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Evans

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(54) **ANTI-RESONANCE MIXING FILTER**

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(51) **Int. Cl.**[7] **H02P 5/165**

(52) **U.S. Cl.** **388/814**; 318/586; 318/580; 318/561; 318/254; 318/138; 318/439; 388/806; 388/815

(58) **Field of Search** 318/586, 580, 318/561, 254, 138, 439; 388/806, 814, 815

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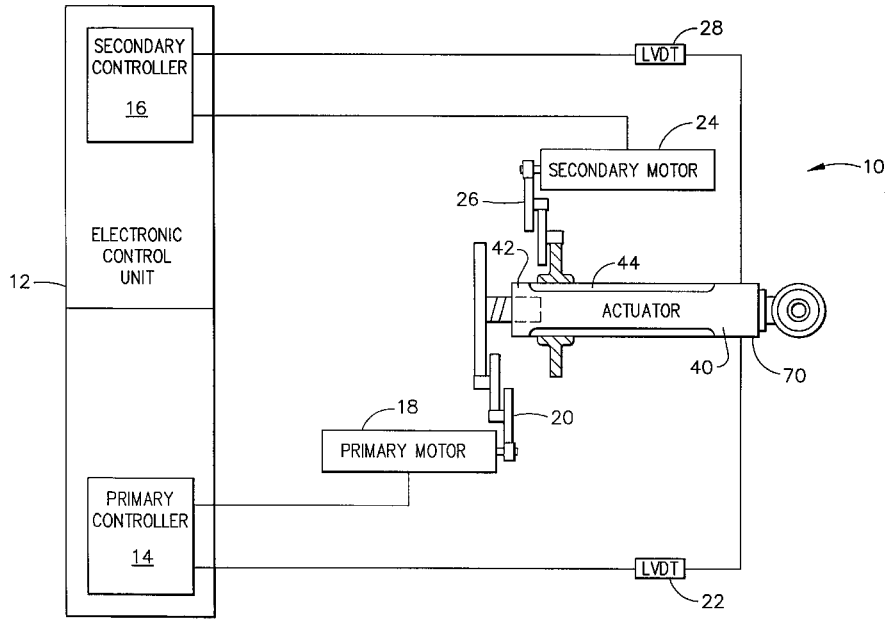
(57) **ABSTRACT**

In a closed loop control system that governs the movement of an actuator a filter is provided that attenuates the oscillations generated by the actuator when the actuator is at a resonant frequency. The filter is preferably coded into the control system and includes the following steps. Sensing the position of the actuator with an LVDT and sensing the motor position where motor drives the actuator through a gear train. When the actuator is at a resonant frequency, a lag is applied to the LVDT signal and then combined with the motor position signal to form a combined signal in which the oscillation generated by the actuator are attenuated. The control system then controls ion this combined signal. This arrangement prevents the amplified resonance present on the LVDT signal, from causing control instability, while retaining the steady state accuracy associated with the LVDT signal. It is also a characteristic of this arrangement that the signal attenuation will always coincide with the load resonance frequency of the system so that variations in the resonance frequency will not effectuate the effectiveness of the filter.

