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Inventor(s)	Fukuchi; Ryohei et al.

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### Construction machine

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#### Abstract

A construction machine including a solenoid valve that reduces a boom lowering pilot pressure for a second directional control valve and a controller that controls the solenoid valve is provided. The controller computes a first opening degree command value in such a manner that a communication area between a boom lowering pressure reducing valve and a pressure receiving chamber of the second directional control valve decreases in association with a bottom pressure of a boom cylinder, computes a second opening degree command value in such a manner that the communication area increases in association with increase in a boom lowering operation amount, decides a minimum opening degree command value as an opening degree command value of the solenoid valve when an elapsed time after boom raising operation is shorter than a set time and decides a minimum selected value of the first and second opening degree command values as the opening degree command value of the solenoid valve when the elapsed time is equal to or longer than the set time, and outputs a command signal according to the decided opening degree command value to the solenoid valve.

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<b>Inventors:</b>	<b>Fukuchi; Ryohei (Tsukuba, JP), Ishida; Shota (Tsukuba, JP)</b>
<b>Applicant:</b>	<b>Hitachi Construction Machinery Co., Ltd. (Tokyo, JP)</b>
<b>Family ID:</b>	<b>1000008768098</b>
<b>Assignee:</b>	<b>Hitachi Construction Machinery Co., Ltd. (Tokyo, JP)</b>
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*Primary Examiner:* Vorce; Amelia

*Attorney, Agent or Firm:* Crowell & Moring LLP

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## **Background/Summary**

### **TECHNICAL FIELD**

(1) The present invention relates to a construction machine such as a hydraulic excavator.

### **BACKGROUND ART**

(2) With a construction machine such as a hydraulic excavator, besides excavation work, various kinds of work such as bumping work and leveling work are executed. The flow rate and the pressure of a pressurized fluid necessary for driving of a boom cylinder are different, depending on work. For example, at a time of boom raising operation, the meter-in flow rate to the boom cylinder is increased through causing delivered hydraulic fluids of a plurality of hydraulic pumps to merge, or the like. In contrast, when boom lowering operation is executed in the state in which a bucket is suspended in the air, the meter-in flow rate to the boom cylinder is limited to suppress energy loss. Moreover, when boom lowering operation is executed in the state in which the bucket is grounded, the meter-in flow rate to the boom cylinder is increased to enable jack-up motion.

(3) Such control of the meter-in flow rate to the boom cylinder is executed by controlling the flow rate of supply of a pressurized fluid to the boom cylinder by a solenoid valve according to the bottom pressure of the boom cylinder, for example (Patent Document 1).

### **PRIOR ART DOCUMENT**

Patent Document

(4) Patent Document 1: JP-2010-275818-A

### **SUMMARY OF THE INVENTION**

#### **Problem to be Solved by the Invention**

(5) Regarding the boom lowering motion executed in the state in which the bucket is suspended in the air or the jack-up motion executed through lowering the boom with the bottom surface of the bucket pressed against a ground surface, the bottom pressure of the boom cylinder does not suddenly change, and therefore the meter-in flow rate can properly be controlled by the technique disclosed in Patent Document 1.

(6) However, for example, at a time of bumping work in which the boom is repeatedly raised and lowered, control of the meter-in flow rate acts contrary to the intention of the operator due to sharp fluctuation of the bottom pressure of the boom cylinder in some cases. At a time of boom lowering in the state in which the bucket is suspended in the air, the bottom pressure of the boom cylinder becomes high, and the rod pressure of the boom cylinder becomes low, so that the meter-in flow rate is controlled to become low. On the other hand, at a time of jack-up in which the bucket is pressed against a ground surface, the bottom pressure of the boom cylinder becomes low, and the rod pressure of the boom cylinder becomes high, so that the meter-in flow rate is controlled to become high. However, at the time of bumping work in which the boom is repeatedly operated to be raised and lowered in a short period of time, there is a possibility that the meter-in flow rate corresponding to jack-up is selected also after switching from boom raising operation to boom lowering operation due to fluctuation of the bottom pressure of the boom cylinder and the state in which the meter-in flow rate is high continues. As a result, the state in which the motion speed of the boom does not correspond with the required motion speed of the boom is caused, and the

operability is possibly affected.

(7) An object of the present invention is to provide a construction machine that can cause the motion speed of a boom to correspond with the required speed and improve the operability.

#### Means for Solving the Problem

(8) In order to achieve the above-described object, the present invention provides a construction machine including a machine body, a front work implement joined to the machine body, a boom cylinder that vertically drives the front work implement, a prime mover, a first hydraulic pump driven by the prime mover, a second hydraulic pump driven by the prime mover, a first directional control valve that controls a pressurized fluid that flows from the first hydraulic pump to the boom cylinder, a second directional control valve that controls a pressurized fluid that flows from the second hydraulic pump to the boom cylinder, a pilot pump that delivers a pilot fluid that drives the first directional control valve and the second directional control valve, a boom lowering pressure reducing valve that outputs a boom lowering pilot pressure that drives the first directional control valve and the second directional control valve in a boom lowering direction with use of the pilot fluid as a source pressure, a boom raising pressure reducing valve that outputs a boom raising pilot pressure that drives the first directional control valve and the second directional control valve in a boom raising direction with use of the pilot fluid as a source pressure, and a boom operation lever to operate the boom lowering pressure reducing valve and the boom raising pressure reducing valve. The construction machine includes a bottom pressure sensor that measures a bottom pressure of the boom cylinder, an operation amount sensor that measures an operation amount of the boom operation lever, a solenoid valve that is disposed on a pilot hydraulic line that couples the boom lowering pressure reducing valve and a pressure receiving chamber of the second directional control valve and reduces the boom lowering pilot pressure for the second directional control valve, and a controller that controls the solenoid valve on the basis of the bottom pressure measured by the bottom pressure sensor and the operation amount measured by the operation amount sensor. The controller is configured to compute a first opening degree command value in such a manner that a communication area between the boom lowering pressure reducing valve and the pressure receiving chamber of the second directional control valve decreases in association with increase in the bottom pressure on the basis of the bottom pressure measured by the bottom pressure sensor, compute a second opening degree command value in such a manner that the communication area increases in association with increase in a boom lowering operation amount on the basis of the boom lowering operation amount measured by the operation amount sensor, decide a minimum opening degree command value that minimizes the communication area as an opening degree command value of the solenoid valve when an elapsed time is shorter than a set time and decide a minimum selected value of the first opening degree command value and the second opening degree command value as the opening degree command value of the solenoid valve when the elapsed time is equal to or longer than the set time, on the basis of the elapsed time after boom raising operation, and output a command signal according to the decided opening degree command value to the solenoid valve.

