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(54) **SERVO-PNEUMATIC ACTUATOR**

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**Related U.S. Application Data**

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(51) **Int. Cl.**
*F15B 15/20* (2006.01)
*F15B 13/04* (2006.01)

(52) **U.S. Cl.** .......................................... **91/392**; 91/466

(58) **Field of Classification Search** ............... 91/363 R, 91/392, 466
See application file for complete search history.

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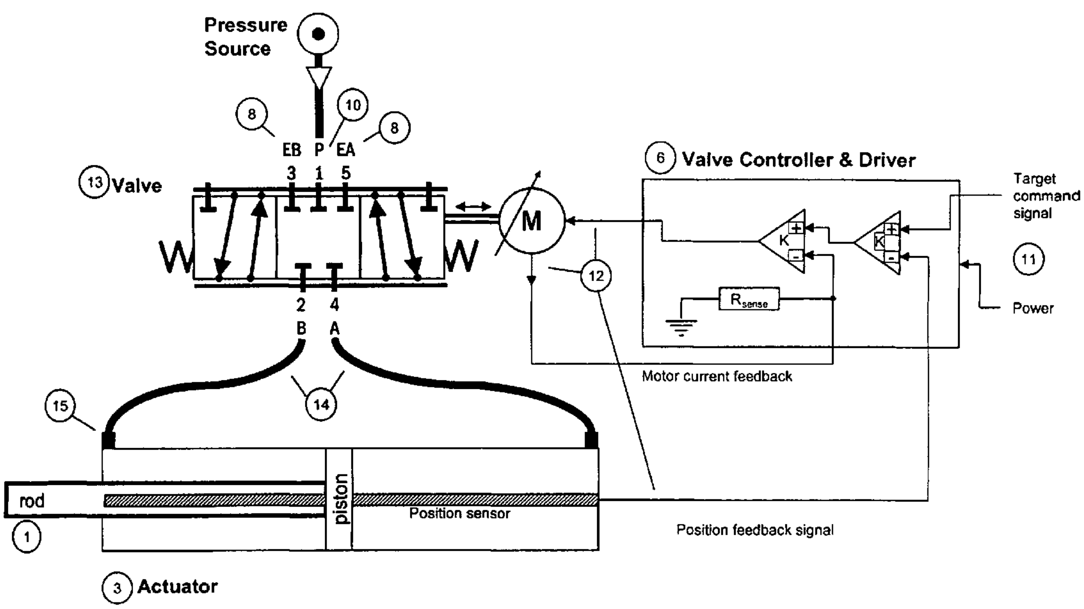
(57) **ABSTRACT**

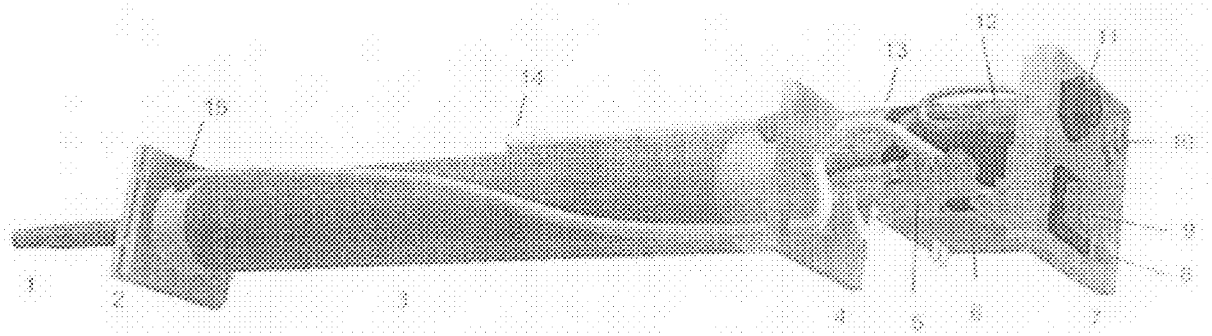
A positioning system includes an actuator, valve (preferably pneumatic), position sensor and an electronic valve controller, integrated in a single unit. Continuously variable set-points are possible within the range of operation. A preferred control circuit includes a signal converter, a ramp generator to smooth the shape of the command or target value signal applied, a position feedback sensor to report the actual position of the actuator, a controller, and a driver, containing an H-bridge, for controlling the pneumatic valve which feeds air into the actuator mechanism. Integration of all these components into a single unit shortens signal paths, improves resistance to electrical noise, and permits faster response time.

**4 Claims, 7 Drawing Sheets**




Notes:
Numbers in circles map to graphical depiction, not all elements depicted on this functional schematic
Valve, actuator, and plumbing follow ISO fluid power diagram conventions
Controller, driver, and wiring follow commonly accepted simplified circuit diagram conventions
Circuits in controller only show key primary functions; see detailed circuit diagrams