18 Claims, 2 Drawing Sheets



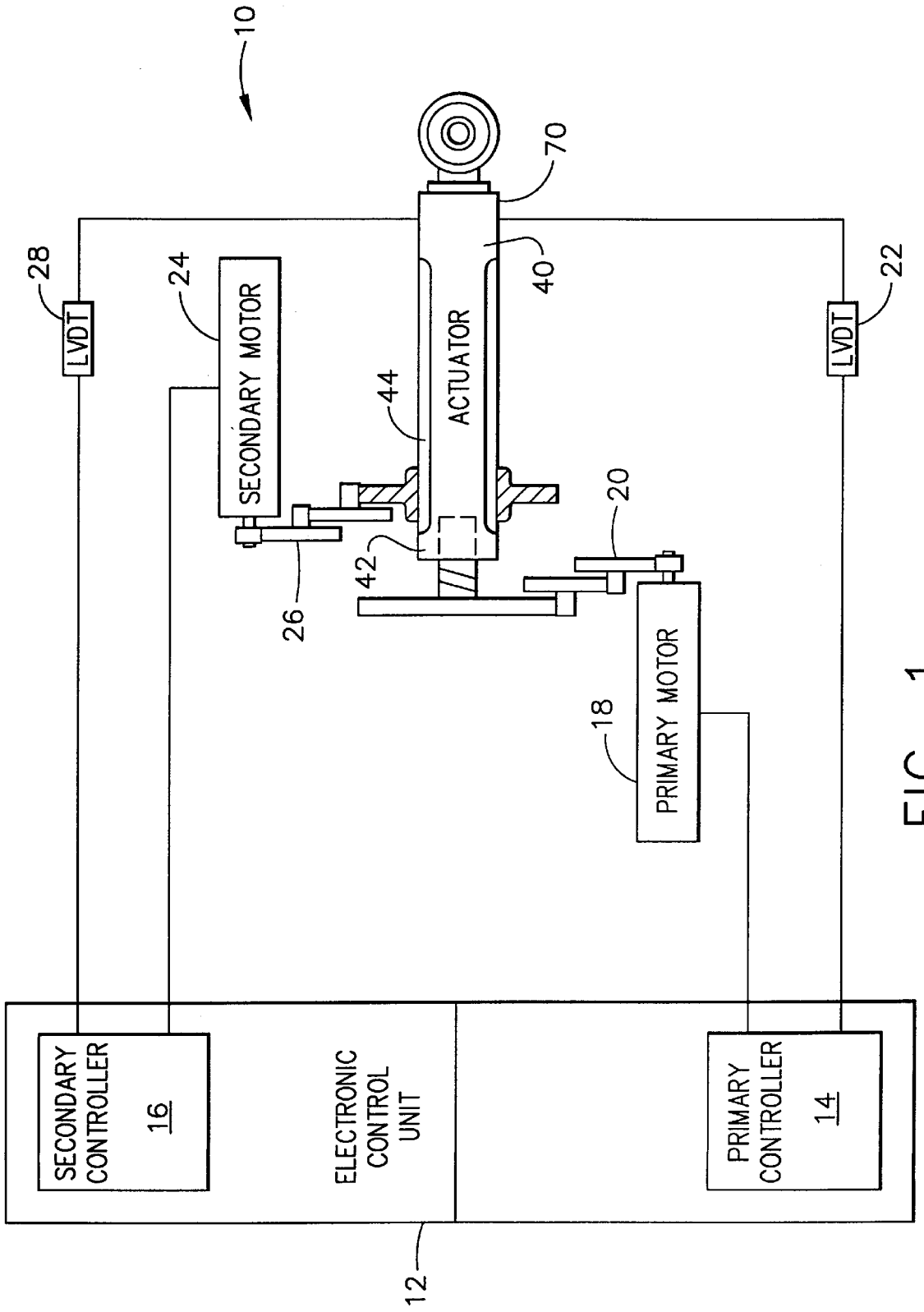

10
28
LVDT
24
SECONDARY MOTOR
26
44
42
ACTUATOR
70
40
20
PRIMARY MOTOR
18
22
LVDT
SECONDARY CONTROLLER
16
ELECTRONIC CONTROL UNIT
PRIMARY CONTROLLER
14
12

