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Control system for suppression of boom or arm oscillation

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Moon

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(54) **CONTROL SYSTEM FOR SUPPRESSION OF BOOM OR ARM OSCILLATION**

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(73) Assignee: **Board of Control of Michigan Technological University**, Houghton, MI (US)

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(21) Appl. No.: **11/224,258**

(22) Filed: **Sep. 12, 2005**

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(60) Provisional application No. 60/687,077, filed on Jun. 3, 2005.

(51) **Int. Cl.**
F16D 31/02 (2006.01)
F15B 13/04 (2006.01)

(52) **U.S. Cl.** **60/469**; 60/426; 91/461

(58) **Field of Classification Search** 60/426, 60/469; 91/433, 461; 700/280
See application file for complete search history.

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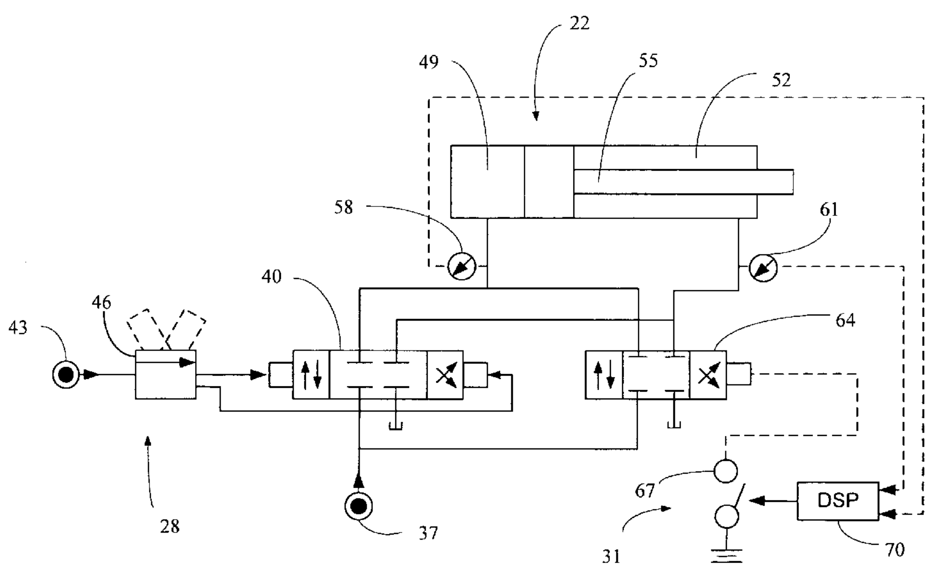
(57) **ABSTRACT**

A control for a working apparatus having a boom arm. The apparatus includes a controller operable to receive signals from at least one pressure sensor. The at least one pressure sensor detects pressure of hydraulic fluid in at least one chamber of a control valve. The controller compares the signals from the at least one pressure sensor to parameters generated by testing the working apparatus. The controller predicts boom arm oscillations based on the comparison of the signals with the parameters, and generates a control signal in response to predicting the boom arm oscillations.