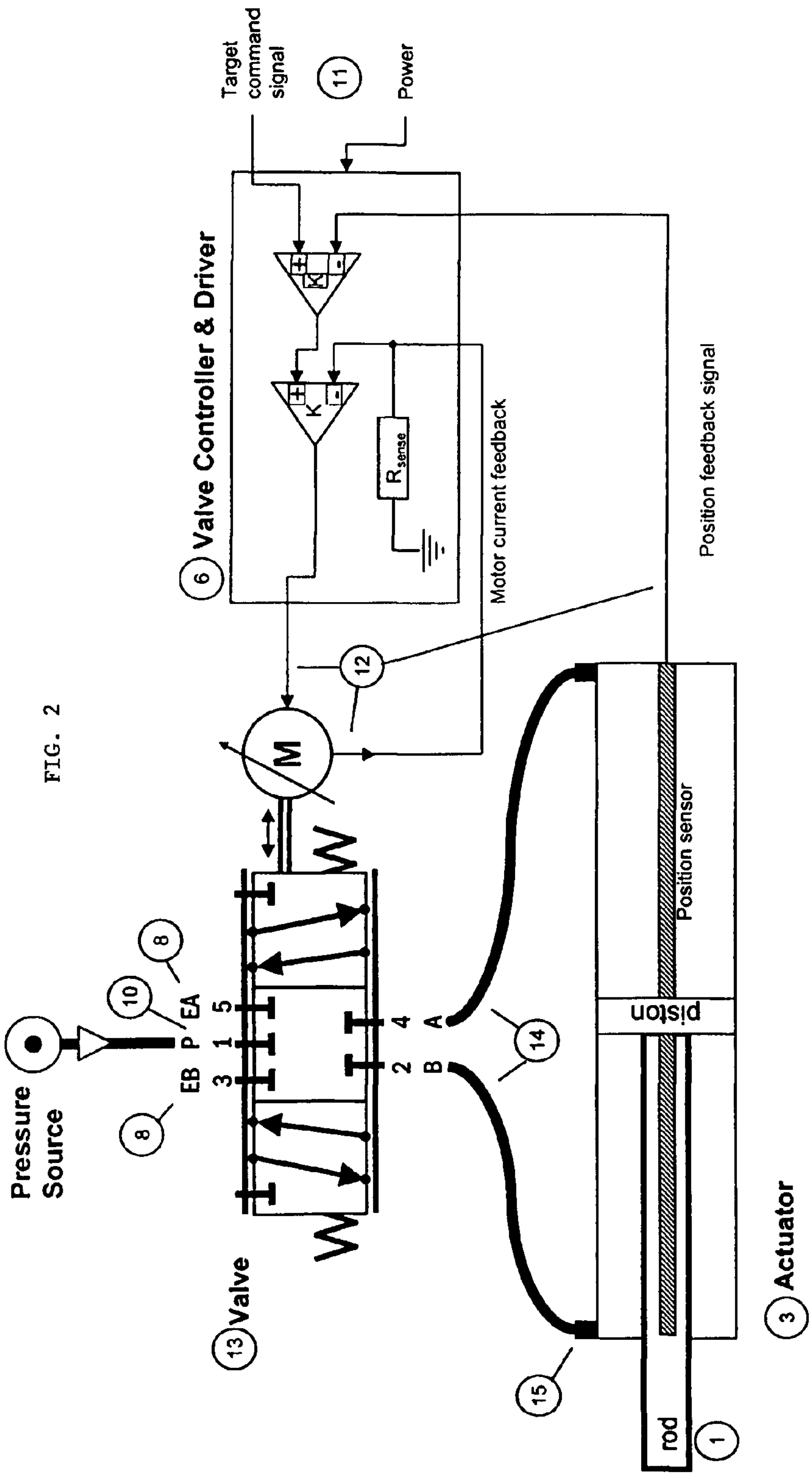
FIG. 1




16 (not shown) outer housing skin connecting caps (2, 7) and mid vertical mounting plate (4), with access panel to electronics (6)

| item | description |
|---|---|
| 1 | actuator rod |
| 2 | front cap |
| 3 | actuator air cylinder (containing piston, rod, internal position feedback sensor) |
| 4 | mid vertical mounting plate |
| 5 | mid horizontal mounting plate (for electronics and valve) |
| 6 | controller and driver electronics |
| 7 | back cap |
| 8 | compressed air exhaust port (shown with muffler) |
| 9 | power switch |
| 10 | compressed air input port (shown with quick connect fitting) |
| 11 | power and signal interface connector |
| 12 | wiring harness to electronics and position sensor |
| 13 | 5 port, 4 way electrically actuated directional control valve |
| 14 | air tubing (flexible tubing shown) |
| 15 | port fitting (barbed fitting shown on front actuator port, also used on valve ports) |
| 16 | outer housing skin (not shown) |

FIG. 2




Notes:
Numbers in circles map to graphical depiction, not all elements depicted on this functional schematic
Valve, actuator, and plumbing follow ISO fluid power diagram conventions
Controller, driver, and wiring follow commonly accepted simplified circuit diagram conventions
Circuits in controller only show key primary functions; see detailed circuit diagrams