FIG. 1

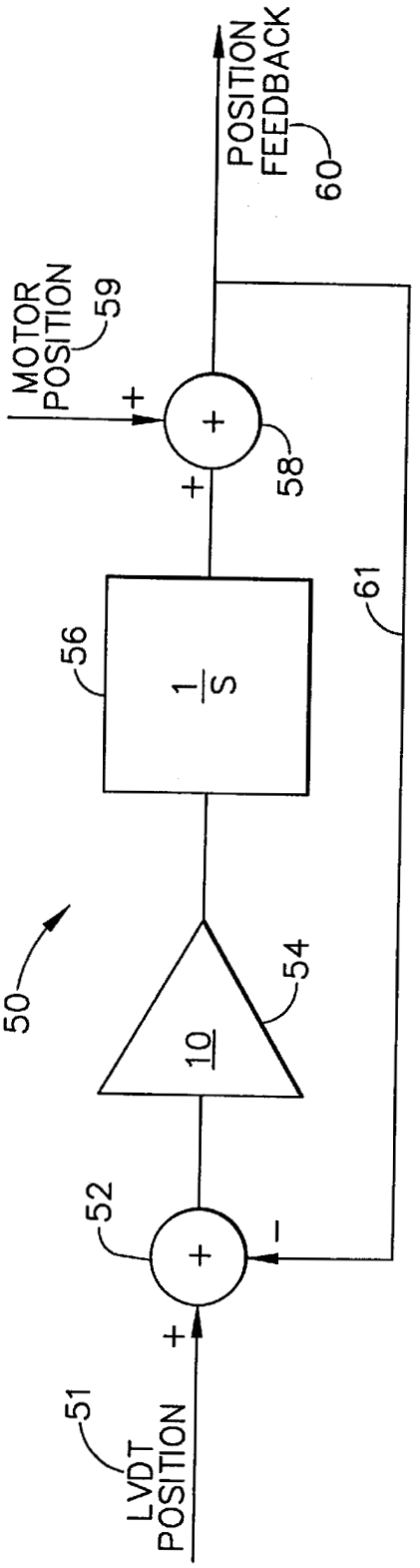

50
LVDT POSITION
51
52
10
54
56
1/S
58
MOTOR POSITION
59
POSITION FEEDBACK
60
61

FIG. 2

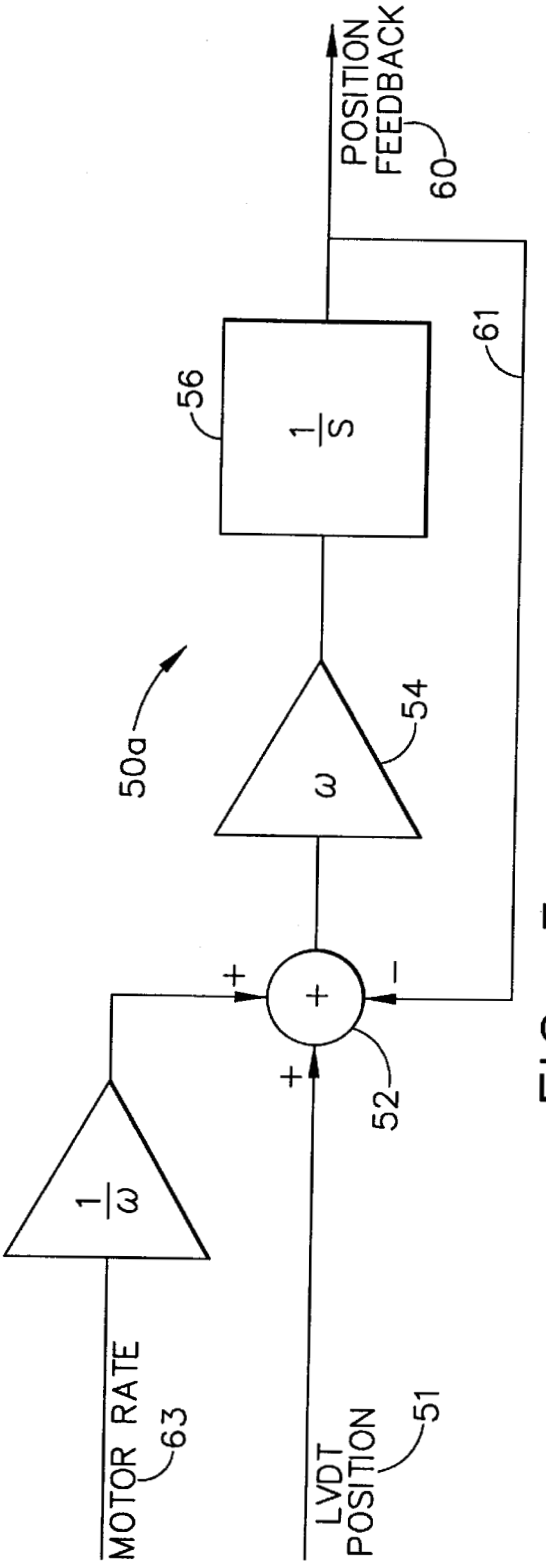

MOTOR RATE
63
LVDT POSITION
51
1/ω
52
ω
54
50a
56
1/S
POSITION FEEDBACK
60
61

FIG. 3

ANTI-RESONANCE MIXING FILTER

CROSS REFERENCE TO RELATED APPLICATION

Priority is claimed to provisional application serial No. 60/106,324, filed Oct. 30, 1998.

GOVERNMENT RIGHTS

The invention described herein was made in the performance of work under NASA Contract No. NCC8-115 and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958 (42 U.S.C. 2457).

TECHNICAL FIELD

The present invention relates a system and method for filtering feedback signals available in an electromechanical actuation system to mitigate the adverse effects of load resonance on position control loop stability.

BACKGROUND OF THE INVENTION

There are many components of an aircraft that are positioned by electromechanical or pneumatic-mechanical actuation systems. In these systems, an electric or pneumatic motor drives an actuator in response to signals from an electronic control unit. To assure that these aircraft components are accurately and correctly positioned, the control unit needs to know position of the actuator moving the component. To achieve this, highly accurate position sensors are used on the actuators to sense the position of the actuator and provide to the control unit a corresponding signal. One such sensor commonly used is a linear variable displacement transducer, (LVDT).

Because of compliance or resilience in the actuator and in the mounting of the actuator, the actuator will amplify displacement oscillations when operating at its natural or resonant frequency. These amplified oscillations are picked up by high accuracy position sensors like the LVDT. The LVDT feeds the oscillation through the control system and as a result can drive the control system unstable.