31 Claims, 9 Drawing Sheets



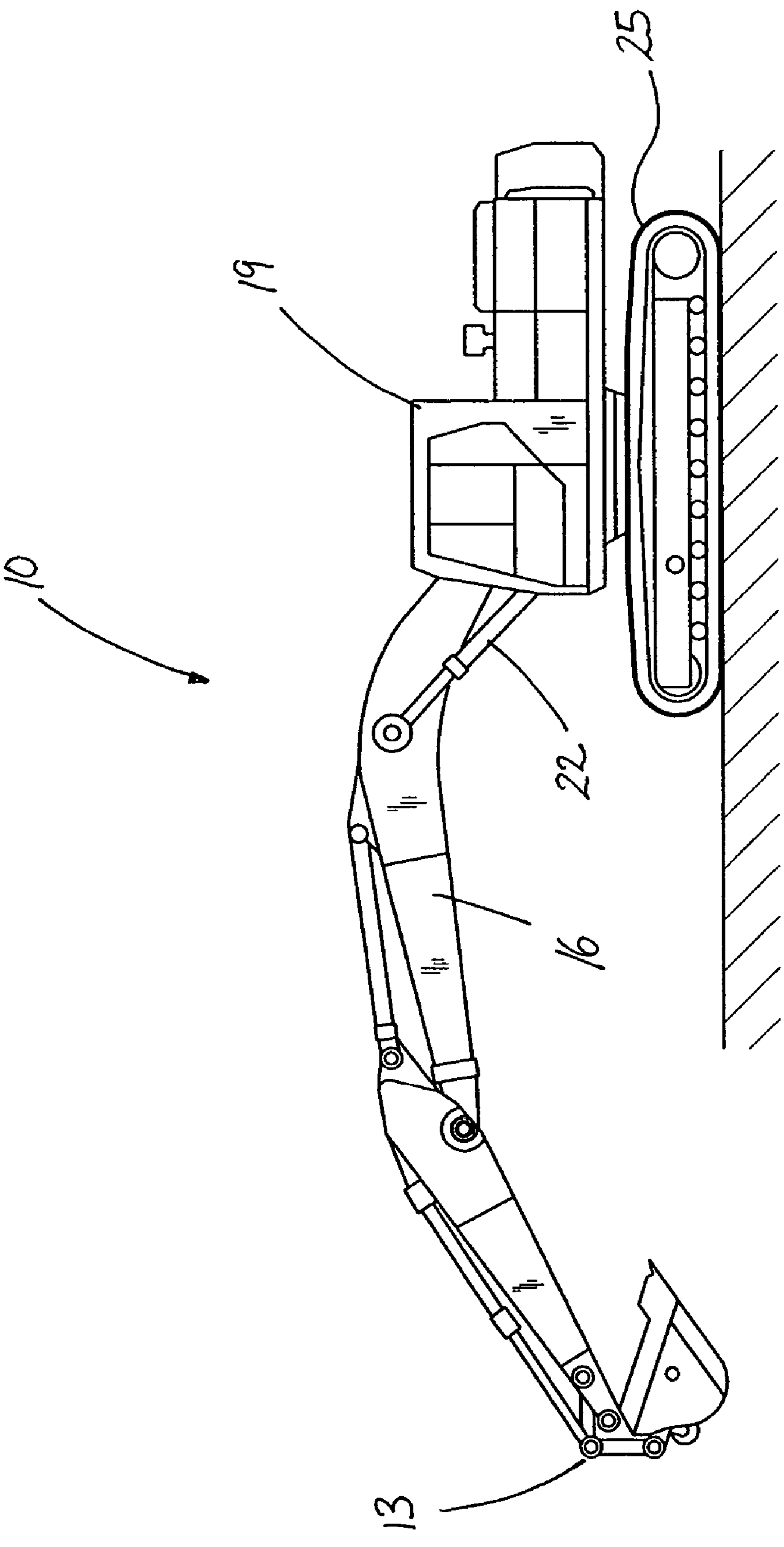


FIG. 1

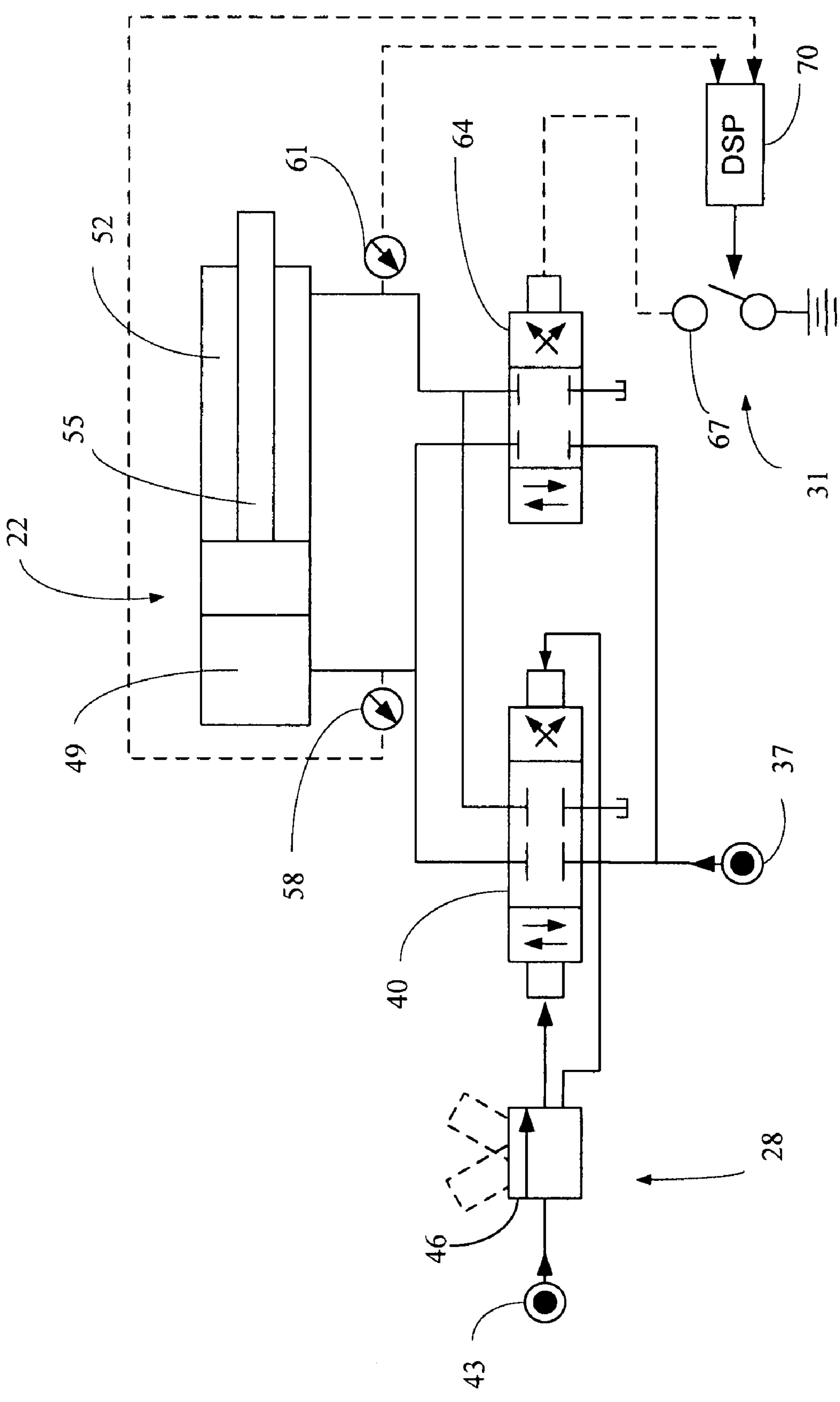


FIG. 2

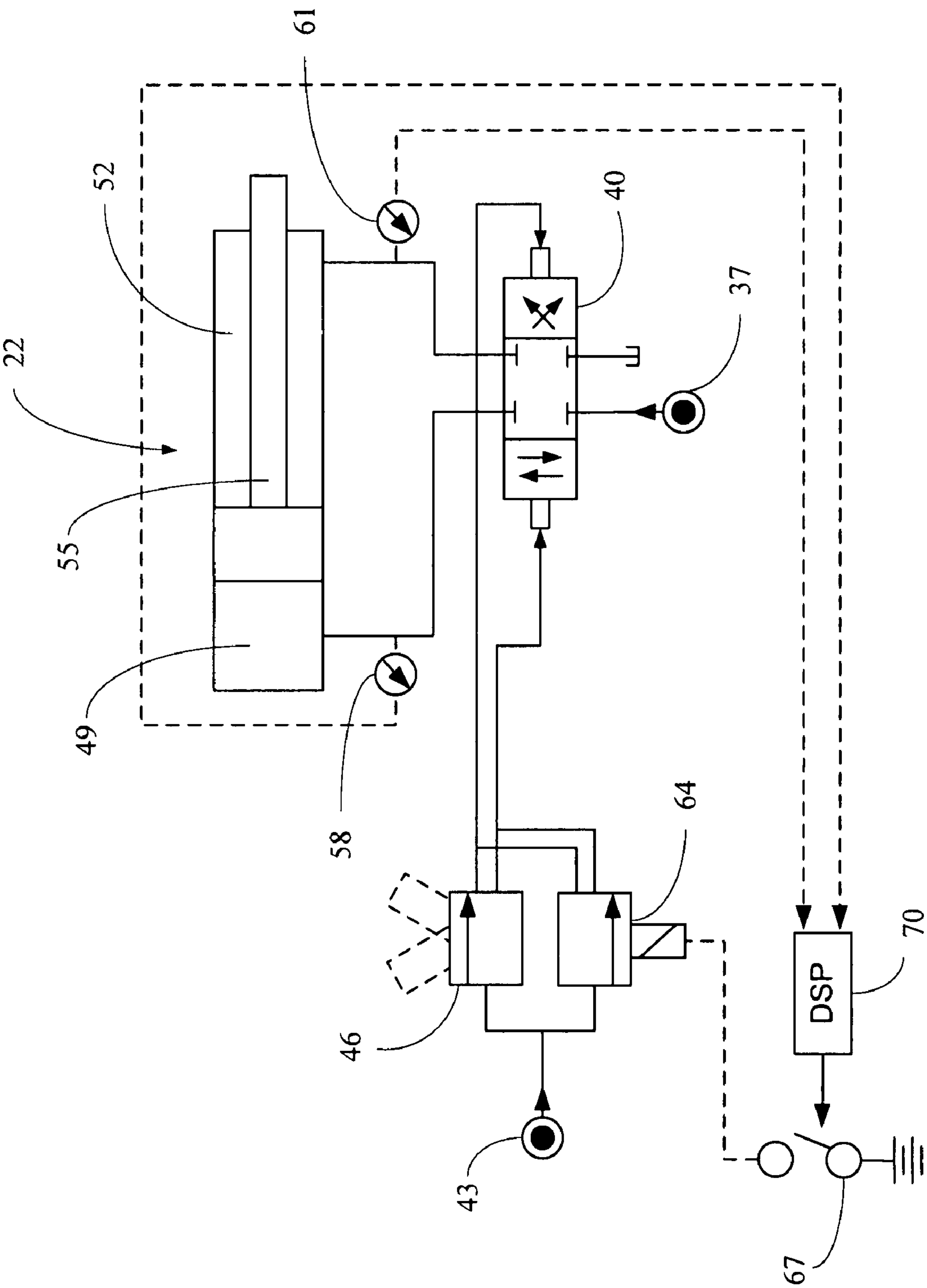
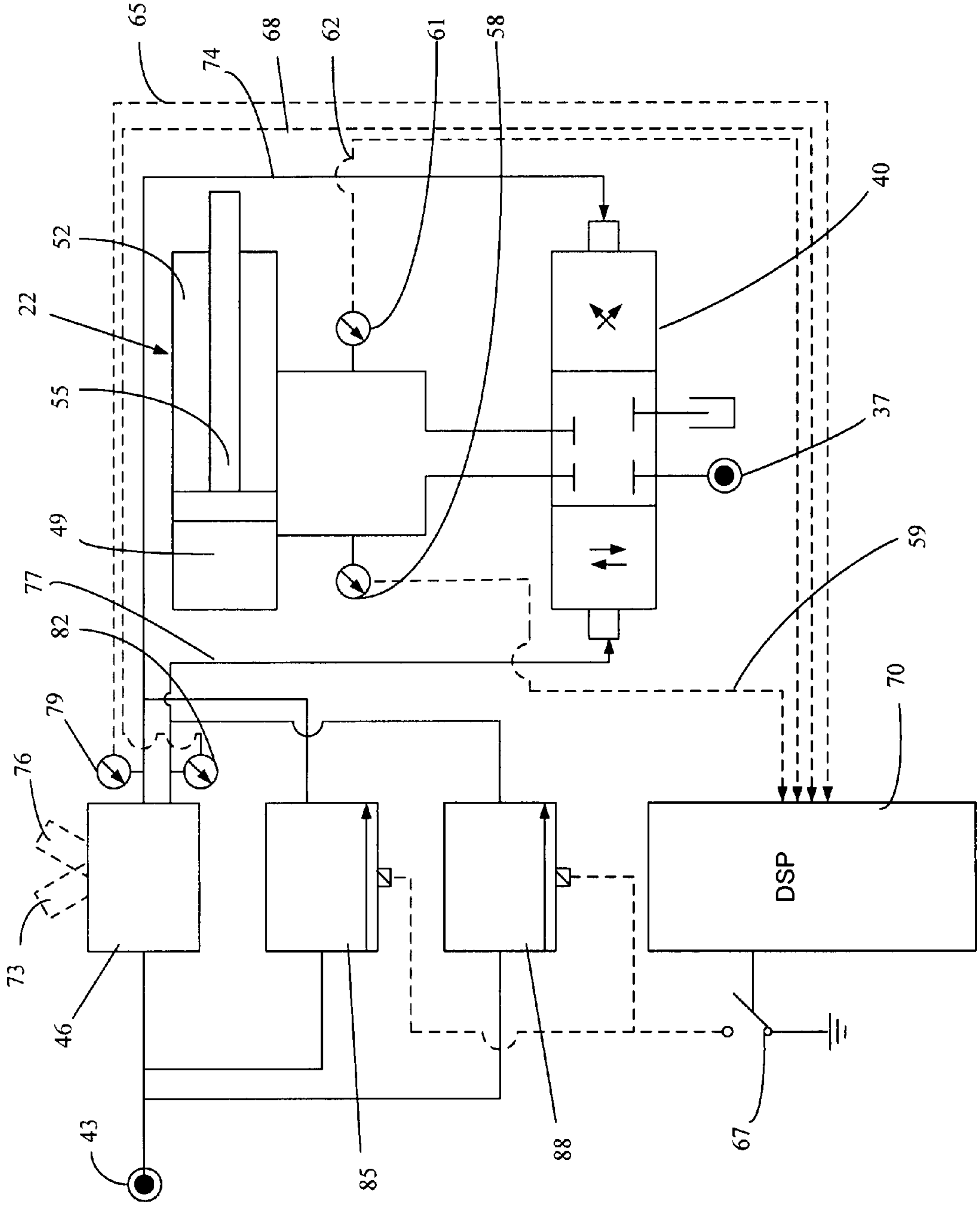