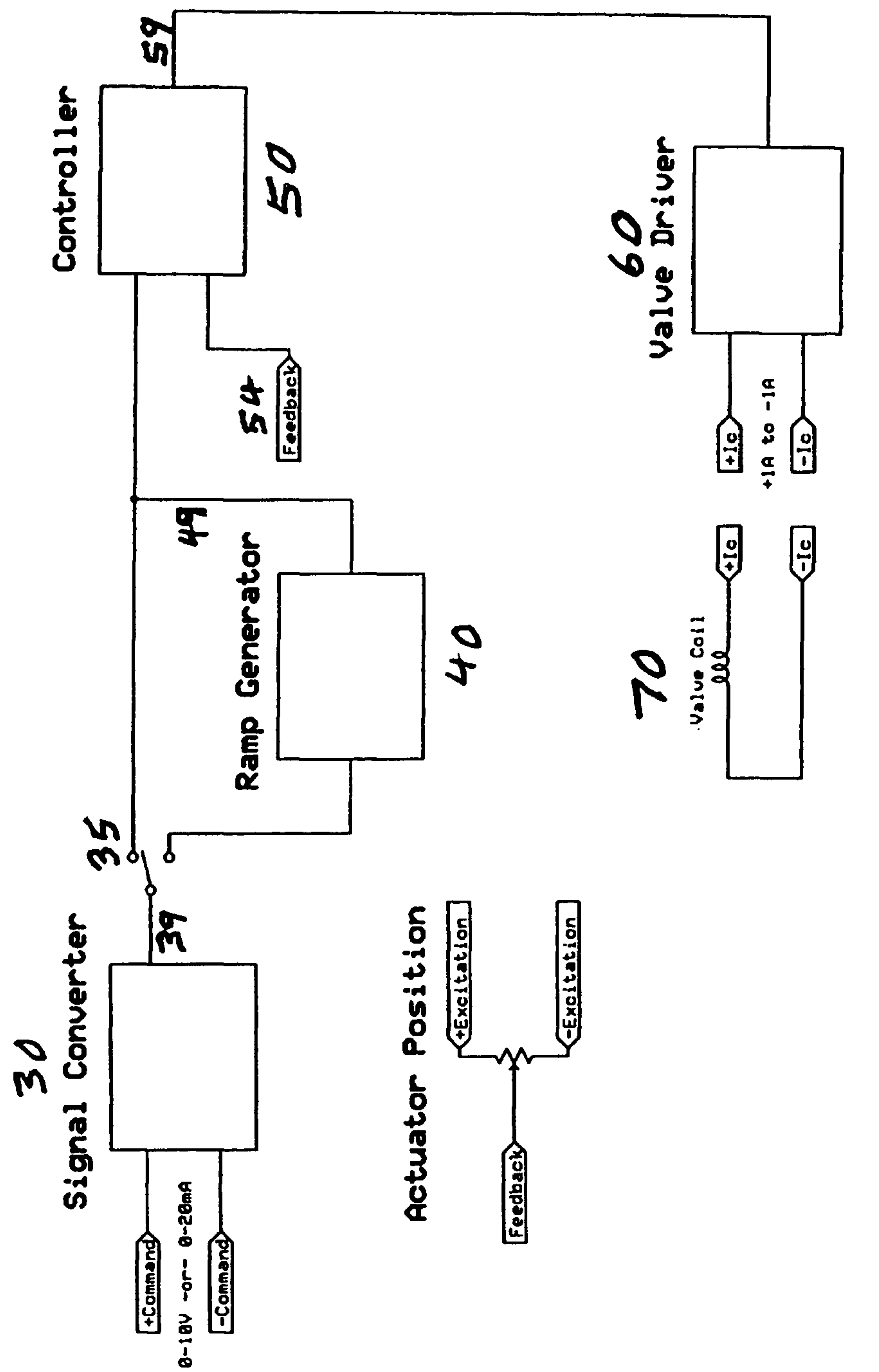

Controller
50
59
54
Feedback
Ramp Generator
40
49
35
39
30
Signal Converter
+Command
0-10V -or- 0-20mA
-Command
Actuator Position
+Excitation
-Excitation
Feedback
60
Valve Driver
+Ic
+1A to -1A
-Ic
70
Valve Coil
+Ic
-Ic