Accordingly, a need exists for a filtering system that isolates these oscillations from the control unit and thus allow the use of high accuracy sensors.

SUMMARY OF THE INVENTION

An object of this invention is to provide a filter that isolates oscillations that are amplified when operating at resonant frequencies.

The present invention achieves this object by providing anti-resonant mixing filter and method therefor that is incorporated into a closed loop control system that controls the movement of a structure that amplifies displacement oscillations when operating at a resonant frequency. The method comprises the steps of sensing a first parameter of the structure and generating a first signal thereof, the first parameter being sensitive to the oscillations and sensing a second parameter that is isolated from the oscillations and generating a second signal thereof, there being a known relationship between the first and second parameters. Applying a lag to the first signal and then combining the first and second signals to form a third signal in which the oscillations in the first signal are attenuated This third signal is then used by the control system so that amplified oscillations, at the resonant frequency, cannot feed through the controller to drive the system unstable. In the preferred embodiment, this method is coded into the control system.

These and other objects, features and advantages of the present invention are specifically set forth in or will become apparent from the following detailed description of a preferred embodiment of the invention when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic of an electromechanical actuator system employing an anti-resonance filter contemplated by the present invention.

FIG. **2** is a control schematic of the anti-resonance filter contemplated by the present invention.

FIG. **3** is a control schematic of an alternative embodiment of the anti-resonance filter contemplated by the present invention.