FIG. 3


DSP
65
68
74
62
61
58
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88
67
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FIG. 4

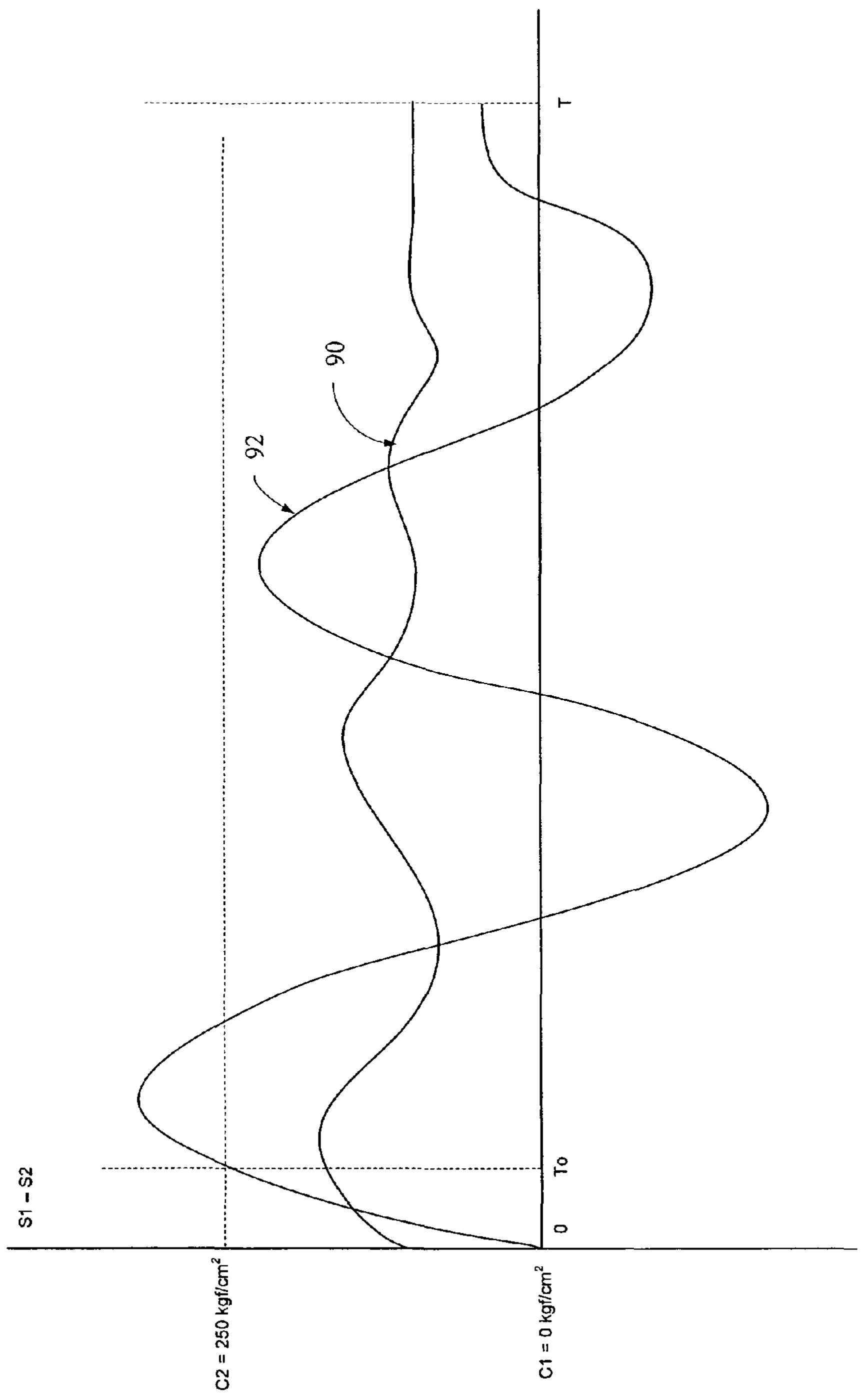


Fig. 5

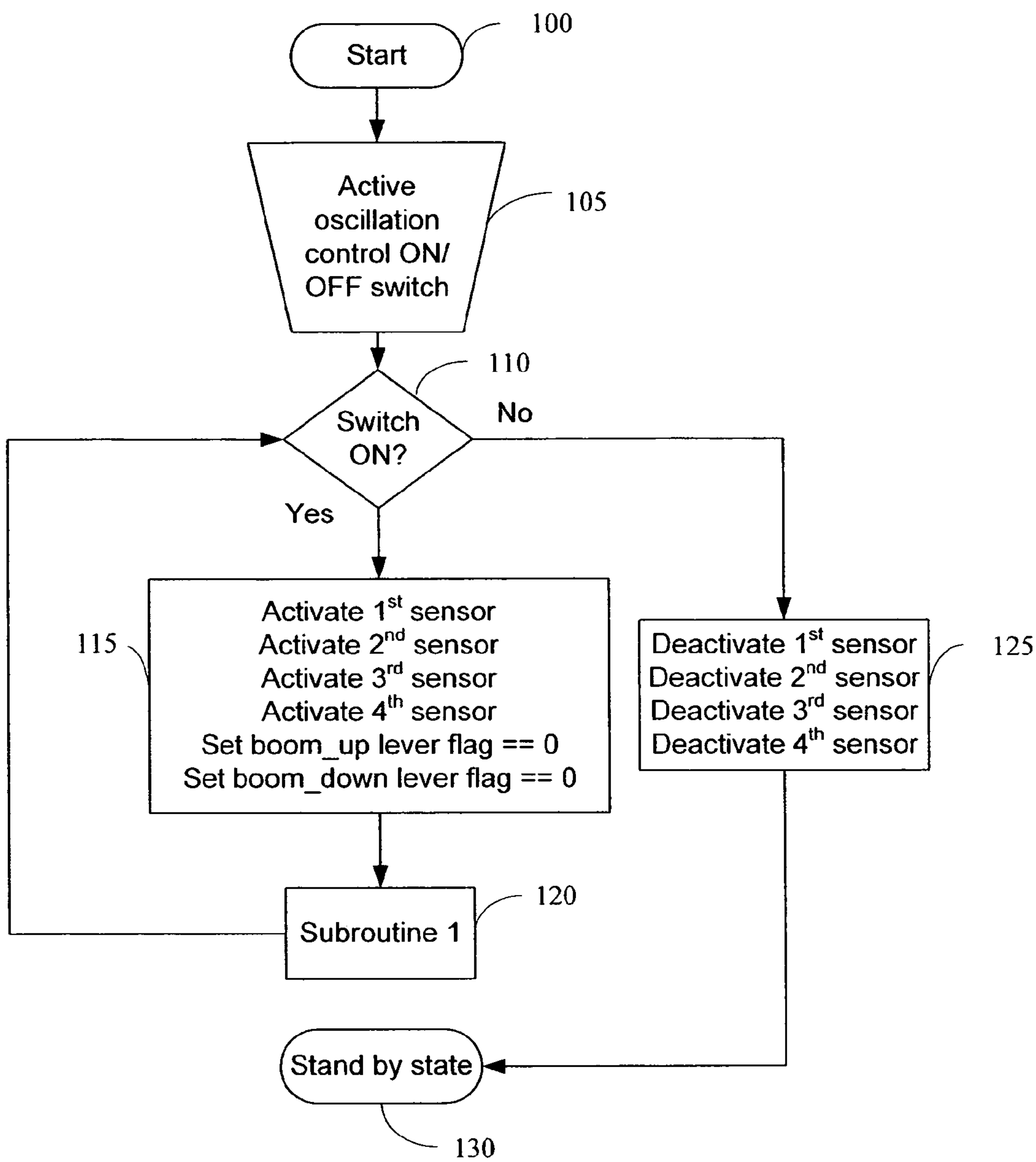

100
Start
Active oscillation control ON/ OFF switch
105
110
Switch ON?
No
Yes
Activate 1st sensor
Activate 2nd sensor
Activate 3rd sensor
Activate 4th sensor
Set boom_up lever flag == 0
Set boom_down lever flag == 0
115
Deactivate 1st sensor
Deactivate 2nd sensor
Deactivate 3rd sensor
Deactivate 4th sensor
125
Subroutine 1
120
Stand by state
130

