1 and the first electrical input inp1; and applying, during a second time period d2, the adjustment value adj1 to a second electrical input inp2 to the electromagnetic actuator 24.

[0051] Determining the adjustment value adj1 based on the electrical response res1 and the first electrical input inp1 may comprise selecting a set of first electrical inputs inp1s during the first time period d1. An exemplifying selected set of first electrical inputs inp1s are encircled in figure 4b. The selected set of first electrical inputs may satisfy a predetermined first validity criterion.

[0052] For example, the set of first electrical inputs inp1s may satisfy the predetermined first validity criterion if a statistical deviation of the set of first electrical inputs inp1s is below a first deviation threshold.

[0053] Determining the adjustment value adj1 based on the electrical response res1 and the first electrical input inp1 may comprise assessing whether a set of electrical responses res1s that correspond to the set of first electrical inputs inp1s satisfies a predetermined second validity criterion.

[0054] The set of electrical responses res1s may satisfy the predetermined second validity criterion if a statistical deviation of the set of electrical responses res1s is below a second deviation threshold.

[0055] As has been described, determining the adjustment value adj1 based on the electrical response res1 and the first electrical input inp1 may comprise calculating the adjustment value based on the first electrical input inp1 and the electrical response res1 that results from the first electrical input inp1.

[0056] Determining the adjustment value adj1 based on the electrical response res1 and the first electrical input inp1 may comprise monitoring the first electrical input inp1 and selecting a set of first electrical inputs, i.e., a set of first discrete electrical inputs. In the example of figure 4b, four first discrete electrical inputs form a set of first electrical inputs.

[0057] The set of first electrical inputs may be selected if they represent a substantially constant magnitude for a certain duration, such as at least 1/10 second. Looking at the exemplified first and second electrical inputs inp1, inp2 of figure 4b, the only discrete electrical inputs that are of a substantially constant magnitude are the encircled ones. Thus, during the second command and the resulting second electrical

input inp2 and response res2, no set of electrical inputs has been selected. This means that the second command did not result in any determination of an adjustment value.

[0058] Referring to figure 4a, the first and second commands are separate from one another. Analogously, the first and second time periods or durations d1 and d2 are separate from one another. Correspondingly, referring to figure 4b, the first and second electrical inputs inp1, inp2 are separate from one another. The method may comprise distinguishing the first and second electrical inputs from one another by identifying an end of the first electrical input. This may be performed by identifying that the first electrical input inp1 returns to a certain value, such as the value zero. The method may comprise distinguishing the first and second time periods from one another by identifying an end of the first time period. This may be performed by identifying that the first electrical input inp1 ceases to cause a flow of hydraulic fluid to the hydraulic actuator 10.

[0059] The method may comprise applying the adjustment value adj1 to the second electrical input inp2 only if there is a predetermined time threshold dt between the second electrical input d2 and the first electrical input d1. A predetermined time threshold dt is indicated in figure 4b. The predetermined time threshold dt may be set to a time period that is small enough to catch as many separate commands as possible but long enough to make sure that there is a separation between the first and second command, i.e. to make sure that first and second commands are individual commands where there is a period of no wanted movement for the hydraulic actuator in question.

[0060] As has been described, the working equipment 1 may be adapted to receive a command com, such as an operator command from the operator interface device 7. The method 100 may comprise receiving a first command com1 and, in response thereto, provide the first electrical input inp1 to the electromagnetic actuator 24. The method 100 may comprise receiving a second command com2 and, in response thereto, provide the second electrical input inp2 to the electromagnetic actuator 24. Importantly, the method comprises to in addition base the second command com2 on the adjustment value adj1.

[0061] Providing the first electrical input inp1 to the electromagnetic actuator 24 may comprise providing the first electrical input inp1 that is calculated based on an estimated resistance of the electromagnetic actuator 24, and the adjustment value adj1 is applied to the second electrical input inp2 to adjust said estimated resistance. In other words, the method may involve adjusting or calibrating a resistance or a resistance value. In figure 4c, the estimated resistance, which may be referred to as a first resistance, is denoted r1. In the same figure, the adjustment or calibration of the first resistance r1 by means of the (first) adjustment value

adj1 is indicated. The adjusted or calibrated resistance may be referred to as a second resistance and is denoted r2.