FIG.3

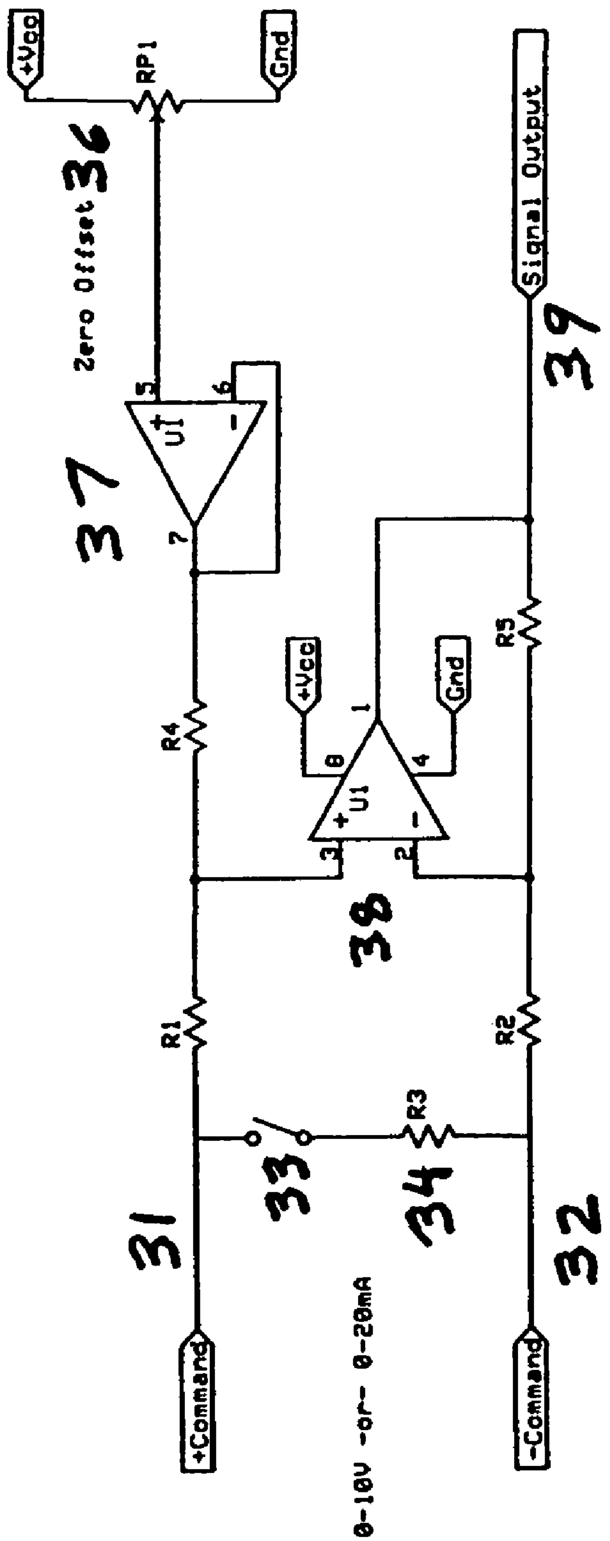

+Vcc
RP1
Gnd
Zero Offset
36
Signal Output
39
37
U1
5
6
7
R4
+Vcc
Gnd
8
4
1
R5
38
3
2
R1
R2
R3
31
33
34
32
+Command
-Command
0-10V -or- 0-20mA

FIG. 4

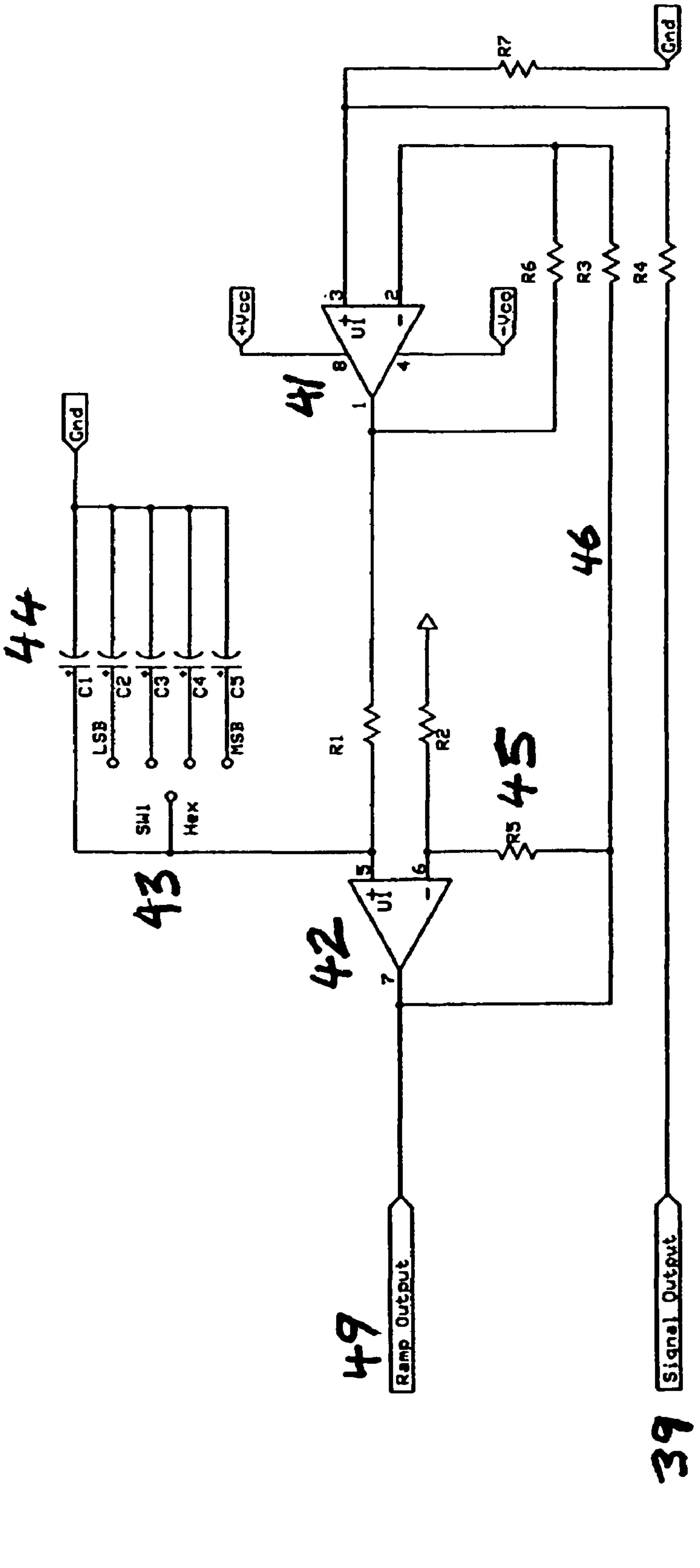

Gnd
R7
R6
R3
R4
+Vcc
-Vcc
U1
41
44
C1
C2
C3
C4
C5
LSB
MSB
SW1
Hex
43
R1
R2
R5
45
46
42
49
Ramp Output
Signal Output
39