FIG. 6

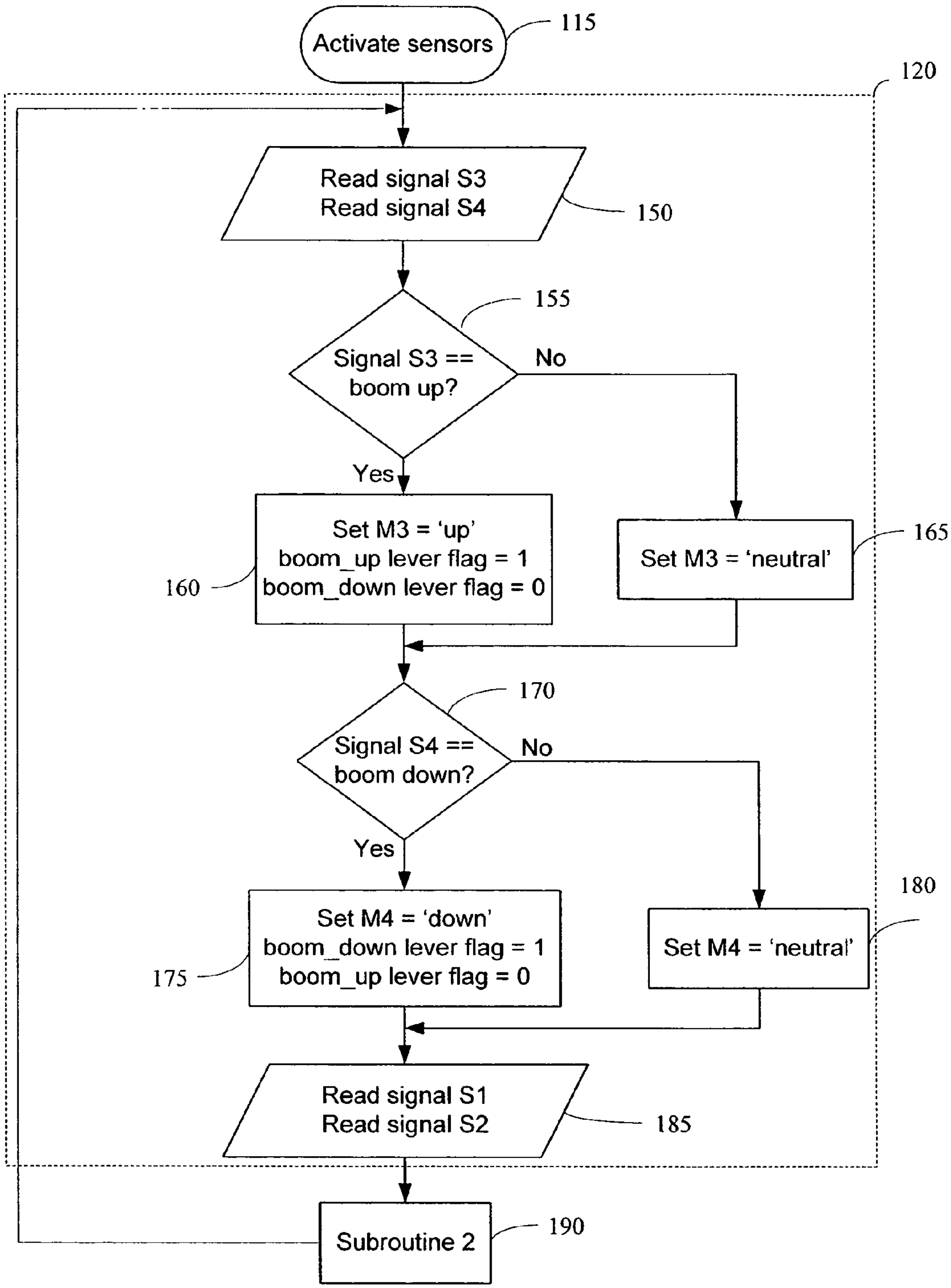

Activate sensors
115
120
Read signal S3
Read signal S4
150
155
Signal S3 == boom up?
No
Yes
Set M3 = 'up'
boom_up lever flag = 1
boom_down lever flag = 0
160
Set M3 = 'neutral'
165
170
Signal S4 == boom down?
No
Yes
Set M4 = 'down'
boom_down lever flag = 1
boom_up lever flag = 0
175
Set M4 = 'neutral'
180
Read signal S1
Read signal S2
185
Subroutine 2
190

FIG. 7

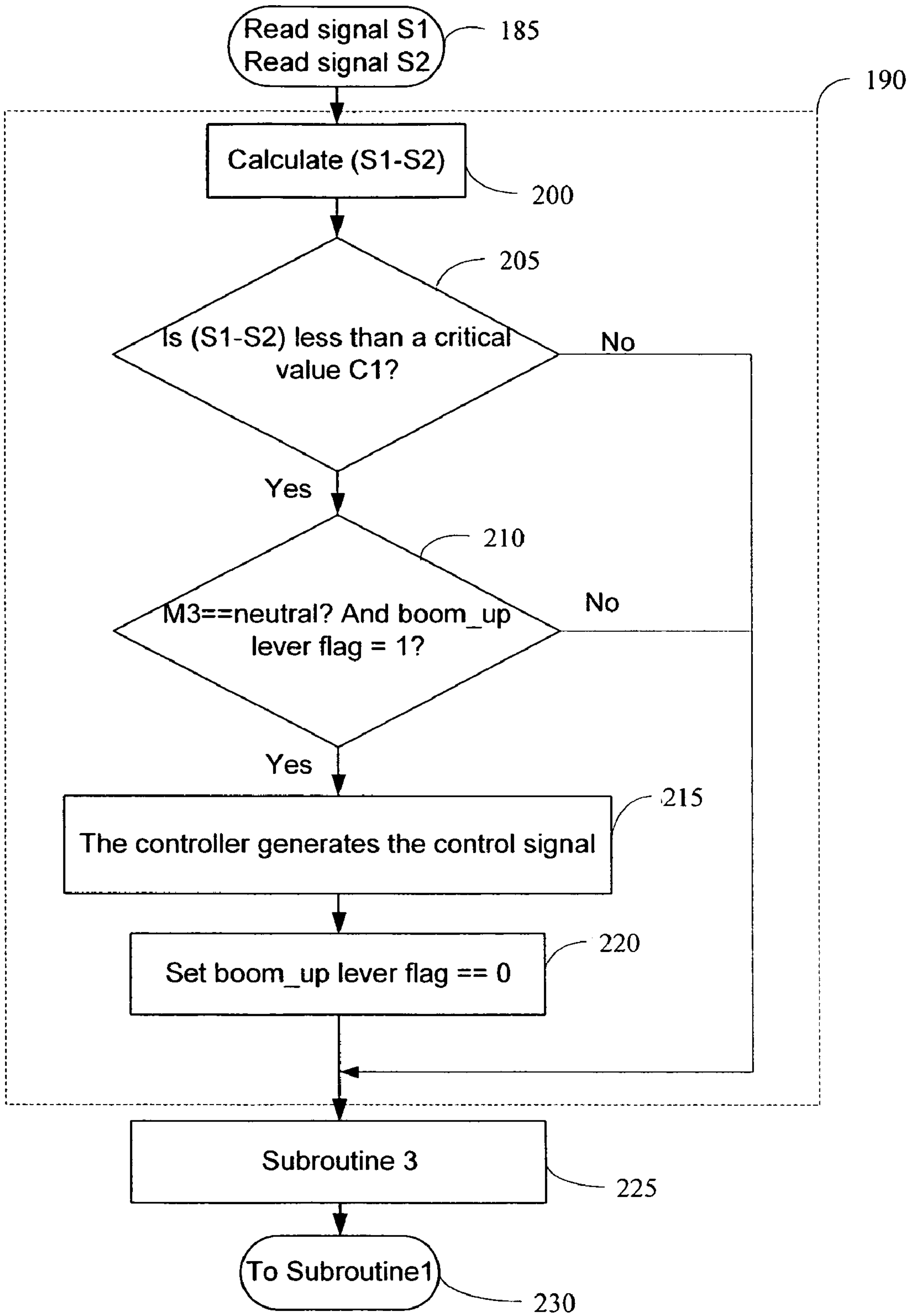
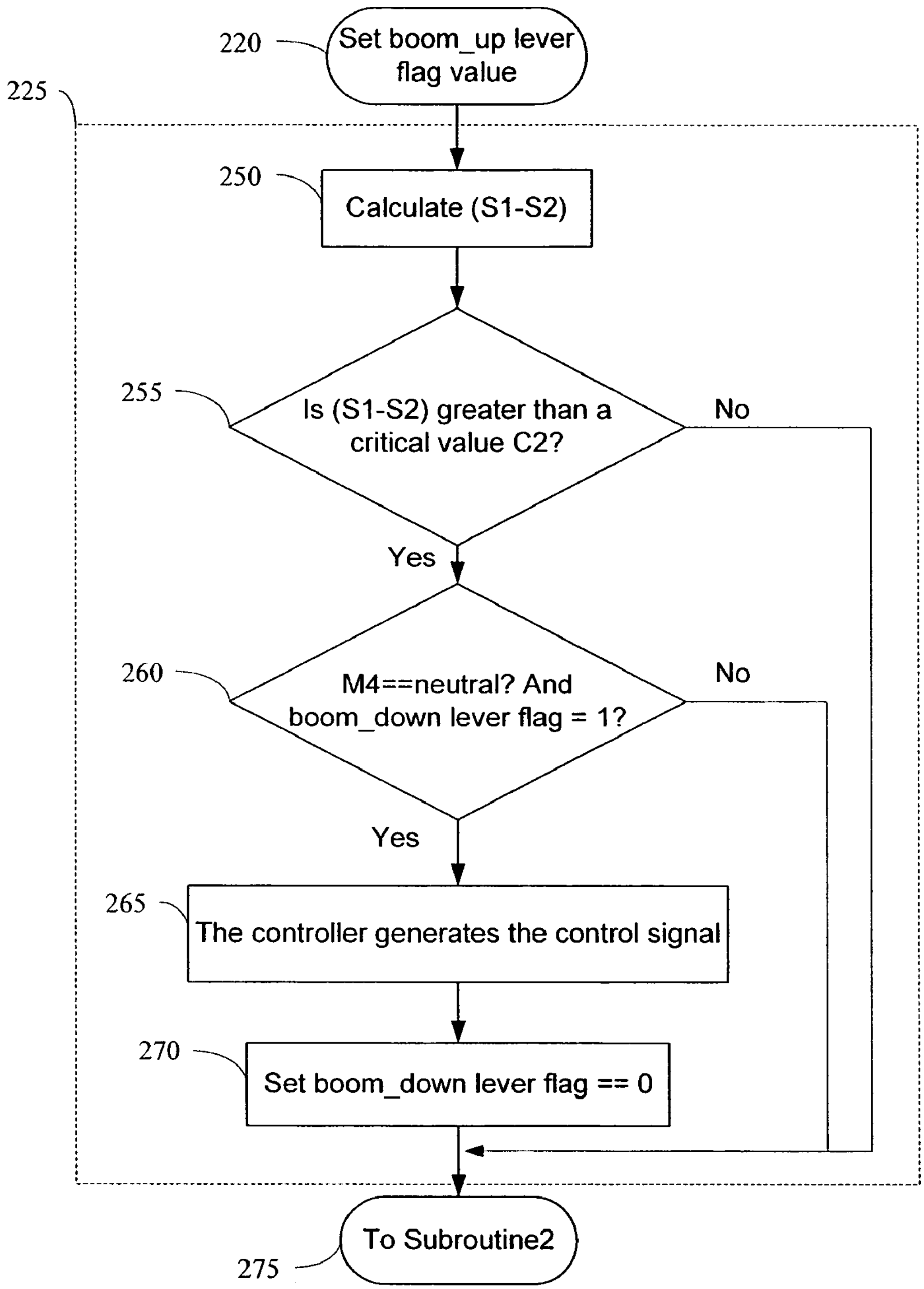