[0062] The first command com1 may correspond to a first desired movement of the movable arm 5, and the second command com2 may correspond to a second desired movement of the movable arm 5. Determining the adjustment value adj1 based on the electrical response res1 and the first electrical input inp1 may be performed only if the first command com1 comprises a first desired constant movement of the movable arm 5. A first desired constant movement of the movable arm 5 may be a movement that remains constant for at least 1/10 second. As has been mentioned, the movable arm 5 typically comprises a number of arm sections and a number of hydraulic actuators 10 for moving the arm sections. The constant movement of the movable arm 5 may be a movement of one section of the movable arm, obtained by one hydraulic actuator 10.

[0063] The methods described herein are typically computer-implemented and thus a computer program product may comprise instructions which, when executed by a processor comprised in or connected to the working equipment 1, cause the processor to carry out the methods described herein. Moreover, a non-transitory computer-readable medium may store instructions which, when executed by a processor comprised in or connected to the working equipment 1, cause the processor to carry out the methods described herein.

[0064] The methods may also be applied to, and the hydraulic valve assembly may also be comprised in, a skip loader, a recycling crane, a hooklift, a forklift, and a tail lift.

[0065] The first electrical input, the electrical response and the second electrical input are typically, as exemplified above, currents. The currents result from the voltage applied as PWM. A method in accordance with the present disclosure may be expressed as providing a target drive current to an electromagnetic actuator arranged to control a flow of hydraulic fluid to the hydraulic actuator, obtaining an actuator current that results from the target drive current, determining an adjustment value based on the target drive current and the actuator current; and applying the adjustment value to a subsequent target drive current.

[0066] It is to be understood that the invention is not limited to the particular embodiments and examples illustrated in the drawings and described herein; instead, it encompasses all modifications and variations within the scope of the appended claims. The actions of methods disclosed herein may be expressed either in the gerund form (e.g. providing, obtaining) or in the infinite form (e.g. to provide, to obtain).

Claims

1. A method (100) of controlling a hydraulic actuator

(10) of a working equipment (1), such as a forestry crane or a loader crane, the working equipment comprising a movable arm (5) and said hydraulic actuator (10) for moving the movable arm (5), the method (100) comprising:

- providing (110), during a first time period (d1), a first electrical input (inp1) to an electromagnetic actuator (24) arranged to control a flow of hydraulic fluid to the hydraulic actuator (10);
 - obtaining (120) an electrical response (res1) that results from the first electrical input (inp1);
 - determining (130) an adjustment value (adj1) based on the electrical response (res1) and the first electrical input (inp1); and
 - applying (140), during a second time period (d2), the adjustment value (adj1) to a second electrical input (inp2) to the electromagnetic actuator (24).
2. The method of claim 1, wherein determining (130) an adjustment value (adj 1) based on the electrical response (res1) and the first electrical input (inp1) comprises selecting (132) a set of first electrical inputs (inp1s) during the first time period (d1), which set of first electrical inputs (inp1s) satisfies a predetermined first validity criterion.
 3. The method of claim 2, wherein the set of first electrical inputs (inp1s) satisfies the predetermined first validity criterion if a statistical deviation of the set of first electrical inputs (inp1s) is below a first deviation threshold.
 4. The method of claim 2 or 3, wherein determining (130) an adjustment value based on the electrical response (res1) and the first electrical input (inp1) comprises assessing (134) whether a set of electrical responses (res1s) that correspond to the set of first electrical inputs (inp1s) satisfies a predetermined second validity criterion.
 5. The method of any preceding claim, wherein determining (130) an adjustment value based on the electrical response (res1) and the first electrical input (inp1) comprises calculating a standard deviation of the difference between the electrical response (res1) and the first electrical input (inp1).
 6. The method of any preceding claim, comprising, when the first electrical input (inp1) ceases to cause a flow of hydraulic fluid to the hydraulic actuator (10), identifying an end of the first time period (d1).
 7. The method of any preceding claim, wherein the working equipment (1) is adapted to receive a command (com), such as an operator command from