#### Advantages of the Invention

(9) According to the present invention, the motion speed of the boom can be caused to correspond with the required speed, and the operability can be improved.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. 1 is a side view representing a construction machine according to one embodiment of the present invention.

(2) FIG. 2 is a circuit diagram representing major parts of a hydraulic system mounted in the

construction machine according to the one embodiment of the present invention.

(3) FIG. 3 is a flowchart representing the procedure of control of a solenoid valve by a controller mounted in the construction machine according to the one embodiment of the present invention.

(4) FIG. 4 is a diagram representing one example of functional blocks of the controller for executing the flow of FIG. 3.

## MODES FOR CARRYING OUT THE INVENTION

(5) An embodiment of the present invention will be described below with use of the drawings.

### (6) —Construction Machine—

(7) FIG. 1 is a side view representing a construction machine according to one embodiment of the present invention. In this diagram, a hydraulic excavator 1 is exemplified as the construction machine. However, the present invention can be applied to other kinds of construction machines, such as a wheel loader and a crane, which are used for various kinds of work such as civil engineering work, construction work, and demolition work. The hydraulic excavator 1 is a crawler type. However, the present invention can be applied also to a construction machine of a wheel type.

(8) The hydraulic excavator 1 includes a machine body 4 and a front work implement 10 attached to the machine body 4. The machine body 4 includes a track structure 2 and a swing structure 3 swingably disposed on the track structure 2. The track structure 2 travels by left and right crawlers being driven by hydraulic motors for travelling. The swing structure 3 has a cab 7 in which an operator rides and is driven to swing relative to the track structure 2 by a hydraulic motor for swing disposed in the machine body 4. Inside the cab 7, the respective operation devices for operating the respective hydraulic actuators mounted in the hydraulic excavator 1, such as a boom cylinder 15 to be described later, an arm cylinder 16, and a bucket cylinder 17, besides the above-described hydraulic motors for travelling and hydraulic motor for swing are disposed.

(9) The front work implement 10 is a work implement in which a bucket 14 that is an attachment suitable for work is mounted on a work arm 11 of an articulated type, and is joined to the swing structure 3. The work arm 11 includes a boom 12 joined to a front part of the swing structure 3 vertically pivotally and an arm 13 joined to the tip of the boom 12 pivotally in the front-rear direction. The boom 12 is driven by the boom cylinder 15. The arm 13 is driven by the arm cylinder 16. The bucket 14 is driven by the bucket cylinder 17. Although a configuration in which the bucket 14 is mounted on the work arm 11 as an attachment is exemplified in FIG. 1, the bucket 14 can be replaced by another attachment such as a grapple.

### (10) —Hydraulic System—

(11) FIG. 2 is a circuit diagram representing major parts of a hydraulic system mounted in the construction machine illustrated in FIG. 1. In FIG. 2, a drive circuit of the boom cylinder 15 is extracted and represented. The hydraulic system illustrated in this diagram includes a prime mover 51, a first hydraulic pump 52, a second hydraulic pump 53, a first directional control valve 54, a second directional control valve 55, a pilot pump 56, an operation lever device 57, a solenoid valve 58, and a controller 60.

### (12) ·Hydraulic Pump

(13) The first hydraulic pump 52 and the second hydraulic pump 53 are pumps of the variable displacement type that deliver a hydraulic operating fluid that drives the hydraulic actuators mounted in the hydraulic excavator 1 and are driven by the prime mover 51. The prime mover 51 in the present embodiment is an engine that converts combustion energy to power, such as an internal combustion engine. However, an electric motor is used as the prime mover 51 in some cases. In FIG. 2, only each one pump is illustrated regarding the first hydraulic pump 52 and the second hydraulic pump 53. However, a plurality of pumps are disposed as at least one of the first hydraulic pump 52 and the second hydraulic pump 53 in some cases. A pressurized fluid that is sucked in from a hydraulic operating fluid tank 59 and is delivered from the first hydraulic pump 52 is supplied to the boom cylinder 15 via the first directional control valve 54. A pressurized fluid that is sucked in from the hydraulic operating fluid tank 59 and is delivered from the second

hydraulic pump 53 is supplied to the boom cylinder 15 via the second directional control valve 55. A return hydraulic fluid from the boom cylinder 15 returns to the hydraulic operating fluid tank 59 through the first directional control valve 54 and the second directional control valve 55.

#### (14) ·Pilot Pump

(15) The pilot pump 56 is a pump of the fixed displacement type that delivers a pilot fluid that drives hydraulically driven control valves such as the first directional control valve 54 and the second directional control valve 55. The pilot pump 56 is driven by the prime mover 51 as with the first hydraulic pump 52 and the second hydraulic pump 53. It is also possible to make a configuration in which the pilot pump 56 is driven by a power source different from the prime mover 51. A delivery hydraulic line 56m of the pilot pump 56 branches and is connected to a boom lowering pressure reducing valve 57d and a boom raising pressure reducing valve 57u of the operation lever device 57 and the like. The delivery pressure of the pilot pump 56 is input to the boom lowering pressure reducing valve 57d, the boom raising pressure reducing valve 57u, and the like through a delivery line 57a as the source pressure of the pilot pressure.