Read signal S1
Read signal S2
185
190
Calculate (S1-S2)
200
205
Is (S1-S2) less than a critical value C1?
No
Yes
210
M3==neutral? And boom_up lever flag = 1?
No
Yes
The controller generates the control signal
215
Set boom_up lever flag == 0
220
Subroutine 3
225
To Subroutine1
230

FIG. 8



220
Set boom_up lever flag value
225
250
Calculate (S1-S2)
255
Is (S1-S2) greater than a critical value C2?
No
Yes
260
M4==neutral? And boom_down lever flag = 1?
No
Yes
265
The controller generates the control signal
270
Set boom_down lever flag == 0
To Subroutine2
275

FIG. 9

CONTROL SYSTEM FOR SUPPRESSION OF BOOM OR ARM OSCILLATION

PRIORITY CLAIM

This application claims priority under 35 USC 119(e) to U.S. Provisional Patent Application No. 60/687,077 filed Jun. 3, 2005.

BACKGROUND

The present invention relates to a control system for suppression of boom oscillations affecting a working apparatus.

SUMMARY

In one embodiment, the invention provides a working apparatus having a first source of pressurized hydraulic fluid; an operator control unit; a boom arm; a boom cylinder coupled to the boom arm, the cylinder having a first chamber and a second chamber; a main control valve selectively directing pressurized hydraulic fluid from the first source to the first and second chambers in response to manipulation of the operator control unit to selectively raise and lower the arm; a first pressure sensor and a second pressure sensor detecting hydraulic pressure in the first and second chambers, respectively, and generating signals in reference to the amount of hydraulic pressure in the first and second chambers, respectively; and a controller receiving the signals from the pressure sensors, processing the signals to predict boom oscillations, and operating the main control valve to help prevent the predicted boom oscillations.

In another embodiment, the invention provides a working apparatus having a first source of pressurized hydraulic fluid; an operator control unit; a boom arm; a boom cylinder coupled to the boom arm; the cylinder having a first chamber and a second chamber; a main control valve selectively directing pressurized hydraulic fluid from the first source to the first and second chambers in response to manipulation of the operator control unit to selectively raise and lower the arm; a first pressure sensor and a second pressure sensor detecting hydraulic pressure in the first and second chambers, respectively, and generating signals in reference to the amount of hydraulic pressure in the first and second chambers, respectively; a controller receiving the signals from the pressure sensors, processing the signals to monitor operation of the cylinder and arm, and generating a control signal when the signals are indicative of impending boom oscillations; and a controller valve overriding the operator control unit and manipulating the main control valve to help prevent boom oscillations in response to receiving the control signal.

In another embodiment, the invention provides a method of inhibiting boom oscillations in a working apparatus having a boom arm coupled to a boom cylinder having first and second chambers, a main control valve, and an operator control unit permitting an operator to manipulate the main control valve to direct hydraulic fluid into one of the first and second chambers to selectively raise and lower the arm. The method comprises (a) detecting pressure of hydraulic fluid in the first and second chambers of the boom cylinder; (b) generating first and second chamber signals in reference to the hydraulic pressure in the first and second chambers, respectively; (c) comparing the first and second chamber signals to parameters; (d) predicting boom oscillations based on the comparison of step (c); (e) generating a control signal in response to predicting boom oscillations; and (f) overriding operation of the control unit to manipulate the main control valve and help prevent predicted boom oscillations in response to creating the control signal.

In another embodiment, the invention provides a control for a working apparatus having an arm, the control including a controller operable to receive at least one signal from a first pressure sensor that is operable to detect a pressure in a first chamber of a control valve, and at least one signal from a second pressure sensor that is operable to detect a pressure in a second chamber of the control valve, wherein the controller is operable to process the at least one signal from each of the first and second sensors, and to control the control valve to help prevent oscillations of the arm.

In another embodiment, the invention provides a method for inhibiting arm oscillations in an apparatus having an arm, the method including generating a first signal indicative of pressure in a first chamber; generating a second signal indicative of pressure in a second chamber; comparing the first signal to the second signal; predicting arm oscillations based on the comparison of the first signal to the second signal; and generating a control signal in response to predicting the arm oscillations.

Other aspects of the invention will become apparent by consideration of the detailed description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a working apparatus.

FIG. **2** is a schematic representation of a hydraulic system and a control system overriding the operation of a master control valve.

FIG. **3** is a schematic representation of the hydraulic system and the control system overriding the operation of a control lever.

FIG. **4** is a schematic representation of the hydraulic system and the control system overriding the operation of the control lever with two controller valves.

FIG. **5** is a pressure vs. time graph illustrating two boom oscillations in terms of a difference of two pressure values **S1–S2**.

FIG. **6** is a flow chart illustrating processes to enable the control system.

FIG. **7** is a flow chart illustrating processes to detect hydraulic pressure between the control lever and the master control valve.

FIG. **8** is a flow chart illustrating processes to identify a first set of conditions related to boom oscillations.

FIG. **9** is a flow chart illustrating processes to identify a second set of conditions related to boom oscillations.

DETAILED DESCRIPTION

Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including," "comprising," or "having" and variations thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. Unless specified or limited otherwise, the terms "mounted," "connected," "supported," and "coupled" and variations thereof are used broadly and encompass both direct and indirect mountings, connections, supports, and couplings, respectively. Further, "connected" and "coupled" are not restricted to physical or mechanical connections or couplings.