an operator interface device (7), the method (100) comprising

- receiving (105) a first command (com1);
 - providing (110), during the first time period (d1), the first electrical input (inp1) to the electromagnetic actuator (24), the first electrical input (inp1) being based on the first command (com1);
 - receiving (135) a second command (com2); and
 - providing (150), during the second time period (d2), the second electrical input (inp2) to the electromagnetic actuator (24), the second electrical input (inp2) being based on the second command (com2) and the adjustment value (adj 1).
8. The method of any preceding claim, wherein providing (110) a first electrical input (inp1) to an electromagnetic actuator (24) comprises providing a pulse width modulated (PWM) first electrical input (inp1).
 9. The method of any preceding claim, wherein obtaining an electrical response (120) comprises detecting an electrical quantity indicative of a current through the electromagnetic actuator (24), for example by measuring a voltage across a resistor (R) that is connected on a return path from the electromagnetic actuator (24).
 10. The method of any preceding claim, wherein providing a first electrical input (inp1) to the electromagnetic actuator (24) comprises providing a first electrical input (inp1) that is calculated based on an estimated resistance of the electromagnetic actuator (24), and the adjustment value (adj1) is applied to the second electrical input (inp2) to adjust said estimated resistance.
 11. The method according to each one of claims 7 to 10, wherein:
 - the first command (com1) corresponds to a first desired movement of the movable arm (5);
 - the second command (com2) corresponds to a second desired movement of the movable arm (5); and
 - determining (130) the adjustment value (adj1) based on the electrical response (res1) and the first electrical input (inp1), only if the first command (com1) corresponds to a first desired movement of the movable arm (5) that remains constant for at least 1/10 second.
 12. A computer program product comprising instructions which, when executed by a processor com-

prised in or connected to a working equipment (1), cause the processor to carry out the method (100) of any preceding claim.

13. A non-transitory computer-readable medium storing instructions which, when executed by a processor comprised in or connected to a working equipment (1), cause the processor to carry out the method (100) according to any of claims 1 to 11.

14. A hydraulic valve assembly (20) for controlling a working equipment (1), such as a forestry crane or a loader crane, that comprises a movable arm (5) and a hydraulic actuator (10) for moving the movable arm (5), the hydraulic valve assembly (20) comprising a valve spool (22) for controlling a flow of hydraulic fluid to the hydraulic actuator (10), an electromagnetic actuator (24) for moving the valve spool (22), and a controller (26) configured to:

- provide a first electrical input (inp1) to the electromagnetic actuator (24);
- obtain an electrical response (res1) that results from the first electrical input (inp1);
- determine an adjustment value (adj1) based on the electrical response (res1) and the first electrical input (inp1); and
- apply the adjustment value (adj1) to a second electrical input (inp2) to the electromagnetic actuator (24).