#### (16) ·First Directional Control Valve

(17) The first directional control valve 54 is a hydraulically driven directional control valve that controls the flow (direction and flow rate) of the pressurized fluid supplied from the first hydraulic pump 52 to the boom cylinder 15 and is driven by the pilot pressure input to a pressure receiving chamber. The first directional control valve 54 is a proportional three-position selector valve having a boom lowering position 54d, a boom raising position 54u, and a neutral position 54n. In the state in which the pilot pressure is not acting, the spool of the first directional control valve 54 is located at the neutral position 54n due to a spring force.

(18) When the first directional control valve 54 is at the neutral position 54n, the first hydraulic pump 52 bypasses the boom cylinder 15 and is connected to the hydraulic operating fluid tank 59, and the rod-side hydraulic chamber and the bottom-side hydraulic chamber of the boom cylinder 15 are closed. This causes the boom cylinder 15 to be held without elongating and contracting.

(19) When the first directional control valve 54 is at the boom lowering position 54d, the first hydraulic pump 52 bypasses the boom cylinder 15 and is connected to the hydraulic operating fluid tank 59 and the bottom-side hydraulic chamber of the boom cylinder 15 is connected to the rod-side hydraulic chamber and the hydraulic operating fluid tank 59. Due to this, part of the pressurized fluid pushed out from the bottom-side hydraulic chamber due to the weight of the front work implement 10 is supplied to the rod-side hydraulic chamber, and the boom cylinder 15 contracts.

(20) When the first directional control valve 54 is at the boom raising position 54u, the first hydraulic pump 52 is connected to the bottom-side hydraulic chamber of the boom cylinder 15, and the rod-side hydraulic chamber of the boom cylinder 15 is connected to the hydraulic operating fluid tank 59. This causes the boom cylinder 15 to elongate due to the pressurized fluid delivered from the first hydraulic pump 52.

#### (21) ·Second Directional Control Valve

(22) The second directional control valve 55 is a hydraulically driven directional control valve that controls the flow (direction and flow rate) of the pressurized fluid supplied from the second hydraulic pump 53 to the boom cylinder 15 and is driven by the pilot pressure input to a pressure receiving chamber. The second directional control valve 55 is a proportional three-position selector valve having a boom lowering position 55d, a boom raising position 55u, and a neutral position 55n. In the state in which the pilot pressure is not acting, the spool of the second directional control valve 55 is located at the neutral position 55n due to a spring force.

(23) When the second directional control valve 55 is at the neutral position 55n, the second hydraulic pump 53 bypasses the boom cylinder 15 and is connected to the hydraulic operating fluid tank 59, and the rod-side hydraulic chamber and the bottom-side hydraulic chamber of the boom cylinder 15 are closed. This causes the boom cylinder 15 to be held without elongating and

contracting.

(24) When the second directional control valve **55** is at the boom lowering position **55d**, the second hydraulic pump **53** is connected to the rod-side hydraulic chamber of the boom cylinder **15**, and the bottom-side hydraulic chamber of the boom cylinder **15** is connected to the hydraulic operating fluid tank **59**. This causes the boom cylinder **15** to contract due to the pressurized fluid delivered from the second hydraulic pump **53**.

(25) When the second directional control valve **55** is at the boom raising position **55u**, the second hydraulic pump **53** is connected to the bottom-side hydraulic chamber of the boom cylinder **15**, and the rod-side hydraulic chamber of the boom cylinder **15** is connected to the hydraulic operating fluid tank **59**. This causes the boom cylinder **15** to elongate due to the pressurized fluid delivered from the second hydraulic pump **53**.

(26) ·Boom Lowering Pressure Reducing Valve

(27) The pressure receiving chambers of the first directional control valve **54** and the second directional control valve **55** on the boom lowering side is connected to the boom lowering pressure reducing valve **57d** through pilot hydraulic lines **56a** and **56b**, respectively, and further is connected to the pilot pump **56** through the boom lowering pressure reducing valve **57d**. The boom lowering pressure reducing valve **57d** is operated by a boom operation lever **57l**. When the boom operation lever **57l** is operated in a boom lowering direction (in FIG. 2, left direction), the boom lowering pressure reducing valve **57d** is actuated according to an operation amount of the boom operation lever **57l**. Due to this, the delivery hydraulic line **56m** of the pilot pump **56** and the pilot hydraulic lines **56a** and **56b** are connected. In addition, a boom lowering pilot pressure according to a boom lowering operation amount of the boom operation lever **57l** is output with the pressure of the pilot fluid from the pilot pump **56** being the source pressure. When this pilot pressure acts on the pressure receiving chambers of the first directional control valve **54** and the second directional control valve **55** on the boom lowering side, the first directional control valve **54** and the second directional control valve **55** are driven in the boom lowering direction from the neutral positions **54n** and **55n** and are switched to the boom lowering positions **54d** and **55d**.

(28) ·Boom Raising Pressure Reducing Valve

(29) The pressure receiving chambers of the first directional control valve **54** and the second directional control valve **55** on the boom raising side is connected to the boom raising pressure reducing valve **57u** through pilot hydraulic lines **56c** and **56d**, respectively, and further is connected to the pilot pump **56** through the boom raising pressure reducing valve **57u**. The boom raising pressure reducing valve **57u** is also operated by the boom operation lever **57l** as with the boom lowering pressure reducing valve **57d**. When the boom operation lever **57l** is operated in a boom raising direction (in FIG. 2, right direction), the boom raising pressure reducing valve **57u** is actuated according to the operation amount of the boom operation lever **57l**. Due to this, the delivered hydraulic line **56m** of the pilot pump **56** and the pilot hydraulic lines **56c** and **56d** are connected, and a boom raising pilot pressure according to a boom raising operation amount of the boom operation lever **57l** is output with the pressure of the pilot fluid from the pilot pump **56** being the source pressure. When this pilot pressure acts on the pressure receiving chambers of the first directional control valve **54** and the second directional control valve **55** on the boom raising side, the first directional control valve **54** and the second directional control valve **55** are driven in the boom raising direction from the neutral positions **54n** and **55n** and are switched to the boom raising positions **54u** and **55u**.

