# United States Patent

**Gorgens et al.**

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[45] **Sept. 19, 1972**


[54] **CONDITION RESPONSIVE APPARATUS**


[72] Inventors: **Joseph E. Gorgens**, Trumbull; **William A. Heske**, Fairfield; **Randall Goff**, Weston, all of Conn.

[73] Assignee: **Dresser Industries, Inc.**, Dallas, Tex.



[22] Filed: **Sept. 11, 1970**

[21] Appl. No.: **71,420**

**Related U.S. Application Data**

[63] Continuation of Ser. No. 859,246, Sept. 17, 1969, abandoned, which is a continuation of Ser. No. 732,472, April 12, 1968, abandoned, which is a continuation-in-part of Ser. No. 565,857, July 18, 1966, abandoned.

[52] **U.S. Cl.**.....**73/411**, 73/385 BN, 73/398 R

[51] **Int. Cl.**.....**G01l 7/04**

[58] **Field of Search**.....73/398, 388 BN, 411, 382; 137/82; 346/31, 32, 33; 318/18, 480



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*Primary Examiner*—Donald O. Woodiel

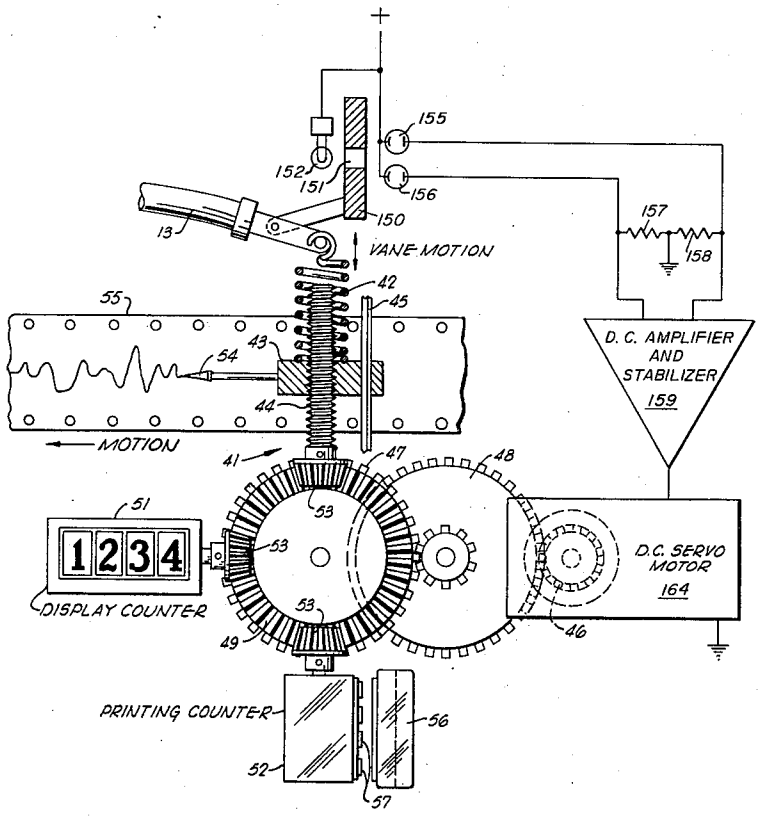
*Attorney*—Daniel Rubin



[57] **ABSTRACT**

Apparatus responsive to sensed magnitude of a variable condition input to provide an output drive for operative connection to a recorder, counter, or the like. The apparatus includes a control operative in response to condition changes by discreet bidirectional movement from a force balance null position at which sensing means for emitting correlated bidirectional signals to the output drive are at a nonemitting signal level.