FIG. 5

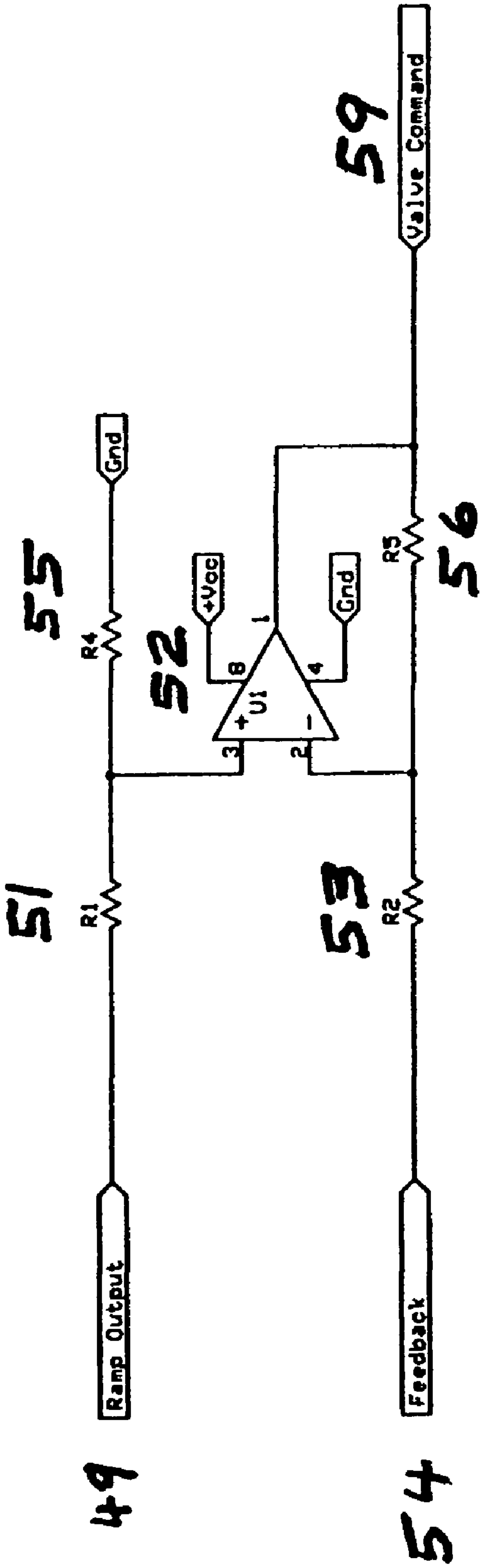

49
Ramp Output
54
Feedback
51
R1
53
R2
52
U1
55
R4
56
R5
Gnd
+Vcc
Gnd
59
Valve Command

FIG. 6

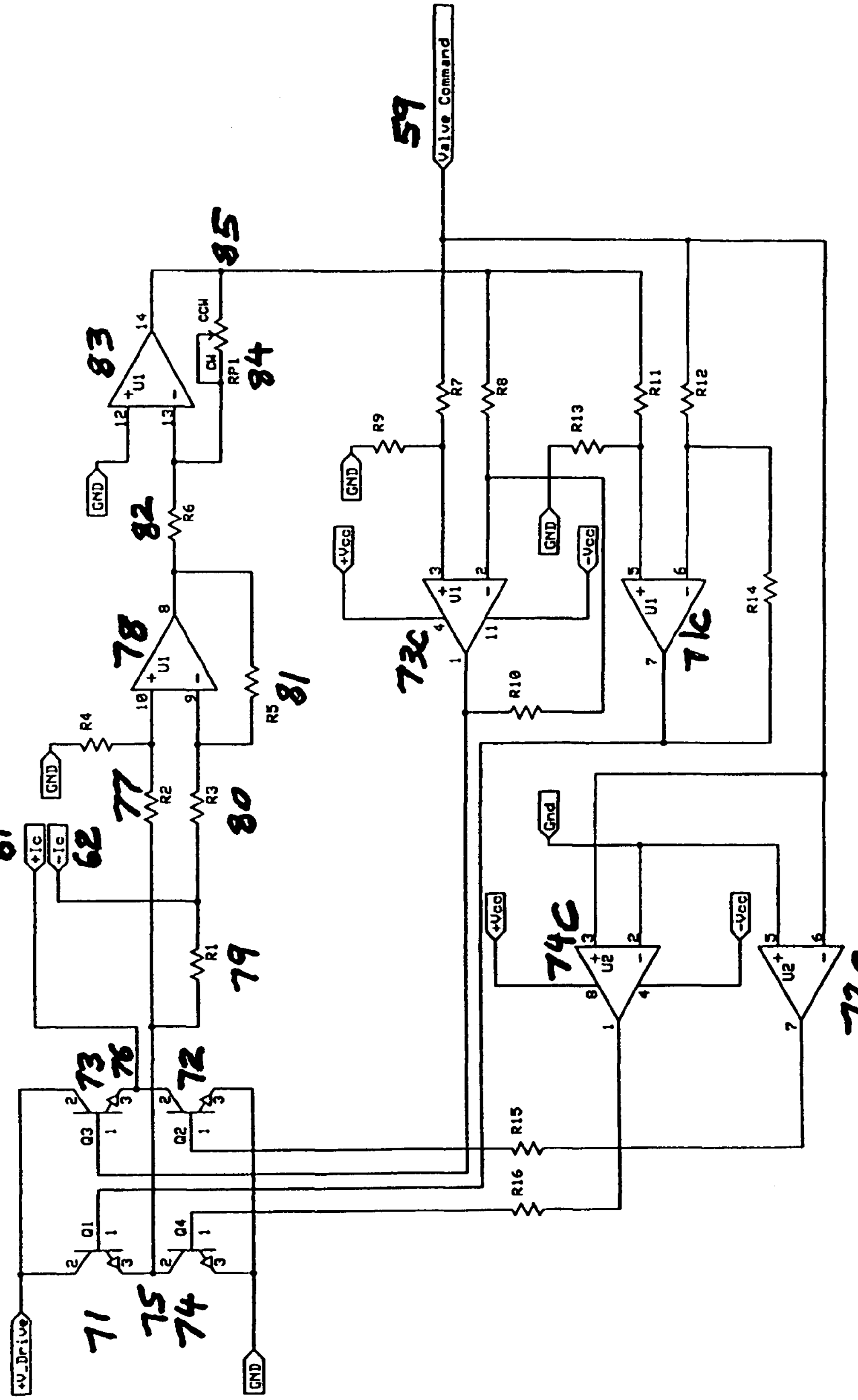

Valve Command
59
85
83
84
RP1
CCW
CW
82
R6
78
81
R5
77
80
R2
R3
R4
R1
79
61
62
+Ic
-Ic
GND
+Vcc
-Vcc
Gnd
73c
71c
74C
72c
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
73
76
72
71
75
74
Q1
Q2
Q3
Q4
+V_Drive

FIG. 7

# SERVO-PNEUMATIC ACTUATOR

## CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit under 35 U.S.C. §119 (e) of provisional application Ser. No. 60/603,453, filed Aug. 20, 2004, the entire content of which is hereby incorporated by reference.

## FIELD OF THE INVENTION

The present invention relates generally to positioning systems and, more particularly, to a pneumatic control valve, for driving an actuator mechanism, which has an electronic feedback control closely integrated with the control valve. We call such a device an "integrated actuator."

## BACKGROUND

There are several so-called "integrated actuators" which contain the elements of a valve, fluid power cylinder, and even a sensor, but these prior art products are not in fact fully integrated. Examples include products offered by Enfield Technologies, assignee of the present invention, as well as those from other vendors such as Norgren or Allen Air.

There are also examples of vendors that provide some or all of these elements as individual items or in various forms of sub-assembly which can be assembled as a construction of separate components, but none are unified into a single product and offered as such. Examples include Bimba, Dyval (Parker Hannifin), Festo, Hoerbiger-Origa, and Si-Plan Electronics, Ltd., as well as in research laboratories such as at Vanderbilt, UC Berkeley, and McMaster to name a few academic institutions who have constructed such systems.

However, none provide for fully integrated on-board closed-loop signal processing and control. The commercial need for such a fully integrated product has not been recognized by others working in the art, and the technical challenges to constructing such a device have been formidable. The present invention has overcome these technical challenges.

Industry standard practice has been to configure systems with control systems and power drivers physically separate from actuators. This holds true for both fluid power (hydraulic and pneumatic) systems as well as electromechanical systems (such as linear motors and rotary motor/leadscrew drives).