(30) ·Solenoid Valve

(31) The above-described solenoid valve **58** is a proportional solenoid pressure reducing valve that reduces the boom lowering pilot pressure output by the boom lowering pressure reducing valve **57d** and outputs a corrected boom lowering pilot pressure (boom lowering pilot pressure that has been corrected) for the pressure receiving chamber of the second directional control valve **55** on the boom lowering side. This solenoid valve **58** is disposed on the pilot hydraulic line **56b** that couples

the boom lowering pressure reducing valve **57d** with the pressure receiving chamber of the second directional control valve **55** on the boom lowering side. The solenoid valve **58** has an opening position **58a** and an interruption position **58b**. In the present embodiment, the spool of the solenoid valve **58** is pressed against the side of the interruption position **58b** by a spring force in the state in which the solenoid is demagnetized, and moves toward the side of the opening position **58a** against the spring force when the solenoid is excited. However, a configuration may be made in which the spool is pressed against the opening position **58a** in the demagnetized state and the spool moves toward the side of the interruption position **58b** when the solenoid is excited.

(32) The solenoid valve **58** is a valve having two positions set to allow switching to the opening position **58a** and the interruption position **58b**. When the solenoid valve **58** is switched to the opening position **58a**, the pressure receiving chamber of the second directional control valve **55** on the boom lowering side is coupled to the boom lowering pressure reducing valve **57d**. When the solenoid valve **58** is switched to the interruption position **58b**, the pressure receiving chamber of the second directional control valve **55** on the boom lowering side is coupled to the hydraulic operating fluid tank **59**. By adjusting the position of the spool by an excitation current to the solenoid of the solenoid valve **58**, the ratio between the area of the opening that couples the pressure receiving chamber of the second directional control valve **55** to the boom lowering pressure reducing valve **57d** and the area of the opening that couples the pressure receiving chamber to the hydraulic operating fluid tank **59** changes. The amount of pressure reduction of the boom lowering pilot pressure can be adjusted on the basis of this ratio of the opening area, and the corrected boom lowering pilot pressure for the second directional control valve **55** can be controlled. When the amount of pressure reduction of the boom lowering pilot pressure for the second directional control valve **55** by the solenoid valve **58** is larger (corrected boom lowering pilot pressure is lower), the amount of movement of the second directional control valve **55** in the boom lowering direction decreases even with the same boom lowering operation amount. Further, the supply amount of the pressurized fluid that flows from the second hydraulic pump **53** to the rod-side hydraulic chamber of the boom cylinder **15** decreases. As a result, the meter-in flow rate from the second hydraulic pump **53** to the rod-side hydraulic chamber of the boom cylinder **15** decreases even with the same boom lowering operation amount.

(33) In the present embodiment, when the solenoid valve **58** is completely switched to the interruption position **58b**, the boom lowering pilot pressure does not act on the second directional control valve **55**, and the pressurized fluid ceases to be supplied from the second hydraulic pump **53** to the rod-side hydraulic chamber of the boom cylinder **15** even if boom lowering operation is executed. On the other hand, when the solenoid valve **58** is completely switched to the opening position **58a**, the amount of pressure reduction of the boom lowering pilot pressure becomes the minimum. Due to this, the second directional control valve **55** operates according to the boom lowering operation amount at the same degree as the first directional control valve **54**, and the pressurized fluid is supplied from the second hydraulic pump **53** to the rod-side hydraulic chamber of the boom cylinder **15**.

(34) —Sensor—

(35) The operation amount of the boom operation lever **57l** is measured by operation amount sensors **S3** and **S4**. The operation amount sensor **S3** measures a boom lowering operation amount  $A_d$ , and the operation amount sensor **S3** measures a boom raising operation amount  $A_u$ . The operation amount sensors **S3** and **S4** are both pressure sensors. The operation amount sensor **S3** is disposed on the pilot hydraulic line **56a** or **56b** that connects the boom lowering pressure reducing valve **57d** to the pressure receiving chamber of the first directional control valve **54** on the boom lowering side and the solenoid valve **58** (for example, at the output port of the boom lowering pressure reducing valve **57d** or the immediately downstream thereof). The boom lowering operation amount  $A_d$  is measured by measuring the boom lowering pilot pressure by the operation amount sensor **S3**. The operation amount sensor **S4** is disposed on the pilot hydraulic line **56c** or



**56d** that connects the boom raising pressure reducing valve **57u** to the first directional control valve **54** and the pressure receiving chamber of the second directional control valve **55** on the boom raising side (for example, at the output port of the boom raising pressure reducing valve **57u** or the immediately downstream thereof). The boom raising operation amount  $A_u$  is measured by measuring the boom raising pilot pressure by the operation amount sensor **S4**. It is also possible to make a configuration in which potentiometers or the like are used as the operation amount sensors **S3** and **S4** instead of pressure sensors and the angle of the boom operation lever **57l** is measured to measure the boom lowering operation amount  $A_d$  and the boom raising operation amount  $A_u$ .

(36) A bottom pressure  $P_b$  (pressure of the bottom-side hydraulic chamber) of the boom cylinder **15** is measured by a bottom pressure sensor **S1**. The bottom pressure sensor **S1** is a pressure sensor disposed on a hydraulic line that connects the bottom-side hydraulic chamber of the boom cylinder **15** to the first directional control valve **54** and the second directional control valve **55** (for example, at the input-output port of the bottom-side hydraulic chamber or the vicinity thereof).

(37) Although being not necessarily required in the present embodiment, a rod pressure  $P_r$  (pressure of the rod-side hydraulic chamber) of the boom cylinder **15** is measured by a rod pressure sensor **S2**. The rod pressure sensor **S2** is a pressure sensor disposed on a hydraulic line that connects the rod-side hydraulic chamber of the boom cylinder **15** to the first directional control valve **54** and the second directional control valve **55** (for example, at the input-output port of the rod-side hydraulic chamber or the vicinity thereof).

(38) Measurement values of the above bottom pressure sensor **S1**, the rod pressure sensor **S2**, and the operation amount sensors **S3** and **S4** are input to the controller **60**.