**33 Claims, 11 Drawing Figures**



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SHEET 1 OF 6

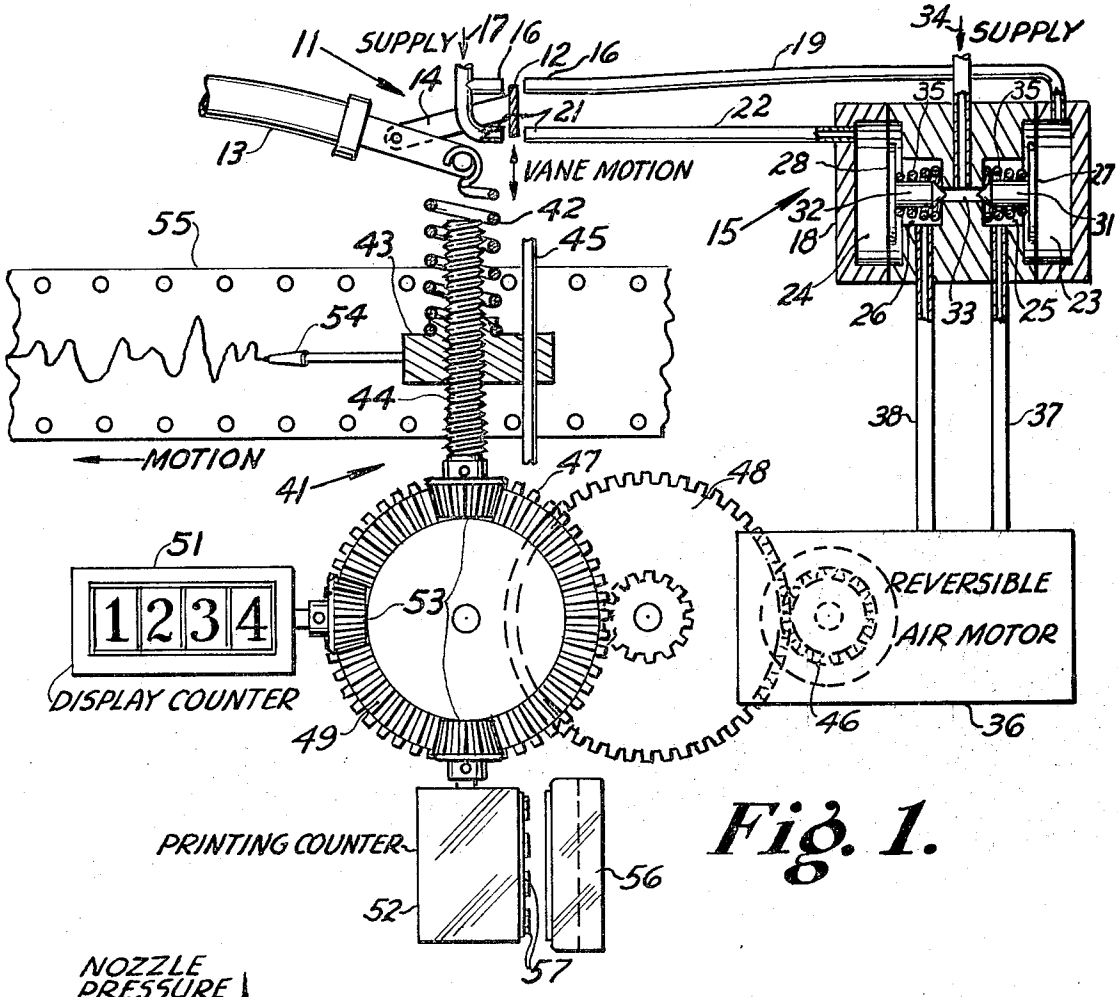



Fig. 1.

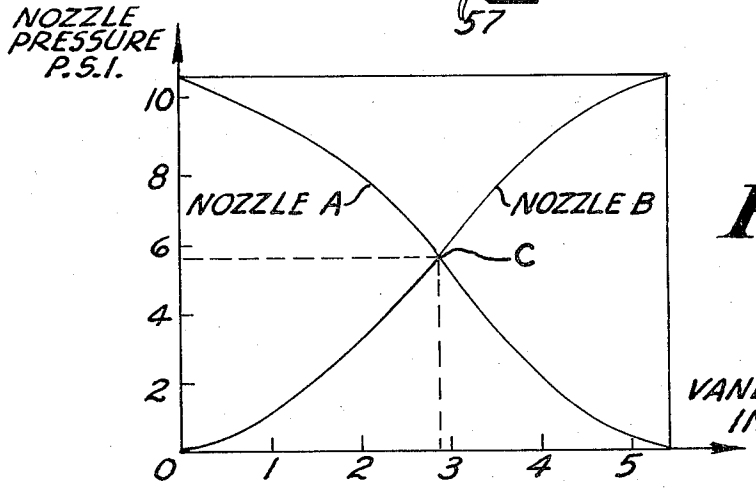



Fig. 2.

INVENTORS:
Joseph E. Gorgens
William A. Heske
Randall Goff
BY John E. Toupal
ATTORNEY.