The challenges have included: the number of valve and valve control devices required to create such a system, and coordination of those devices, control electronics small enough to be placed on-board the actuator itself, and schemes to provide command signals without degradation.

## SUMMARY OF THE INVENTION

Accordingly, we have invented a fully integrated position, pressure (including vacuum), or force control system, allowing continuously variable set-points within the respective range of operation, containing the following key performance elements (components or sub-systems):

- a fluid power actuator (pneumatic or hydraulic; linear or rotary),
- actuator sensors (position, pressure, and/or force),
- a fluid power valve (pneumatic or hydraulic; standard or proportional),
- valve controller electronics (integrated driver/controller),
- internal wiring and plumbing for valve, actuator, controller, and sensors,
- encased as a single unit with interfaces for fluid media source (compressed air or pressurized hydraulic fluid), command signals (position, pressure, and/or force set points), and human interfaces (switches and indicators).



## ADVANTAGES OVER THE PRIOR ART

We have recognized the need for such a fully integrated product, and have overcome the challenges to construction of such a device. Additional advantages of such a fully integrated system include: ease of specification and application design, simplified installation and maintenance procedures, and unified components protected from damage and environment.

Advantages of the pneumatic system of the present invention, compared with prior art hydraulic systems include; the use of clean, more readily available and familiar compressed air, and size and weight. Advantages with respect to electric motor systems specifically include the ability to achieve higher forces for equivalent physically sized systems.

## BRIEF FIGURE DESCRIPTION

FIG. **1** is a perspective view of an integrated pneumatic valve, actuator, and valve controller according to the invention;

FIG. **2** is a simplified schematic diagram illustrating the principal elements of the integrated device of FIG. **1**;

FIG. **3** is a block diagram showing elements of a control circuit for use in the invention;

FIG. **4** is a more detailed diagram of the input signal converter or conditioner of FIG. **3**;

FIG. **5** is a more detailed diagram of the ramp generator of FIG. **3**;

FIG. **6** is a more detailed diagram of the convergence controller of FIG. **3**; and

FIG. **7** is a more detailed diagram of the valve driver of FIG. **3**.