(39) —Controller—

(40) Operation of the solenoid valve **58** is controlled by the controller **60** on the basis of the bottom pressure  $P_b$  of the boom cylinder **15** and the operation amount of the boom operation lever **57l**. The controller **60** is an in-machine computer including a CPU, a memory, a timer, and the like and executes a program stored in the memory in advance by the CPU to execute various kinds of processing. In the present embodiment, the controller **60** is equipped with a characteristic function of, at the time of boom lowering operation, controlling the solenoid valve **58** on the basis of the bottom pressure measured by the bottom pressure sensor **S1**, the boom lowering operation amount measured by the operation amount sensor **S3**, and the elapsed time after boom raising operation. This function will be described next.

(41) FIG. 3 is a flowchart representing the procedure of control of the solenoid valve **58** by the controller **60**. The controller **60** repeatedly executes the flow of FIG. 3 with a short cycle time (for example, 0.1 s) when being energized (for example, when a key switch is ON).

(42) When the controller **60** starts the flow of this diagram, first, measurement values (output signals) of the bottom pressure sensor **S1** and the operation amount sensors **S3** and **S4** are input to the controller **60** (step **S01**).

(43) Subsequently, the controller **60** determines whether boom lowering operation is being executed (whether boom lowering operation amount  $A_d > 0$ ) according to the measurement value of the operation amount sensor **S3** (step **S02**). When boom lowering operation is being executed, the controller **60** shifts the procedure from the step **S02** to a step **S03**. When boom lowering operation is not being executed, the controller **60** shifts the procedure from the step **S02** to a step **S07**.

(44) When boom lowering operation is being executed, the controller **60** computes a first opening degree command value  $V_1$  of the solenoid valve **58** on the basis of the bottom pressure  $P_b$  of the boom cylinder **15** measured by the bottom pressure sensor **S1** (step **S03**). The first opening degree command value  $V_1$  is computed according to a control table set in such a manner that the communication area between the boom lowering pressure reducing valve **57d** and the pressure receiving chamber of the second directional control valve **55** (opening area of the hydraulic line at the opening position **58a**) decreases in association with increase in the bottom pressure  $P_b$ .

(45) Next, the controller **60** computes a second opening degree command value  $V_2$  of the solenoid

valve **58** on the basis of the boom lowering operation amount  $Ad$  measured by the operation amount sensor **S3** (step **S04**). The order of the steps **S03** and **S04** may be reversed or be simultaneous. The second opening degree command value  $V2$  is computed according to a control table set in such a manner that the communication area between the boom lowering pressure reducing valve **57d** and the pressure receiving chamber of the second directional control valve **55** (opening area of the hydraulic line at the opening position **58a**) increases in association with increase in the boom lowering operation amount  $Ad$ .

(46) Subsequently, the controller **60** computes an elapsed time  $T$  after the most recent boom raising operation on the basis of the measurement value of the operation amount sensor **S4** and determines whether the elapsed time  $T$  is equal to or longer than a set time  $Ts$  set in advance (step **S05**). The elapsed time  $T$  is, for example, the time from the clock time when the boom raising operation amount  $Au$  ( $>0$ ) input most recently has become 0 to the current clock time. The clock time when the boom raising operation amount has reached a predetermined pilot pressure may be deemed as the beginning of the elapsed time  $T$ . When the elapsed time  $T$  is equal to or longer than the set time  $Ts$ , the controller **60** shifts the procedure from the step **S05** to the step **S06**. When the elapsed time  $T$  is shorter than the set time  $Ts$ , the controller **60** shifts the procedure from the step **S05** to the step **S07**.

(47) When the elapsed time  $T$  after the boom raising operation is equal to or longer than the set time  $Ts$ , the controller **60** decides the minimum selected value (smaller value) of the first opening degree command value  $V1$  and the second opening degree command value  $V2$  as a final opening degree command value  $V$  (step **S06**).

(48) When the elapsed time  $T$  after the boom raising operation is shorter than the set time  $Ts$ , the controller **60** decides a minimum opening degree command value  $Vmin$  as the final opening degree command value  $V$  (step **S07**). This is the same also when it is determined that boom lowering operation is not being executed in the step **S02**. The minimum opening degree command value  $Vmin$  is a value that minimizes the communication area between the boom lowering pressure reducing valve **57d** and the pressure receiving chamber of the second directional control valve **55** (opening area of the hydraulic line at the opening position **58a**). The minimum value of the communication area (opening area of the hydraulic line at the opening position **58a**) is 0, for example. In this case, interruption is caused between the pressure receiving chamber of the second directional control valve **55** on the boom lowering side and the boom lowering pressure reducing valve **57d**, and this pressure receiving chamber is connected to only the hydraulic operating fluid tank **59**.

(49) Upon deciding the opening degree command value  $V$  in the step **S06** or **S07**, the controller **60** generates a command signal (current or voltage) according to the decided opening degree command value  $V$  and outputs the generated command signal to the solenoid valve **58** (applies the command signal to the solenoid) to return the procedure to the step **S01** (step **S08**).

(50) By controlling the solenoid valve **58** as above, motion of the second directional control valve **55** at the time of boom lowering operation is limited depending on the condition. When the motion of the second directional control valve **55** is limited, the meter-in flow rate from the second hydraulic pump **53** to the bottom-side hydraulic chamber of the boom cylinder **15** decreases even with the same boom lowering operation amount  $Ad$ .

(51) FIG. 4 is a diagram representing one example of functional blocks of the controller **60** for executing the flow of FIG. 3. In the example illustrated in FIG. 4, the controller **60** is equipped with functions of executing processing of first opening degree command value computation **61**, second opening degree command value computation **62**, computation **63** of the elapsed time after boom raising operation, third opening degree command value computation **64**, and opening degree command value decision **65**.

(52) The first opening degree command value computation **61** is processing of computing the first opening degree command value  $V1$  on the basis of the bottom pressure  $Pb$  measured by the bottom

pressure sensor **S1** in accordance with a control line (control table) stored in the memory. As indicated in the block of the first opening degree command value computation **61**, the control line is defined in such a manner that **V1** decreases in association with increase in **Pb** in a **Pb-V1** coordinate system in which **Pb** is plotted on the abscissa axis and **V1** is plotted on the ordinate axis. The first opening degree command value **V1** is equivalent to a value to make a command of the communication area between the boom lowering pressure reducing valve **57d** and the pressure receiving chamber of the second directional control valve **55** on the boom lowering side, and the communication area increases when **V1** is larger. **V1** computed under the control line indicated in the block of the first opening degree command value computation **61** decreases in association with increase in the bottom pressure **Pb**.