FIG. **1** illustrates a working apparatus **10** in the form of an excavator comprising an arm and bucket assembly **13**, a boom arm **16** connected to the assembly **13** at one end and to a control station **19** at the opposite end, a boom cylinder **22** coupled to the boom arm **16**, and tracks **25** supporting the control station **19**. The excavator **10** also includes a hydraulic system **28** operating the boom cylinder **22**, and a control system **31** coupled to the hydraulic system **28** (better illustrated in FIGS. **2-4**). The arm and bucket assembly **13** is connected to the control station **19**, and it is operable to collect and transport dirt or other materials. The boom cylinder **22** selectively raises and lowers the boom arm **16** in response to manipulation of the hydraulic system **28** operated from the control station **19**. The arm and bucket assembly **13** raises and lowers material as a consequence of raising and lowering the boom arm **16**. The control station **19** is operable to rotate above the tracks **25** supporting the control station **19** to transport material to a location within the same radius defined by the distance between the control station **19** and the assembly **13**.

The excavator **10** may experience oscillations, particularly boom oscillations, as a result of operating the boom arm **16** with the boom cylinder **22**. An operator in the control station **19** manipulates the hydraulic system **28** to operate the boom cylinder **22** raising and lowering the boom arm **16**. The inertial force of the boom arm **16** and the assembly **13** produced by the boom arm **16** rapidly ceasing motion or changing direction, can cause boom oscillations that affect the excavator **10**. The control system **31** coupled to the hydraulic system **28** is operable to predict oscillations and operate the hydraulic system **28** to help prevent the boom oscillations from occurring. In alternate embodiments, the control system may be used in different machines. For example, the control system **31** may by used in robots. Robotic arms may include a hydraulic system to raise and lower an end effector in a manner similar to the excavator **10**. Thus, it is to be understood that the control system is not restricted to excavators **10** and that the invention may encompass implementing the control system in other devices.

FIG. **2** illustrates the hydraulic system **28** and the control system **31** in one embodiment of the invention. The hydraulic system **28** includes a main source of pressurized hydraulic fluid **37** hydraulically connected to a master control valve ("MCV") **40**, and a pilot source **43** of hydraulic fluid hydraulically connected to a control lever **46**. It is to be understood that the control lever may include devices such as a joystick. The boom cylinder **22** schematically represented in FIGS. **2-4** includes a first chamber **49**, a second chamber **52**, and a piston **55** separating the first and second chambers **49** and **52**, and coupling the cylinder **22** to the boom arm **16**, illustrated in FIG. **1**. The operator manipulates the control lever **46** to direct hydraulic fluid from the pilot source **43** to one end or the other of the MCV **40** to shift the MCV **40**. If the MCV **40** is shifted one way, it directs hydraulic fluid from the main source **37** into the first chamber **49**, which increases pressure in the first chamber **49**. A decrease in hydraulic pressure in the second chamber **52** is caused simultaneously by decreasing hydraulic fluid in the second chamber **52** thus moving the piston **55** to raise the boom arm **16**. Alternatively, if the MCV **40** is shifted in another way, it directs hydraulic fluid from the main source **37** to the second chamber **52**, thus increasing pressure in the second chamber **52** and decreasing pressure in the first chamber **49** to lower the boom arm **16**.

The control system **31** comprises a first pressure sensor **58**, a second pressure sensor **61**, a controller valve **64**, a relay switch **67**, and a controller **70**, such as a digital signal processor, microprocessor, or other device. The first and second pressure sensors **58** and **61** detect hydraulic pressure, and generate signals representative of the hydraulic pressure in the first and second chambers **49** and **52**, respectively. The controller **70** receives the signals generated by the first and second sensors **58** and **61**, and processes the signals to predict boom oscillations. The operator in the control station **19** selectively opens or closes the relay switch **67** connecting the controller **70** and the controller valve **64** to disable or enable the control system **31**, respectively. The controller **70** sends a control signal to the controller valve **64** generated in response to predicting boom oscillations when the relay switch **67** is in a closed position. The controller valve **64**, illustrated in FIG. **2**, is in a parallel configuration with the MCV **40**, and hydraulically connects the main source **37** to the boom cylinder **22** along a path independent of the MCV **40**. In response to receiving the control signal, the controller valve **64** directs hydraulic fluid between the main source **37** and the first and second chambers **49** and **52**, overriding the operation of the MCV **40** to prevent oscillations.

FIG. **3** illustrates the hydraulic system **28** and the control system **31** in an alternate configuration. The controller valve **64** is in a parallel configuration with the control lever **46**. In response to receiving the control signal, the controller valve **64** overrides the operation of the control lever **46**, and directs hydraulic fluid between the pilot source **43** and the MCV **40** to manipulate the MCV **40**. For example, the operator can manipulate the control lever **46** to increase pressure in the first chamber **49** and lower pressure in the second chamber **52**, thus raising the boom arm **16**. The operator may rapidly cease or reverse motion of the boom arm **16**. This causes a change of pressure in the first and second chambers **49** and **52** that is detected by the first and second sensors **58** and **61**, respectively. The controller **70** generates the control signal in response to predicting the boom oscillations, causing the controller valve **64** to operate the MCV **40**. The controller valve **64** operates the MCV **40**. The MCV **40** directs hydraulic fluid between the main source **37** and the first and second chambers **49** and **52** in a manner to substantially prevent or help prevent the predicted boom oscillations.

FIG. **4** illustrates the control lever **46** and two positions between which the lever **46** can be moved: a first position **73** and a second position **76**. Hydraulic fluid flows through line **74** when the control lever **46** is in the first position **73**. When the control lever **46** is in the second position **76**, hydraulic fluid flows through line **77**. The operator may manipulate the control lever **46** to the first position **73** to shift the MCV **40** under the influence of the pilot source **43**. As a consequence, hydraulic fluid is directed from the main pressure source **37** into the second chamber **52** and out of the first chamber **49**, lowering the boom arm **16**. Similarly, the operator may manipulate the control lever **46** to the second position **76** to shift the MCV **40** under the influence of the pilot source **43**. As a consequence, hydraulic fluid is directed from the main pressure source **37** into the first chamber **49** and out of the second chamber **52**, raising the boom arm **16**.

As illustrated in FIG. **4**, the control system **31** includes a third pressure sensor **79** configured to detect hydraulic pressure between the control lever **46** and the MCV **40** when the control lever **46** is in the first position **73**, a fourth pressure sensor **82** configured to detect hydraulic pressure between the control lever **46** and the MCV **40** when the control lever **46** is in the second position **76**, a first controller valve **85** operable to override the control lever **46** when it is in the first position **73**, and a second controller valve **88** operable to override the control lever **46** when it is in the second position **76**. The controller **70** receives signals from the first, second, third, and fourth pressure sensors **58**, **61**, **79**, and **82** through lines **59**, **62**, **80**, and **83**, respectively, to predict boom oscillations. The controller **70** uses these signals and parameters that take into account the physical characteristics of the excavator **10** to predict the boom oscillations.

In certain embodiments, the controller **70** identifies two cases in which the operation of the boom cylinder **22** causes boom oscillations. The identification is made based on the detected pressures in the first and second chambers **49** and **52**. The pressure reading from the first pressure sensor **58** ("S**1**") and the pressure reading from the second pressure sensor **61** ("S**2**") are compared to a first parameter ("C**1**") and a second parameter ("C**2**") to determine cases (which on one embodiment are case 1 and case 2) when operating the hydraulic system **28** causes boom oscillations. In case 1, the value of S**2** is subtracted from S**1**(S**1**−S**2**) and the difference is compared to C**1**. If the difference is less than C**1**, it is assumed that the boom arm **16** has been raised and rapidly stopped or reversed in direction. In case 2, the difference S**1**−S**2** is compared to C**2**. If the difference is greater than C**2**, it is assumed that the boom arm **16** has been lowered and rapidly stopped or reversed in direction. The controller **70** generates the control signal when cases 1 and 2 are identified. Thus, the controller valve **64** overrides the operation of the MCV **40** (illustrated in FIG. **2**) or the control lever **46** (illustrated in FIG. **3**) to ultimately direct hydraulic fluid between the main pressure source **37** and the boom cylinder **22** to help prevent boom oscillations.

The control signal is generated until the difference of S**1**−S**2** is greater than C**1** and less than C**2**. The values C**1** and C**2** can be determined by following a testing procedure. The testing procedure can be conformed to a particular type of excavator **10**, and may include deliberately causing boom oscillations and measuring the pressure in the first and second chambers **49** and **52**. A first testing procedure may include raising and stopping the boom arm. This causes a rapid drop of pressure in the first chamber **49** and a rapid increase of pressure in the second chamber **52**. A second testing procedure may include lowering and stopping the boom arm. This causes a rapid increase of pressure in the first chamber **49** and a rapid decrease of pressure in the second chamber **52**. In particular, the first testing procedure indicates that boom oscillations may occur when the difference S**1**−S**2** is less than a first critical value. In addition, the second testing procedure indicates that boom oscillations may occur when the difference S**1**−S**2** is greater than a second critical value. Thus, the first and second testing procedures help determining the values of C**1** and C**2**, respectively. The first and second testing procedures usually yield different values of C**1** and C**2** based of the type of excavator **10** being tested. However, the values of C**1** and C**2** are generally constant for excavators **10** of the same type.