## DETAILED DESCRIPTION

FIG. **1** shows a preferred embodiment of an integrated pneumatic valve, actuator, and valve controller according to the present invention. A primary application for such a device is to position some object (not shown) which is coupled to a free end of an actuator rod **1**. In FIG. **1**, the free end is shown at left. A right end of rod **1** is coupled to a piston (not visible in this view) in a conventional manner.

Actuator rod **1** is essentially cylindrical, and slides in and out of an actuator air cylinder **3**, which preferably is also a cylinder, having a larger diameter than rod **1**. A feedback sensor inside actuator cylinder **3** reports the position of rod **1** to a valve controller **6** which controls a pneumatic valve **13** to modify air pressure within cylinder **3**, in order to adjust the linear position of rod **1** with respect to cylinder **3**. There is an annular air space inside cylinder **3** between a front cap **2**, near the free end of rod **1**, and a mounting plate **4** which is essentially perpendicular to a major axis of cylinder **3**.

Pneumatic valve **13** can supply air pressure to a right end of cylinder **3**, for example via a port in plate **4**, to cause rod **1** to extend, and can supply air pressure to a left or front end of cylinder **3**, to the left of the piston, for example via tubing to a port **15** adjacent front cap **2**, to cause rod **1** to retract.

A back cap **7** is arranged essentially parallel to front cap **2** and mounting plate **4**, with pneumatic valve **13** and its valve controller **6** arranged between mounting plate **4** and back cap **7**. For example, a horizontal mounting plate **5**, supported between back cap **7** and mounting plate **4**, can support the valve and valve controller. A wiring harness **12** provides electrical connections between the position sensor, valve **13**, valve controller **6**, and other elements. Back cap **7** can be equipped with an electrical power switch **9**, a compressed air input port **10**, and a compressed air exhaust port **8**, preferably having a muffler to reduce noise.

The general principle of positioning servo-mechanisms, namely providing a target or command value of position of an actuator, sensing an actual value of actuator position, and attempting to drive the actuator until the actual value matches the target value, is well known in both the pneumatic arts and other branches of engineering. Various types of position sensors are likewise well known, as are the advantages/disadvantages of particular sensor types for particular engineering applications. Historically, one problem with pneumatic positioning servo-mechanisms has been that locating electrical controllers at a distance from the valve and/or from the position sensor(s) renders the signal paths between the elements vulnerable to amplitude drops, electrical noise, and transmission delay. Therefore, the present invention shortens the signal paths by integrating the control electronics with the valve and actuator.

FIG. **3** illustrates a preferred control circuit. A target or command value signal, in the form of a voltage value in the range 0-10 volts or a current value in the range 0-20 milliAmps, is applied to a signal converter **30**. An actual actuator position feedback signal is received from a position sensor. The output signal from signal converter **30** is fed, depending upon the setting of a switch **35**, either directly to one input of a controller **50**, or via a ramp generator **40** to controller **50**. Use of a ramp generator as part of the invention is optional, but is preferred because it changes an abrupt "steplike" variation in the target value signal to a sloped or more gradual signal pattern, permitting smoother movement of the valve and actuator elements.

Controller **50** compares the feedback or actual actuator position signal to the target or command signal, and generates an output signal which is applied to the input of valve driver circuit **60**. Valve driver circuit **60** has two terminals +Ic and −Ic which are coupled to respective terminals of a voice coil inside pneumatic valve **13**. Valve **13** is preferably a spool-and-sleeve valve, structured as disclosed in BORCEA et al. U.S. Pat. Nos. 5,460,201 and 5,960,831, the disclosures of which are hereby incorporated by reference. A preferred embodiment is a 5-port, 4-way electrically actuated directional control valve.

FIG. **4** is a more detailed diagram of signal converter **30**. A positive command signal comes in on line **31** and a negative command signal comes in on line **32**. These lines can be connected via a resistor **34** by closing a switch **33**. An output from a variable resistor **36** is applied to a positive input terminal of a first op-amp **37**, whose output is coupled back to its negative input. This serves to pull up the voltage on positive line **31** to a minimum value set at **36**. The output of first op-amp **37** is coupled to the positive input of a second op-amp **38**, whose negative input is coupled via a resistor to input signal **32**. The output of second op-amp **38** constitutes the signal output **39** of signal converter **30**.

FIG. **5** is a more detailed diagram of ramp generator **40**. At lower left, signal **39** from converter **30** comes in, and is applied to the positive input terminal of a third op-amp **41**, whose output is applied to the positive input terminal of a fourth op-amp **42**. The negative input terminal of third op-amp **41** is also connected back via a resistor to its output. The output of fourth op-amp **42** is also coupled via a different resistor to the negative input of third op-amp **41**. The positive input terminal of fourth op-amp **42** is also coupled via a switch **43** to a bank of parallel-arranged capacitors **44**, whose other terminal is grounded. The function of the capacitor(s) is to charge up in response to a sudden rise in output voltage from op-amp **41** or to discharge in response to a sudden drop in output voltage from op-amp **41**, thereby turning a "step-like" voltage change into a "ramped" voltage change, as previously described, and softening the abruptness of actuator rod motion. The slope of the ramp depends upon which capacitance is selected by switch **43**. The negative input terminal of fourth op-amp **42** is connected via a resistor **45** to the line **46** connecting the output of **42** back to the negative input of op-amp **41**. The output of fourth op-amp **42** constitutes the ramp output **49** which is then applied to the "target value" input of controller **50**.