(53) At this time, in the present embodiment, a first control line **L1** and a second control line **L2** are included in the control line to which a reference is made in the first opening degree command value computation **61**. The first control line **L1** is a control line to which a reference is made at a time of rise in the bottom pressure **Pb**, and the second control line **L2** is a control line to which a reference is made at a time of fall in the bottom pressure **Pb**. **P1** to **P4** indicated in the block of the first opening degree command value computation **61** are set values about **Pb** ( $P1 < P2 < P3 < P4$ ).

(54) The first control line **L1** is defined in such a manner that  $V1 = V_{\max}$  (maximum opening degree command value) holds in a region of  $Pb < P2$  and **V1** monotonically decreases from  $V_{\max}$  to  $V_{\min}$  in association with increase in **Pb** in a region of  $P2 \leq Pb \leq P4$  and  $V1 = V_{\min}$  (minimum opening degree command value) holds in a region of  $Pb > P4$ . The other second control line **L2** is defined in such a manner that  $V1 = V_{\min}$  holds in a region of  $Pb > P3$  and **V1** monotonically increases from  $V_{\min}$  to  $V_{\max}$  in association with decrease in **Pb** in a region of  $P1 \leq Pb \leq P3$  and  $V1 = V_{\max}$  holds in a region of  $Pb < P1$ . As above, in the **Pb-V1** coordinate system, the second control line **L2** is offset in the decrease direction of **Pb** ( $-Pb$  direction) by a predetermined value  $\Delta Pb$  ( $= P2 - P1 = P4 - P3$ ) with respect to the first control line **L1**.

(55) Detailed description will be made about the value of **V1** computed in association with increase and decrease in **Pb** by the controller **60** under the control line. When **Pb** rises from a value equal to or larger than **P2** (that is, a value with which **V1** takes  $V_{\max}$ ), the controller **60** decreases **V1** along the first control line **L1** (computes **V1** corresponding to **Pb** on the first control line **L1**). Conversely, when **Pb** falls from a value equal to or larger than **P3** (that is, a value with which **V1** takes  $V_{\min}$ ), the controller **60** increases **V1** along the second control line **L2** (computes **V1** corresponding to **Pb** on the second control line **L2**). Therefore, for example, when **Pb** rises from **P1** to **P4** and thereafter decreases to **P1**, **V1** decreases from  $V_{\max}$  to  $V_{\min}$  along the first control line **L1** in association with the rise in **Pb** simply, and thereafter **V1** increases from  $V_{\min}$  to  $V_{\max}$  along the second control line **L2** in association with the fall in **Pb**.

(56) In contrast, in the case in which the value of **Pb** turns to fall when having risen to **Px** ( $P2 < Px < P4$ ) from a value equal to or smaller than **P2** before rising to **P4**, **V1** is kept at  $Vx$  corresponding to **Px** on the first control line **L1** only while **Pb** falls by  $\Delta P$ . Then, when **Pb** falls from  $P_y$  ( $= Px - \Delta Pb$ ), **V1** increases along the second control line **L2**.

(57) The same applies also to the case in which the value of **Pb** turns to fall before falling to **P1** from a value equal to or larger than **P3**. **V1** keeps a value from the value on the second control line **L2** to the value on the first control line **L1** and thereafter decreases in association with rise in **Pb** along the first control line **L1**.

(58) The second opening degree command value computation **62** is processing of computing the second opening degree command value **V2** on the basis of the boom lowering operation amount **Ad** measured by the operation amount sensor **S3** in accordance with a control line (control table) stored in the memory. As indicated in the block of the second opening degree command value computation **62**, the control line is defined in such a manner that **V2** increases in association with increase in **Ad** in an **Ad-V2** coordinate system in which **Ad** is plotted on the abscissa axis and **V2** is plotted on the ordinate axis. The second opening degree command value **V2** is also equivalent to a

value to make a command of the communication area between the boom lowering pressure reducing valve **57d** and the pressure receiving chamber of the second directional control valve **55** on the boom lowering side, and the communication area increases when  $V2$  is larger.  $V2$  computed under the control line indicated in the block of the second opening degree command value computation **62** increases in association with increase in  $Ad$ .

(59)  $A1$  and  $A2$  indicated in the block of the second opening degree command value computation **62** are set values about  $Ad$  ( $0 < A1 < A2$ ). The control line to which a reference is made in the second opening degree command value computation **62** is defined in such a manner that  $V2 = V_{min}$  holds in a region of  $Ad < A1$  and  $V2$  monotonically increases from  $V_{min}$  to  $V_{max}$  in association with increase in  $Ad$  in a region of  $A1 \leq Ad \leq A2$  and  $V2 = V_{max}$  holds in a region of  $Ad > A2$ . Differently from the control line to which a reference is made in the first opening degree command value computation **61**, the control line to which a reference is made in the second opening degree command value computation **62** is a single line, and a value on the control line is always computed as  $V2$  with respect to  $Ad$ .

(60) The computation **63** of the elapsed time after boom raising operation is processing of computing the elapsed time  $T$  from stop of the most recent boom raising operation to the current time on the basis of the boom raising operation amount  $Au$  measured by the operation amount sensor **S4** and the measured clock time of a timer. The beginning of the elapsed time  $T$  is the clock time when the most recent boom raising operation amount  $Au$  ( $>0$ ) has become 0. The clock time when the boom raising operation amount  $Au$  has become 0 can be identified from log data of the boom raising operation amount  $Au$  stored in the memory, for example, and the elapsed time  $T$  after boom raising operation is computed through taking the difference between this identified clock time and the current clock time.