Alternatively, the operator can modify the values of C**1** and C**2** to accommodate for an individual manner of operating the excavator **10**. For example, FIG. **5** illustrates a pressure vs. time graph indicating the critical values C**1**=0 kgf/cm^2 and C**2**=250 kgf/cm^2, a first pressure profile **90** and a second pressure profile **92**, over a period of time from 0 to T. The first and second pressure profiles **90** and **92** are indicative of the difference S**1**−S**2** caused by boom oscillations occurring from time 0 to time T. The first pressure profile **90** indicates that the difference S**1**−S**2** is not less than C**1** or greater than C**2** during the time 0 to T. Thus, the controller **70** does not generate the control signal and it is assumed that the oscillations are acceptable by operator. The second pressure profile **92** indicates that the difference S**1**−S**2** is greater than C**2** at time T_0. Thus, the controller **70** generates the control signal until the difference S**1**−S**2** is less than C**2**.

The controller **70** is configured to sense when the operator manipulates the control lever **46** between the first and second positions **73** and **76** based on the pressure readings generated by the fourth pressure sensor **82** ("S**3**") and the third pressure sensor **79** ("S**4**"), respectively. The controller **70** generates the control signal when identifying case 1 and a change in the signal S**3** or when identifying case 2 and a change in the signal S**4**. FIGS. **6-9** include flow charts describing one method to predict boom oscillations in reference to the control system **31** illustrated in FIG. **4**.

FIG. **6** is a flow chart illustrating processes to initiate the controller **70** and the pressure sensors. The operator starts the excavator **10** (at step **100**), and selectively enables the operation of the hydraulic system **28**. The operator then turns an on/off switch (illustrated in FIGS. **2-4** as the relay switch **67**) to an on position (at step **105**), thus enabling the operation of the control system **31**. The controller **70** checks the position of the on/off switch (at step **110**) and activates the first, second, third, and fourth sensors **58**, **61**, **79**, and **82** (at step **115**) to receive signals indicative of the pressure in the first and second chambers **49** and **52**, and the pressure between the control lever **46** and the MCV **40**. The controller **70** also sets the values of a boom_up lever flag and a boom_down lever flag to 0, and continues to the operations in subroutine **1** (at step **120**) illustrated in FIG. **7**. The controller **70** checks the on/off switch (at step **110**) after completing the operations in subroutine **1** until the operator places the on/off switch in the off position, in which case the controller **70** deactivates the first, second, third, and fourth pressure sensors **58**, **61**, **79**, and **82** (at step **125**), and proceeds to a stand-by or off state (at step **130**).

FIG. **7** illustrates subroutine **1**, which describes processes to read the signals S**3** and S**4**, and set the values for the boom_up and boom_down lever flags. After activating the pressure sensors and setting the boom_up and boom_down lever flags to 0 (at step **115**), the controller **70** reads the signals S**3** and S**4** (at step **150**). S**3** and S**4** refer to the hydraulic pressure between the control lever **46** and the MCV **40** when the operator manipulates the control lever **46** between the first ("down") and second ("up") positions **73** and **76**. The controller **70** is configured to sense when the operator manipulates the control lever **46** to raise the boom arm **16** (at step **155**). As a consequence, the value of a variable M**3** is set to 'up', and the values of the boom_up and boom_down lever flags are set to 1 and 0, respectively (at step **160**). Alternatively, the value of M**3** may be set to 'neutral' (at step **165**) indicating a significantly low or non existent signal S**3** . The controller **70** then senses when the operator manipulates the control lever **46** to lower the boom arm **16** (at step **170**). As a consequence, the value of a variable M**4** is set to 'down', and the values of the boom_up and boom_down lever flags are set to 0 and 1, respectively (at step **175**). Alternatively, the value of M**4** may be set to 'neutral' (at step **180**) indicating a significantly low or non existent signal S**4**. The controller **70** senses the signals S**1** and S**2** (at step **185**), and begins operations described in a subroutine **2** (at step **190**). When the subroutine **2** is completed, the controller **70** reads the signals S3 and S4 (at step **150**) to update the values of the lever flags, M3, and M4.

After the controller **70** receives the signals S1 and S2 (at step **185**), as illustrated in FIG. **8**, the controller **70** subtracts S2 from S1 (at step **200**) and compares the difference to C1 to identify case 1 (at step **205**). The controller **70** checks the values of M3 and the boom_up lever flag (at step **210**). The controller generates the control signal (at step **215**) when the values of M3 and the boom_up lever flag are 'neutral' and 1, respectively. The controller **70** sets the boom_up lever flag to 0 (at step **220**) and continues to the processes described in a subroutine **3** (at step **225**) illustrated in FIG. **9**. When the processes of the subroutine **3** are completed, the controller **70** returns to subroutine **1** (at step **230**). Alternatively, when conditions are not indicative of case 1 (at step **205**), the controller **70** proceeds to the processes described in subroutine **3**. Additionally, when case 1 is identified (at step **205**) and the value of the boom_up lever flag is 0 or the value of M3 is set to 'up' (at step **210**), the controller **70** also proceeds to the processes of subroutine **3** (at step **225**).

After the controller **70** sets the value of the boom_up lever flag to 0 (at step **220**) as illustrated in FIG. **9**, the controller **70** subtracts S2 from S1 (at step **250**) and compares the difference to C2 to identify case 2 (at step **255**). The controller **70** checks the values of M4 and the boom_down lever flag (at step **260**). The controller **70** generates the control signal (at step **265**) when the values of M4 and the boom_down lever flag are 'neutral' and 1, respectively. The control signal generated by the controller **70** (at step **215** and step **265**) takes into account the amount of time it takes the signal to reach the first and second controller valves **85** and **88** and the amount of time it takes for the controller valves to open and shut. The controller **70** sets the boom_down lever flag to 0 (at step **270**), returns to subroutine **2** (at step **275**), and subsequently to subroutine **1** (at step **230**). Alternatively, when the conditions are not indicative of case 2 (at step **255**), the controller **70** returns to subroutine **2**. Additionally, when case 2 is identified (at step **255**) and the value of the boom_down lever flag is 0 or the value of M4 is set to 'down' (at step **260**), the controller **70** proceeds to subroutine **2** (at step **275**).

For example, if the controller **70** reads the signal S3 (at step **150**) and senses the operator manipulating the control lever **46** to the second position **76** (at step **155**), the values of M3, boom_up lever flag, and boom_down level flag are set to 'up', 1, and 0, respectively (at step **160**). Since the signal S3 indicates that the boom arm is up, the value of M4 is set to 'neutral' (at step **180**). The controller **70** then senses signals S1 and S2 (at step **185**), and subtracts S2 from S1 (at step **200**) to identify case 1 (at step **205**). The value of S1–S2 may not be less than C1 when the operator manipulates the control lever **46** to the second position **76**. Thus, the controller **70** proceeds to the processes of subroutine **3** (at step **225**). The controller **70** calculates S1–S2 (at step **250**), and compares the difference to C2 (at step **255**). If the conditions for case 2 are met (at step **255**), the controller **70** checks whether the values of M4 and the boom_down lever flag are 'neutral' and 0, respectively (at step **260**). The controller **70** proceeds to subroutine **2** (at step **275**) and subsequently to subroutine **1** (at step **230**) to sense signals S3 and S4 (at step **150**).

In response to the operator stopping or reversing direction of the control lever **46**, the controller **70** senses a very low or non existent signal S3 (at step **155**), thereby setting the value of M3 to 'neutral' (at step **165**). The controller **70** can carry out the operations described in FIGS. **6-9** at a relatively fast rate. Thus, the controller **70** sets the value of M4 to 'neutral' (at step **180**). The operator stopping or reversing direction of the control lever **46** generates an excessive high pressure in the second chamber **52** and an excessive low pressure in the first chamber **49**. The excessive low and high pressures reaching equilibrium causes boom oscillations. The controller **70** senses signals S1 and S2 (at step **185**) and calculates S1–S2 (at step **200**) to identifying case 1 (at step **205**). The controller **70** also senses that the values of M3 and the boom_up lever flag are 'neutral' and 1, respectively (at step **210**), thus generating the control signal (at step **215**). The processes described in FIGS. **7-9** may repeat until the operator positions the on/off switch in the off position (at step **105**), thereby disabling the operation of the control system **31**.

Thus, the invention provides, among other things, a control system **31** coupled to a hydraulic system **28** operable to help predict and prevent boom oscillations. Various features of the embodiments are set forth in the following claims.

What is claimed is:

1. A working apparatus comprising:

a first source configured to provide pressurized hydraulic fluid;

an operator control unit;

a boom arm;

a boom cylinder configured to be coupled to the boom arm, the cylinder having a first chamber and a second chamber;

a main control valve configured to direct the pressurized hydraulic fluid from the first source to the first and second chambers in response to manipulation of the operator control unit to selectively raise and lower the arm;

a first pressure sensor and a second pressure sensor operable to detect hydraulic pressure in the first and second chambers, respectively, and generate a signal in reference to the amount of hydraulic pressure in the first and second chambers, respectively;

a controller valve operable in a parallel configuration with the operator control unit to override the operation of the control unit and manipulate the main control valve; and

a controller operable to receive the signals from the pressure sensors, process the signals to predict boom oscillations, and control the controller valve to operate the main control valve and help prevent the predicted boom oscillations.