DESCRIPTION OF THE INVENTION

FIG. **1** shows an actuator system **10** having an dual drive actuator **40**. The operation of the system **10** is controlled by an electronic control unit **12** which has a primary controller **14** and a secondary controller **16**. When movement of a control surface to which the actuator **40** is attached is required, the primary controller **14** sends a signal to a primary electric motor **18** which in turn drives the primary gear train **20**. The primary gear train **20** is secured to a support structure, (not shown) and is also coupled to an inner tubular member **42** of the actuator **40**. A linear variable displacement transducer (LVDT) **22** measures the linear position of the output tube **70** of the actuator **40** and sends a signal indicative of such position to the primary controller **14**, thereby closing the control loop. When the required position of the control surface is reached as sensed by the LVDT, the primary controller **14** stops the movement of the actuator **40**. The combination of primary controller **14**, primary motor **18**, primary gear train **20** and actuator **40** define the primary load path.

In the event of a failure in the primary drive a secondary drive is provided. The secondary drive includes the secondary controller **16** which controls a secondary motor **24** which in turn drives a secondary gear train **26**. The secondary gear train **26**, like its counterpart, is secured to a support structure, (not shown). The gear train **26** is also coupled to a ball screw nut **44** of the dual drive actuator **40**. An LVDT **28** measures the linear position of the output tube **70** of the actuator and sends a signal indicative of such position to the secondary controller **16**, thereby closing the control loop. The secondary load path operates in the same control manner as the primary control path described above. When the primary load path is operating the secondary load path is locked.

Because the motors **18**, **24** are coupled by gear trains to the actuator **40**, there is a known, steady state relationship between the motor's rotational speed or position and the position of the output tube **70**. Specifically, in the preferred embodiment the motor position and the actuator position are related by a factor equal to the gear ratio of the particular gear train **20**, **26**. Also, because the apparent inertia of the motors reflected through the gear train is high, the motor position is not significantly affected by a mechanical resonance at the actuator output. The anti-resonance mixing filter contemplated by the present invention takes advantage of this known relationship.

Referring to FIG. **2**, the anti-resonance mixing filter is generally denoted by reference numeral **50** and resides in the controllers **14** and **16**. The filter **50** has a summer **52** which

receives the position signal **51** from one of the LVDTs **22** or **28**. From the summer **52** the position signal is sent to a gain **54** and then to first order lag integrator **56**. From the integrator **56** the signal flows to second summer **58**. At the summer **58** the signal from the integrator **56** is added to the position signal **59** from the motor to form a position feedback signal **60** which is used by the controller. The motor position signal **59** can be obtained from a motor's commutation signal or from a sensor such as a tachometer. A loop **61** brings the position feedback signal **60** back into summer **52** where it is subtracted from the LVDT position signal **51**.

Either both or one of the LVDT position signals **51** and the motor position signal **59** is scaled, in a manner familiar to those skilled in the art, so that their amplitudes are the same in the steady state condition. Thus in steady state condition the integrator **56** is idle because the signal entering the integrator is zeroed out at the summer **52**. However, when the LVDT position signal starts oscillating because the actuator **40** is operating at a resonant frequency, the LVDT position signal will no longer be zeroed out at the summer **52**. Instead it will be amplified in the gain **54** and then integrated in integrator **56**. The integrator **56** imparts a lag to the signal so that it is ninety degrees out of phase with the motor position signal **59** by the time it reaches the summer **58**. At summer **58** the position signal **59** cancels the oscillation signal driving the position feedback signal to zero. As a result the controller is isolated from these oscillations. Once the actuator is no longer at a resonant frequency, the oscillations subside and the anti-resonance mixing filter returns to a steady state operation.

FIG. **3** shows an alternative embodiment **50***a* where a motor rate signal **63** is used in place of motor position signal **59**. The motor rate signal **63** is divided by the gain of **54** and then summed in summer **52** with the LVDT position signal **51** and position feedback signal **60**.