(61) The third opening degree command value computation **64** is processing of computing a third opening degree command value  $V3$  of the solenoid valve **58** on the basis of the elapsed time  $T$  after boom raising operation. In the processing of the third opening degree command value computation **64**, when the elapsed time  $T$  is shorter than the set time  $Ts$ , the third opening degree command value  $V3$  of the solenoid valve **58** is computed to cause the communication area between the boom lowering pressure reducing valve **57d** and the pressure receiving chamber of the second directional control valve **55** on the boom lowering side to become the minimum value ( $V3 = V_{min}$ ). Further, when the elapsed time  $T$  is equal to or longer than the set time  $Ts$ , the third opening degree command value  $V3$  of the solenoid valve **58** is computed to cause the communication area between the boom lowering pressure reducing valve **57d** and the pressure receiving chamber of the second directional control valve **55** on the boom lowering side to become the maximum value ( $V3 = V_{max}$ ).

(62) The opening degree command value decision **65** is processing of deciding the minimum selected value of the first opening degree command value  $V1$ , the second opening degree command value  $V2$ , and the third opening degree command value  $V3$  as the opening degree command value  $V$  and generating the command signal for the solenoid valve **58** on the basis of the decided opening degree command value  $V$  to output the command signal to the solenoid valve **58**. The third opening degree command value  $V3$  is the minimum opening degree command value  $V_{min}$  when the elapsed time  $T$  after boom raising operation is shorter than the set time  $Ts$ . Thus, if  $T < Ts$  holds, inevitably  $V = V_{min}$  holds. Moreover,  $V3 = V_{max}$  holds when the elapsed time  $T$  after boom raising operation is equal to or longer than the set time  $Ts$ . Thus, if  $T \geq Ts$  holds, inevitably the minimum selected value of  $V1$  and  $V2$  becomes  $V$ .

(63) By controlling the solenoid valve **58** by the processing exemplified above, the limitation amount of the meter-in flow rate to the bottom-side hydraulic chamber of the boom cylinder **15** at the time of boom lowering operation is favorably controlled as described previously with FIG. 3.

(64) In the present embodiment, when the boom lowering operation amount  $Ad$  is small or the bottom pressure  $Pb$  is high, the motion of the second directional control valve **55** is limited (motion limitation is strengthened) and the meter-in flow rate to the rod-side hydraulic chamber of the

boom cylinder **15** decreases. When the boom lowering operation amount  $A_d$  is small or the bottom pressure  $P_b$  is high, it is presumed that boom lowering motion is being executed in the state in which the bucket **14** is suspended in the air, and energy loss can be suppressed by suppressing the unnecessary meter-in flow rate for boom lowering in such a scene.

(65) Further, when the boom lowering operation amount  $A_d$  is large and the bottom pressure  $P_b$  is low, the motion limitation of the second directional control valve **55** is released (motion limitation is weakened) and the meter-in flow rate to the rod-side hydraulic chamber of the boom cylinder **15** increases. When the boom lowering operation amount  $A_d$  is large and the bottom pressure  $P_b$  is low, a situation in which the bucket **14** is strongly pushed into a ground surface as in jack-up motion or the like is presumed, and the meter-in flow rate for boom lowering can be ensured in a scene of such high-load work.

(66) Moreover, during the period until the elapsed time  $T$  after the most recent boom raising operation reaches the set time  $T_s$ , the motion of the second directional control valve **55** is prohibited (motion limitation becomes the maximum), and the meter-in flow rate to the rod-side hydraulic chamber of the boom cylinder **15** does not immediately increase even when boom lowering operation is executed. For example, in the case in which boom raising operation and boom lowering operation are alternately repeated with a short cycle as in bumping work, the bottom pressure  $P_b$  of the boom cylinder **15** often greatly varies, for example, when the motion is switched from boom raising to boom lowering. If the control condition of the solenoid valve **58** is incidentally satisfied in such a scene, there is a possibility that the solenoid valve **58** is actuated in an undesired scene, and the operability deteriorates. However, the solenoid valve **58** is not actuated until the set time  $T_s$  elapses from boom raising operation, and therefore the deterioration of the operability can be suppressed.

#### Effects

(67) (1) As described above, according to the present embodiment, in a scene in which boom lowering motion of a low load like one executed in the state in which the bucket **14** is suspended in the air is presumed, energy loss can be suppressed by suppressing the meter-in flow rate for boom lowering. Further, in a scene in which boom lowering motion of a high load in which the bucket **14** is strongly pressed against a ground surface as in jack-up motion or the like is presumed, the requisite output power can be ensured through increasing the meter-in flow rate for boom lowering. Moreover, in a scene in which the solenoid valve **58** is possibly actuated in an undesired form in the case in which boom raising operation and boom lowering operation are repeated as in bumping work or the like, the actuation of the solenoid valve **58** is inhibited until the set time  $T_s$  elapses from boom raising operation. This can suppress the occurrence of a high meter-in flow rate at the time of boom lowering and suppress the deterioration of the operability.

(68) As above, according to the present embodiment, the motion speed of the boom can be caused to correspond with the required speed, and both reduction in energy loss and improvement in the operability can be achieved.

(69) (2) There is a moment at which the bottom pressure  $P_b$  increases or decreases in operation of the front work implement **10**, such as when a transition is made from the state in which the bucket **14** is suspended in the air to jack-up motion in boom lowering motion or when the boom cylinder **15** is rapidly contracted by sudden operation, for example. When the first opening degree command value  $V_1$  is increased or decreased in response to such instantaneous increase or decrease in the bottom pressure  $P_b$ , there is a possibility that the solenoid valve **58** is sensitively actuated and the operability is affected.

(70) In contrast, in the present embodiment, the first control line  $L_1$  and the second control line  $L_2$  are prepared, the first opening degree command value  $V_1$  is computed under the first control line  $L_1$  at the time of rise in  $P_b$ , and the first opening degree command value  $V_1$  is computed under the second control line  $L_2$  at the time of fall in  $P_b$ . The first control line  $L_1$  and the second control line  $L_2$  are offset by  $\Delta P_b$  in the  $P_b$ -axis direction in the  $P_b$ - $V_1$  coordinate system. Thus, when the value

of Pb turns from increase to decrease (or from decrease to increase), the first opening degree command value V1 does not change until the change in Pb exceeds the certain amount ( $\Delta P_b$ ). Therefore, it is possible to suppress the sensitive motion of the solenoid valve 58 in the scene in which the bottom pressure Pb increases or decreases as described above.