15. A vehicle-mountable working equipment (1) comprising the hydraulic valve assembly (20) of claim 14.

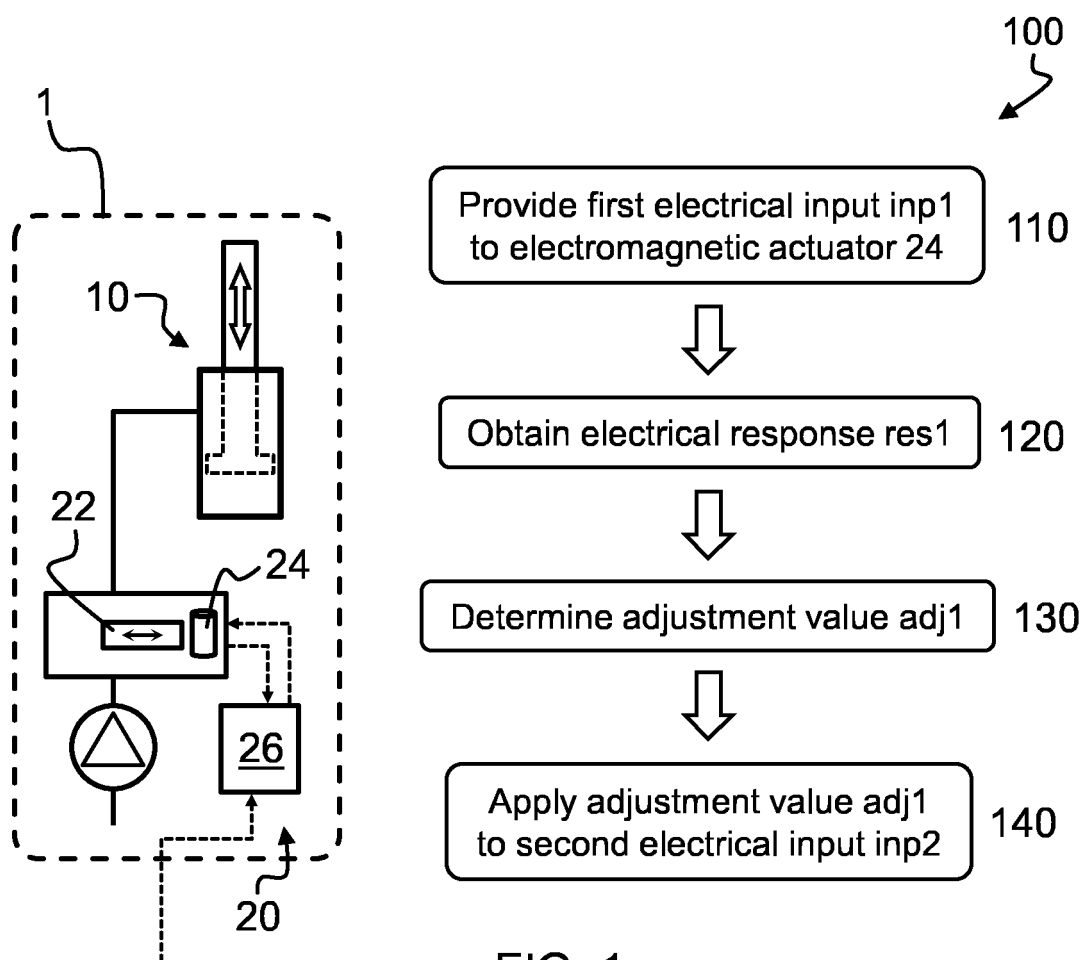


FIG. 1

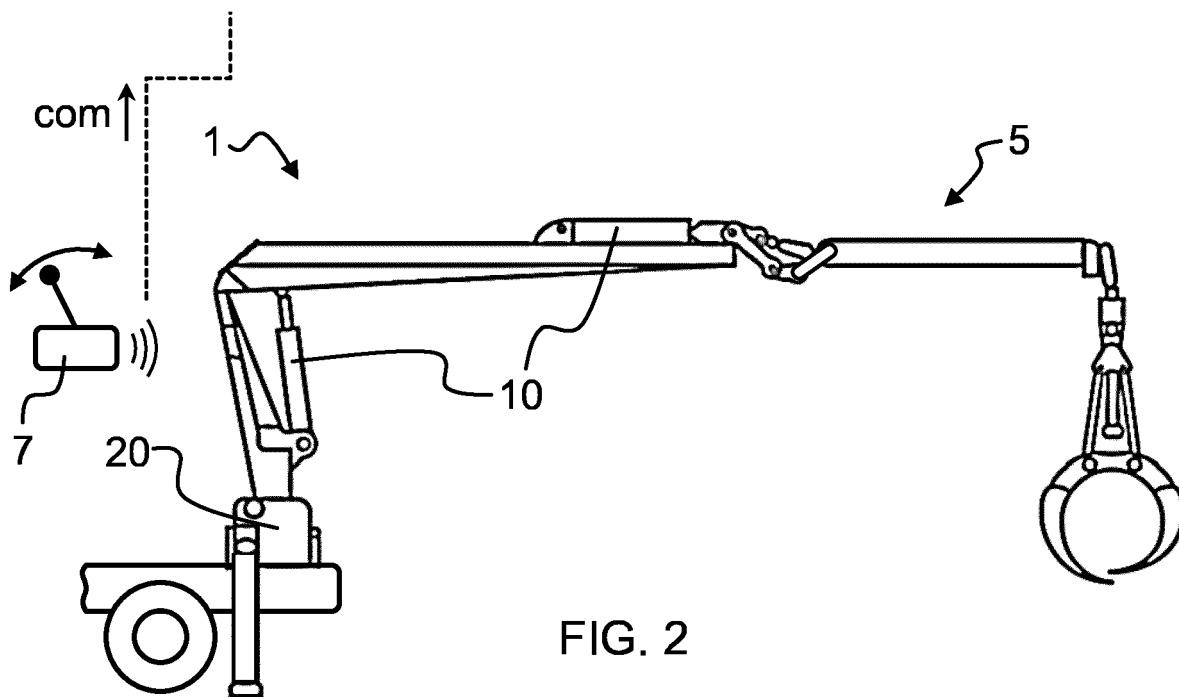


FIG. 2