2. The working apparatus of claim **1**, further comprising a second source configured to provide pressurized hydraulic fluid, and operable to communicate with the main control valve; the controller valve operable to communicate the second source and the main control valve; wherein the main control valve is operable to operate under the influence of the second source to direct hydraulic fluid from the first source into one of the first and second chambers.

3. The working apparatus of claim **2**, wherein the operator control unit is operable to control the delivery of hydraulic fluid from the second source to the main control valve to control operation of the main control valve.

4. The working apparatus of claim **3**, further comprising a control pressure sensor operable to detect pressure of hydraulic fluid between the second source and the main control valve, and to send a signal to the controller indicative of the sensed pressure.

5. The working apparatus of claim **4**, wherein the controller is operable to receive the signal from the control pressure sensor, process the signal to predict boom oscillations, and send a control signal to the controller valve; and wherein the controller valve is operable to override the operator control unit and manipulate the main control valve to help prevent the predicted boom oscillations in response to receiving the control signal.

6. The working apparatus of claim **1**, wherein the operator control unit includes a joystick unit; and the main control valve is operable to direct hydraulic fluid from the first source into one of the first and second chambers in response to manipulation of the joystick.

7. The working apparatus of claim **6**, further comprising a sensor operable to detect a signal between the joystick and the main control valve, and send the signal to the controller indicative of the joystick controlling the main control valve; and wherein the controller is operable to receive the signals from the sensors, process the signals to predict boom oscillations, and override the joystick to manipulate the main control valve and help prevent the predicted boom oscillations.

8. A working apparatus comprising:

a first source of pressurized hydraulic fluid;

an operator control unit;

a boom arm;

a boom cylinder coupled to the boom arm, the cylinder having a first chamber and a second chamber;

a main control valve selectively directing pressurized hydraulic fluid from the first source to the first and second chambers in response to manipulation of the operator control unit to selectively raise and lower the arm;

a first pressure sensor and a second pressure sensor detecting hydraulic pressure in the first and second chambers, respectively, and generating signals in reference to the amount of hydraulic pressure in the first and second chambers, respectively;

a controller receiving the signals from the pressure sensors, processing the signals to monitor operation of the cylinder and arm, and generating a control signal when the signals are indicative of impending boom oscillations; and

a controller valve overriding the operator control unit and manipulating the main control valve to help prevent boom oscillations in response to receiving the control signal.

9. The working apparatus of claim **8**, further comprising a second source of pressurized hydraulic fluid communicating with the main control valve; wherein the operator control unit controls the delivery of hydraulic fluid from the second source to the main control valve to direct hydraulic fluid from the first source into one of the first and second chambers; and wherein the controller valve communicates the second source and the main control valve and selectively overrides the operator control unit to manipulate the operation of the main control valve and help prevent boom oscillations in response to receiving the control signal.

10. The working apparatus of claim **9**, further comprising a control pressure sensor detecting hydraulic pressure between the operator control unit and the main control valve and sending signals to the controller in reference to the sensed pressure.

11. The working apparatus of claim **8**, wherein the operator control unit includes a joystick unit; and wherein the main control valve selectively directs hydraulic fluid from the first source into one of the first and second chambers in response to manipulation of the joystick.

12. The working apparatus of claim **11**, further comprising a sensor operable to detect signals between the joystick and the main control valve, and sending signals to the controller in reference to the joystick controlling the main control valve; and wherein the controller receives the signals from the sensors, process the signals to monitor the operation of the cylinder and arm, and overrides the operation of the joystick to manipulate the main control valve and help prevent boom oscillations in response to receiving the control signal.

13. A method for inhibiting boom oscillations in a working apparatus having a boom arm coupled to a boom cylinder having first and second chambers, a main control valve, and an operator control unit permitting an operator to manipulate the main control valve to direct hydraulic fluid into one of the first and second chambers to selectively raise and lower the arm, the method comprising:

(a) detecting pressure of hydraulic fluid in the first and second chambers of the boom cylinder;

(b) generating first and second signals indicative of the hydraulic pressure in the first and second chambers, respectively;

(c) comparing the first and second signals to parameters;

(d) predicting boom oscillations based on the comparison of step (c);

(e) generating a control signal in response to predicting boom oscillations; and

(f) overriding operation of the control unit to manipulate the main control valve and help prevent predicted boom oscillations in response to creating the control signal.

14. The method of claim **13**, further comprising: (g) detecting pressure of hydraulic fluid between the operator control unit and the main control valve; (h) generating a third signal indicative of the detected pressure in step (g); and (i) comparing the third signal to another parameter; wherein step (d) includes predicting boom oscillations based on the comparison of step (c) and based on the comparison of step (i).

15. The method of claim **13**, wherein step (a) includes attaching a first chamber sensor and a second chamber sensor to the first and second chambers, respectively, to generate the first and second signals.

16. The method of claim **15**, the working apparatus including a controller; wherein step (c) includes using the controller to compare the first and second signals to parameters; wherein step (d) includes using the controller to predict boom oscillations based on the comparison of step (c); and wherein step (e) includes using the controller to generate the control signal in response to predicting boom oscillations.

17. The method of claim **16**, the working apparatus including a controller valve; wherein step (f) includes using the controller valve to override the operation of the control unit to manipulate the main control valve and help prevent predicted boom oscillations in response to receiving the control signal.

18. The method of claim **17**, the working apparatus including a control pressure sensor; wherein step (g) includes using the control sensor to detect hydraulic pressure between the operator control unit and the main control valve; wherein step (h) includes using the control sensor to generate the third signal in reference to the detected pressure; and wherein step (i) includes using the controller to compare the third signal to another parameter.

19. The method of claim **14**, further comprising: (j) presetting the parameters based on the type of working apparatus; and wherein step (c) includes comparing the first and second signals to the preset parameters.

20. The method of claim **19**, further comprising: (k) presetting the another parameter based on the type of working apparatus; and wherein step (i) includes comparing the third signal to the another preset parameter.

21. A control for a working apparatus having an arm; the control comprising:

a controller operable to receive at least one signal from a first pressure sensor that is operable to detect a pressure in a first chamber of a boom cylinder, and at least one signal from a second pressure sensor that is operable to detect a pressure in a second chamber of the boom cylinder;

wherein the controller is operable to process the at least one signal from each of the first and second sensors, and to control a controller valve coupled in a parallel configuration to an operator control unit to help prevent oscillations of the arm.

22. The control of claim **21**, wherein the controller is operable to compare the at least one signal from the first pressure sensor to the at least one signal from the second pressure sensor.

23. The control of claim **22**, wherein the controller is operable to generate a control signal when the difference of the value of the at least one signal from the first pressure sensor and the value of the at least one signal from the second pressure sensor is less than a first parameter.

24. The control of claim **22**, wherein the controller is operable to generate a control signal when the difference of the value of the at least one signal from the first pressure sensor and the value of the at least one signal from the second pressure sensor is greater than a second parameter.

25. The control of claim **21**, wherein the controller is operable to receive at least one signal from a third pressure sensor configured to detect an operating condition of the operator control unit.

26. The control of claim **25**, wherein the controller is operable to generate the control signal when the value of the at least one signal from the third pressure sensor is similar to a third parameter, and when the difference of the value of the at least one signal from the first pressure sensor and the value of the at least one signal from the second pressure sensor is less than a first parameter.

27. The control of claim **26**, wherein the controller is operable to generate the control signal when the value of the at least one signal from the third pressure sensor is similar to a fourth parameter, and when the difference of the value of the at least one signal from the first pressure sensor and the value of the at least one signal from the second pressure sensor is greater than a second parameter.

28. A method for inhibiting arm oscillations in an apparatus having an arm, the method comprising:

generating a first signal indicative of pressure in a first chamber;

generating a second signal indicative of pressure in a second chamber;

comparing the first signal to the second signal;

predicting arm oscillations based on the comparison of the first signal to the second signal; and

generating a control signal to override an operator control unit operable to control the arm in response to predicting the arm oscillations.

29. The method of claim **28**, wherein comparing the first and second signals includes subtracting the value of the first signal from the value of the second signal.

30. The method of claim **28**, wherein predicting arm oscillations includes at least one of predicting the arm oscillations when the difference of the value of the first signal and value of the second signal is less than the first parameter; and predicting the arm oscillations when the difference of the value of the first signal and the value of the second signal is greater than the second parameter.

31. The method of claim **28**, further comprising generating a third signal indicative of an operating condition of the operator control unit; and predicting the arm oscillations is further based on the operating condition of the arm.

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