#### MODIFICATION EXAMPLES

(71) Although the one embodiment of the present invention has been described above, embodiments of the present invention are not limited to the above mode and can be variously changed within such a range as not to depart from the gist of the present invention. Several modification examples will be exemplified below.

(72) For example, the example in which the first opening degree command value V1 is computed according to only the bottom pressure Pb of the boom cylinder 15 has been described. Regarding this point, it is also possible to make a configuration in which the controller 60 computes the difference between the rod pressure Pr measured by the rod pressure sensor S2 and the bottom pressure Pb and computes the first opening degree command value V1 on the basis of this difference.

(73) Further, the operation lever device 57 including the boom operation lever 57l mechanically linked to the boom lowering pressure reducing valve 57d and the boom raising pressure reducing valve 57u has been described. However, it is also possible to employ an electrical lever device as the operation lever device 57. In this case, a configuration is made in which the boom lowering pressure reducing valve 57d and the boom raising pressure reducing valve 57u are made into an electromagnetically driven type and the boom lowering pressure reducing valve 57d and the boom raising pressure reducing valve 57u are operated according to the command signal output from the controller 60 in response to an operation signal of the electrical lever device. Also when the electrical lever device is employed as the operation lever device 57, the operation amount of the boom operation lever 57l can be sensed by a potentiometer or the like, and the present invention can be applied.

(74) Moreover, description has been made by taking as an example the configuration including one first hydraulic pump 52 and one second hydraulic pump 53. However, it is also possible to make a configuration in which a plurality of pumps are disposed as at least one of the first hydraulic pump 52 and the second hydraulic pump 53.

#### DESCRIPTION OF REFERENCE CHARACTERS

(75) 1: Hydraulic excavator (construction machine) 4: Machine body 10: Front work implement 15: Boom cylinder 51: Prime mover 52: First hydraulic pump 53: Second hydraulic pump 54: First directional control valve 55: Second directional control valve 56: Pilot pump 56b: Pilot hydraulic line 57d: Boom lowering pressure reducing valve 57l: Boom operation lever 57u: Boom raising pressure reducing valve 58: Solenoid valve 60: Controller Ad: Boom lowering operation amount (operation amount) Au: Boom raising operation amount (operation amount) L1: First control line L2: Second control line Pb: Bottom pressure Pr: Rod pressure S1: Bottom pressure sensor S2: Rod pressure sensor S3, S4: Operation amount sensor T: Elapsed time Ts: Set time V: Opening degree command value V1: First opening degree command value V2: Second opening degree command value V3: Third opening degree command value Vmax: Maximum opening degree command value Vmin: Minimum opening degree command value

#### Claims

1. A construction machine including a machine body, a front work implement joined to the machine body, a boom cylinder that vertically drives the front work implement, a prime mover, a first hydraulic pump driven by the prime mover, a second hydraulic pump driven by the prime mover, a first directional control valve that controls a pressurized fluid that flows from the first hydraulic pump to the boom cylinder, a second directional control valve that controls a pressurized fluid that

flows from the second hydraulic pump to the boom cylinder, a pilot pump that delivers a pilot fluid that drives the first directional control valve and the second directional control valve, a boom lowering pressure reducing valve that outputs a boom lowering pilot pressure that drives the first directional control valve and the second directional control valve in a boom lowering direction with use of the pilot fluid as a source pressure, a boom raising pressure reducing valve that outputs a boom raising pilot pressure that drives the first directional control valve and the second directional control valve in a boom raising direction with use of the pilot fluid as a source pressure, and a boom operation lever to operate the boom lowering pressure reducing valve and the boom raising pressure reducing valve, the construction machine comprising: a bottom pressure sensor that measures a bottom pressure of the boom cylinder; an operation amount sensor that measures an operation amount of the boom operation lever; a solenoid valve that is disposed on a pilot hydraulic line that couples the boom lowering pressure reducing valve and a pressure receiving chamber of the second directional control valve and reduces the boom lowering pilot pressure for the second directional control valve; and a controller that controls the solenoid valve on a basis of the bottom pressure measured by the bottom pressure sensor and the operation amount measured by the operation amount sensor, wherein the controller is configured to compute a first opening degree command value in such a manner that a communication area between the boom lowering pressure reducing valve and the pressure receiving chamber of the second directional control valve decreases in association with increase in the bottom pressure on a basis of the bottom pressure measured by the bottom pressure sensor, compute a second opening degree command value in such a manner that the communication area increases in association with increase in a boom lowering operation amount on a basis of the boom lowering operation amount measured by the operation amount sensor, decide a minimum opening degree command value that minimizes the communication area as an opening degree command value of the solenoid valve when an elapsed time after boom raising operation is shorter than a set time and decide a minimum selected value of the first opening degree command value and the second opening degree command value as the opening degree command value of the solenoid valve when the elapsed time is equal to or longer than the set time, on a basis of the elapsed time after boom raising operation, and output a command signal according to the decided opening degree command value to the solenoid valve.

2. The construction machine according to claim 1, wherein the controller is configured to store a first control line and a second control line that are defined in such a manner that the first opening degree command value decreases in association with increase in the bottom pressure and are offset in a direction of an abscissa axis in a coordinate system in which the bottom pressure is plotted on the abscissa axis and the first opening degree command value is plotted on an ordinate axis, and compute the first opening degree command value with reference to the first control line at a time of rise in the bottom pressure and compute the first opening degree command value with reference to the second control line at a time of fall in the bottom pressure.

3. The construction machine according to claim 1, further comprising: a rod pressure sensor that measures a rod pressure of the boom cylinder, wherein the controller is configured to compute a difference between the bottom pressure measured by the bottom pressure sensor and the rod pressure measured by the rod pressure sensor and compute the first opening degree command value on a basis of the difference.

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