FIG. **6** is a more detailed diagram of controller **50**. Ramp output signal **49** comes in at top left and is applied, via a resistor **51** to the positive input of a fifth op-amp **52**, whose negative input is coupled via a resistor **53** to actual actuator position feedback signal **54**. The positive input of op-amp **52** is also connected via a resistor **55** to ground. The output of op-amp **52** is coupled back via a resistor **56** to its negative input. The output signal from op-amp **52** constitutes the controller output signal **59** which is applied to the input of valve driver **60**.

FIG. **7** is a more detailed diagram of the valve driver **60**, which includes an H-bridge circuit for controlling the driving current applied to first and second terminals **61** and **62** of a voice coil inside control valve **13**. The H-bridge consists of four transistors **71**-**74**, each of whose gates is controlled by the output of a respective op-amp **71**C, **72**C, **73**C, **74**C. Only two of the transistors conduct at a given time. When transistors **71** and **72** are conductive, current flows from V+ via transistor **71** and node **75** to into voice coil terminal **62**, out voice coil terminal **61** and back via node **76** and transistor **72** to ground. This is one direction of current flow. For current flow through the voice coil in the opposite direction, transistors **73** and **74** must conduct. Then, current flows from V+ via transistor **73** and node **76** into voice coil terminal **61**, and back out from terminal **62** via node **75** and transistor **74** to ground.

The lower half of FIG. **7** shows the control of the H-bridge transistors. Controller output signal **59** is applied to the positive inputs of op-amps **73**C and **74**C and to the negative inputs of op-amps **71**C and **72**C. A signal from node **75** is applied via a resistor **77** to the positive input of a sixth op-amp **78** and via resistors **79** and **80** of the negative input of op-amp **78**. Resistor **79** is in the path between node **75** and terminal **62**, while resistor **80** is in the path between terminal **62** and op-amp **78**. The output of op-amp **78** is coupled via a resistor **81** back to its negative input. The output of op-amp **78** is also coupled via a resistor **82** to the negative input of a seventh op-amp **83**, whose positive input is grounded. Op-amp **83** is connected in parallel with a variable resistor **84**. The output terminal of op-amp **83** and one terminal of variable resistor **84** are connected to a node **85**. The voltage at node **85** is connected to the positive input of op-amp **71**C and to the negative input of op-amp **73**C. Thus, when the voltage at node **85** goes high, op-amp **71**C turns on transistor **71** and op-amp **73**C turns off transistor **73**. Conversely, when the voltage at node **85** goes low, op-amp **71**C turns off transistor **71** and op-amp **73**C turns on transistor **73**. The positive input of op-amp **72**C and the negative input of op-amp **74**C are connected to ground. In this manner, the value of output signal **59** of controller **50** determines whether current is applied to the voice coil terminals **61**, **62** and in which direction.

Various changes and modifications are possible within the scope of the inventive concept. For example, a hydraulic valve, rather than a pneumatic valve, could be used. Further, a rodless cylinder, rather than a single rod cylinder, could be used. Therefore, the invention is not limited to the specific embodiments shown and described, but rather is defined by the following claims.

What is claimed is:

**1**. An integrated electronically actuated fluid power actuator, comprising:

a movable actuator portion (**1**);

a stationary actuator portion (**3**) arranged adjacent said movable portion and adapted to receive (**14**, **15**) a fluid for moving said movable portion (**1**)

means for sensing a position of said movable portion (**1**) with respect to said stationary portion (**3**);

a pneumatic fluid power valve (**13**) adapted to supply at least one fluid to said stationary actuator portion (**3**);

a valve controller (**6**) containing means (**50**) for comparing a target position for said movable actuator portion with an actual position, as detected by said sensing means,

means for generating a sequence of command signals to said fluid power valve, to thereby supply fluid through said valve (**13**) to said stationary actuator portion (**3**), to bring said movable actuator portion (**1**) to said target position,

a signal converter (**30**), and

a valve driver (**60**),

wherein the valve driver includes an H-bridge circuit (**71**-**74**) and the valve includes a voice coil.

**2**. The integrated actuator of claim **1**, further comprising

a ramp generator (**40**), connected between said signal converter (**30**) and said means for comparing (**50**), to smooth abrupt signal changes.

**3**. An integrated electronically actuated fluid power actuator, comprising:

a movable actuator portion (**1**);

a stationary actuator portion (**3**) arranged adjacent said movable portion and adapted to receive (**14**, **15**) a fluid for moving said movable portion (**1**);

means for sensing a position of said movable portion (**1**) with respect to said stationary portion (**3**);

a hydraulic fluid power valve (**13**) adapted to supply at least one fluid to said stationary actuator portion (**3**);

a valve controller (**6**) containing means (**50**) for comparing a target position for said movable actuator portion with an actual position, as detected by said sensing means,

means for generating a sequence of command signals to said fluid power valve, to thereby supply fluid through said valve (**13**) to said stationary actuator portion (**3**), to bring said movable actuator portion (**1**) to said target position,

a signal converter (**30**), and

a valve driver (**60**),

wherein the valve driver includes an H-bridge circuit (**71**-**74**) and the valve includes a voice coil.

**4**. The integrated actuator of claim **3**, further comprising

a ramp generator (**40**), connected between said signal converter (**30**) and said means for comparing (**50**), to smooth abrupt signal changes.

* * * * *