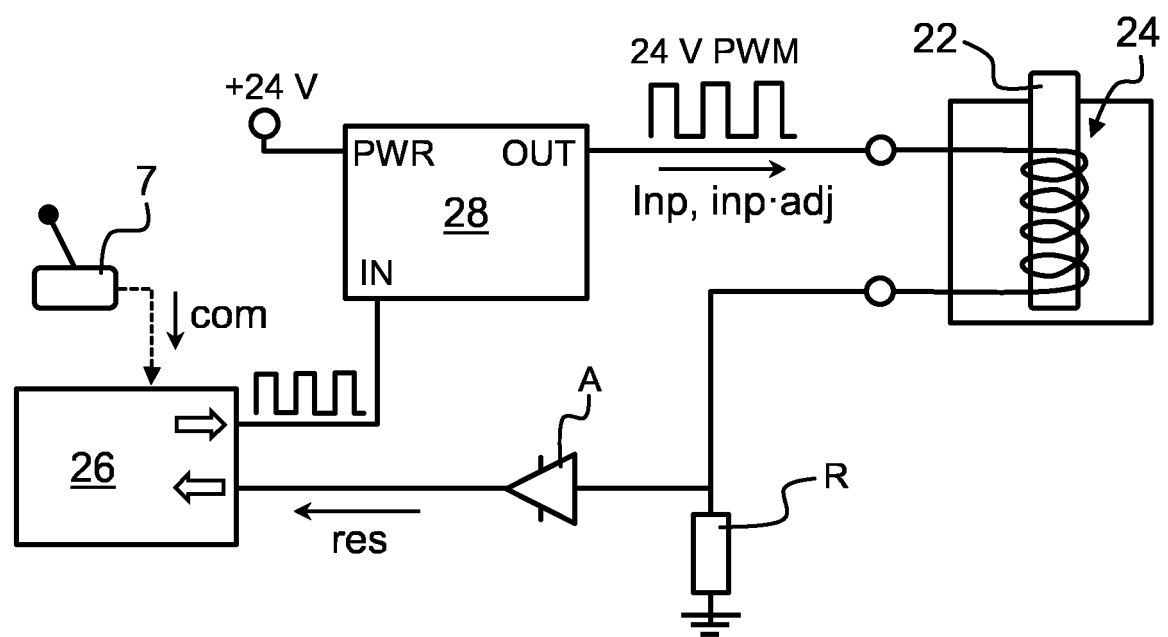


FIG. 3

FIG. 4a

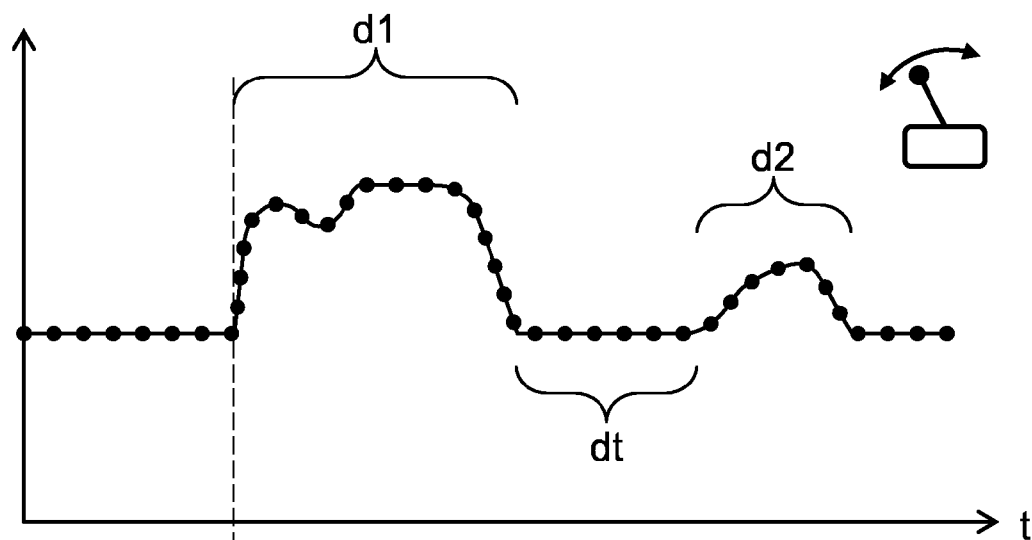


FIG. 4b

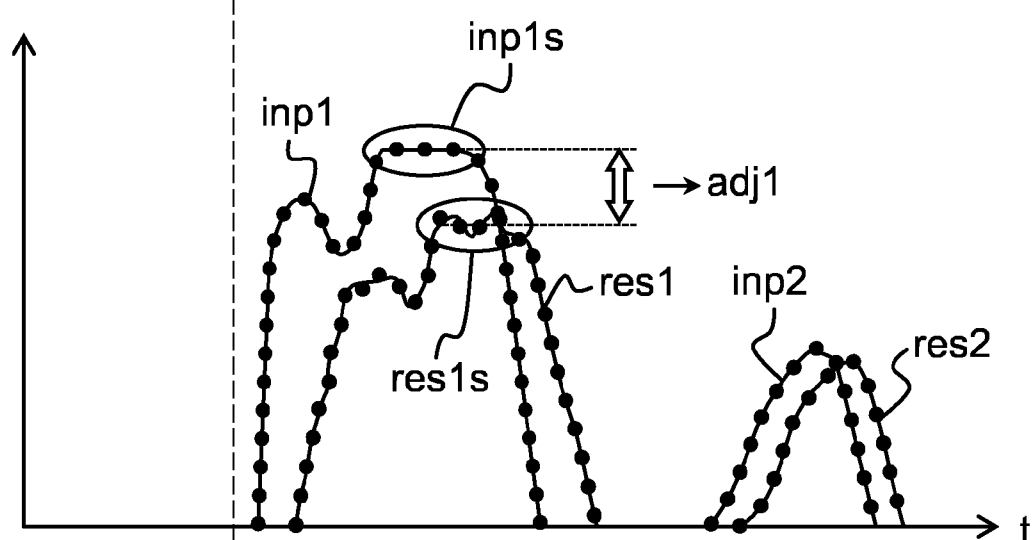
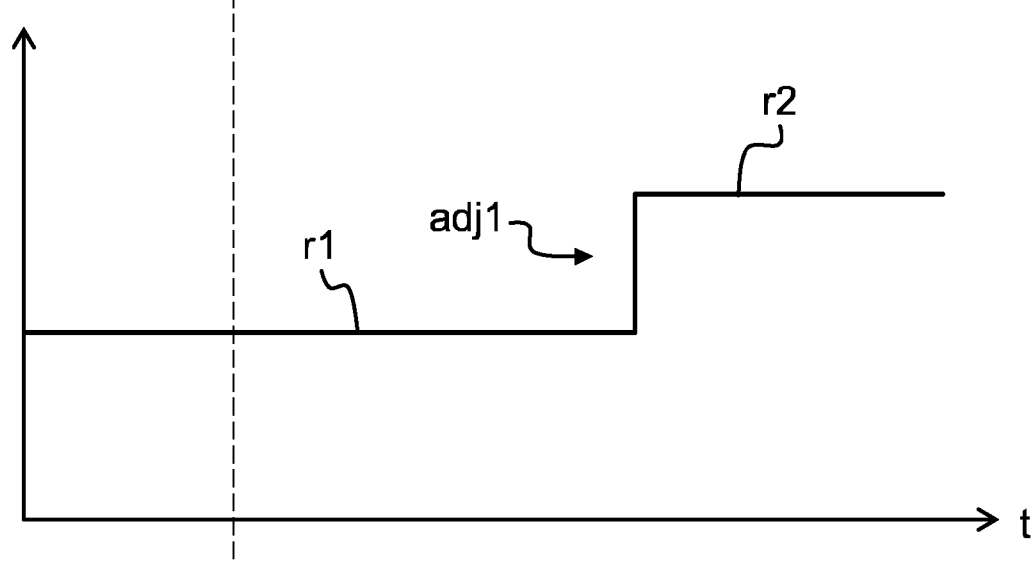


FIG. 4c





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Place of search Munich		Date of completion of the search 1 December 2025	Examiner Deligiannidis, N
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