Thus by combining the motor position or motor rate signal, used for motor commutation, with the LVDT signal, a dynamic feedback signal can be constructed that retains the steady state accuracy of the LVDT signal but mitigates the adverse effects of the load resonance peaking that appears on the LVDT signal. As the motor position signal is already available in most cases for use in motor commutation, this approach can be implemented in software with no additional hardware required.

Though the preferred embodiment has been described with respect to analog components, the anti-resonance mixing filter can be implemented in software with code "C" being the preferred language.

Various modifications and alterations to the above-described preferred embodiment will be apparent to those skilled in the art. For example other types of motors such as pneumatic motors can be used in driving the actuator. Also, instead of motor position a signal of motor rotational speed can be used. Accordingly, these descriptions of the invention should be considered exemplary and not as limiting the scope and spirit of the invention as set forth in the following claims.

What is claimed is:

1. In a closed loop control system for controlling the movement of a structure, a method for filtering oscillations generated when said structure is at a resonant frequency comprising the steps of:

(a) sensing a first parameter of said structure and generating a first signal thereof, said first parameter being sensitive to said oscillations;

(b) sensing a second parameter that is isolated from said oscillations and generating a second signal thereof, there being a known relationship between said first and second parameters;

(c) applying a lag to said first signal;

(d) combining said first and second signal to form a third in which the oscillations in said first signal are attenuated; and

(e) using said third signal in said control system.

2. The method of claim **1** further comprising between steps (b) and (c) the step of applying a gain to said first signal.

3. The method of claim **2** wherein said structure is an actuator.

4. The method of claim **3** wherein said first parameter is actuator position.

5. The method of claim **4** wherein said second parameter is the rotor position of a motor that is driving said actuator.

6. The method of claim **4** wherein said second parameter is the rotational speed of a motor that is driving said actuator.

7. The method of claim **5** wherein said third signal is a position feedback signal.

8. The method of claim **1** further comprising the step of bypassing step (c) when said structure is not at a resonant frequency.

9. An anti-resonance mixing filter for use in a control system for controlling a first member that is driven by a second member in response to said control system, said first member being subject to oscillations at its resonant frequencies, said filter comprising:

a first sensor for sensing a first parameter of said first member and generating a first signal thereof, said sensor having a sensitivity so as to pickup said oscillations when said first member is at a resonant frequency;

a second sensor for sensing a second parameter of said second member and generating a signal thereof;

said filter further comprising in series:

a first summer receiving said first signal;

a gain;

an integrator;

a second summer receiving said second signal; and

a feedback loop between the upstream side of said second summer and said first summer.

10. The filter of claim **9** wherein said first sensor is a linear variable displacement transducer.

11. The filter of claim **9** wherein said first member is an actuator and said second member is a motor.

12. The filter of claim **11** wherein said first parameter is actuator position and said second parameter is motor position.

13. The filter of claim **11** wherein said first parameter is actuator position and said second parameter to motor rotational speed.

14. An anti-resonance mixing filter for use in a control system for controlling a first member that is driven by a second member in response to said control system, said first member being subject to oscillations at its resonant frequencies, said filter comprising:

means for sensing a first parameter of said first member and generating a first signal thereof, said sensing means having a sensitivity so as to pickup said oscillations when said first member is at a resonant frequency;

means for sensing a second parameter of said second member and generating a second signal thereof;

said filter further comprising in series:

means for summing said first signal with a third signal;

means for amplifying the signal from said summing means;

means for integrating the signal from said amplifying means; and

means for summing the signal from said amplifying means

with said second signal to form said third signal.

15. The filter of claim **14** wherein said first sensing means is a linear variable displacement transducer.

16. The filter of claim **14** wherein said first member is an actuator and said second member is a motor.

17. The filter of claim **16** wherein said first parameter is actuator position and said second parameter is motor position.

18. The filter of claim **16** wherein said first parameter is actuator position and said second parameter to motor rotational speed.

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