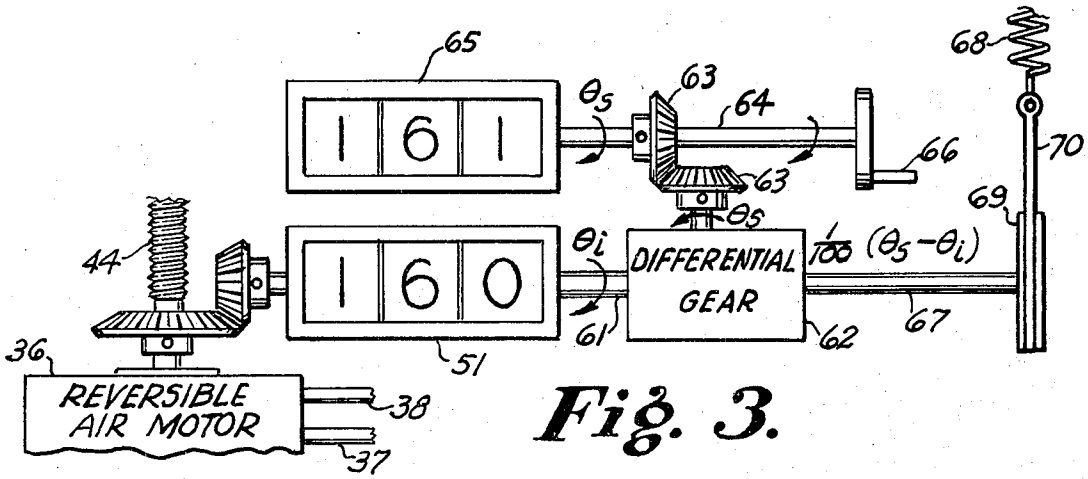



Fig. 3.

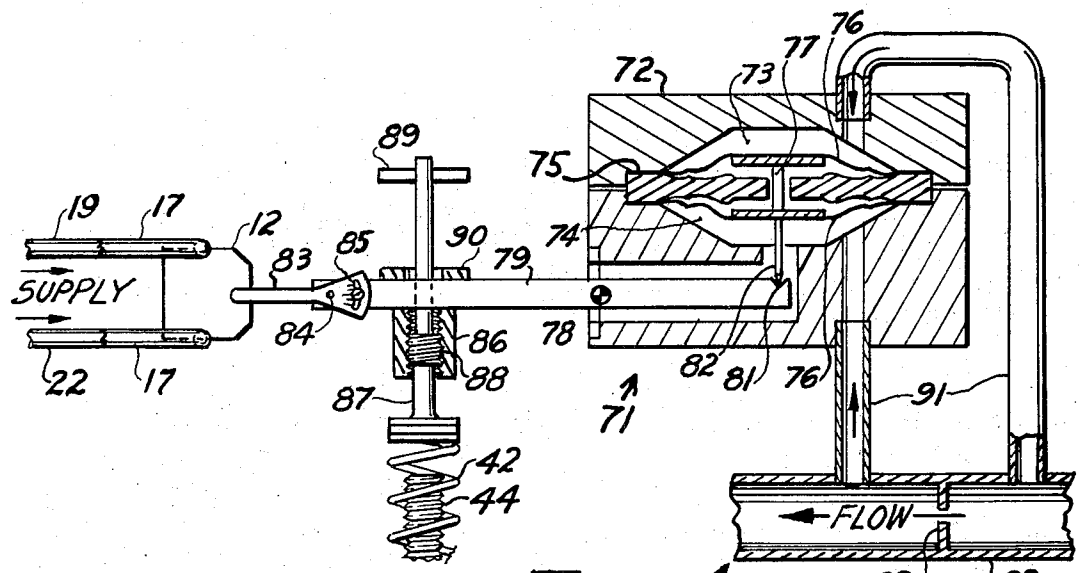



Fig. 4.

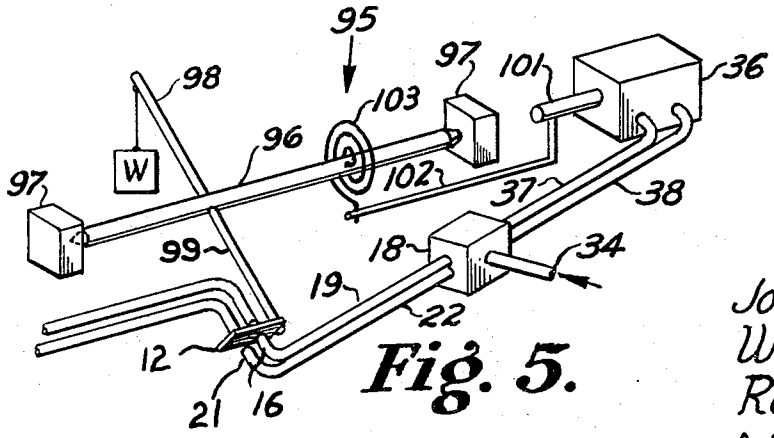



Fig. 5.

INVENTORS:
Joseph E. Gorgens
William A. Heske
Randall Goff
BY John E. Toupal
ATTORNEY.

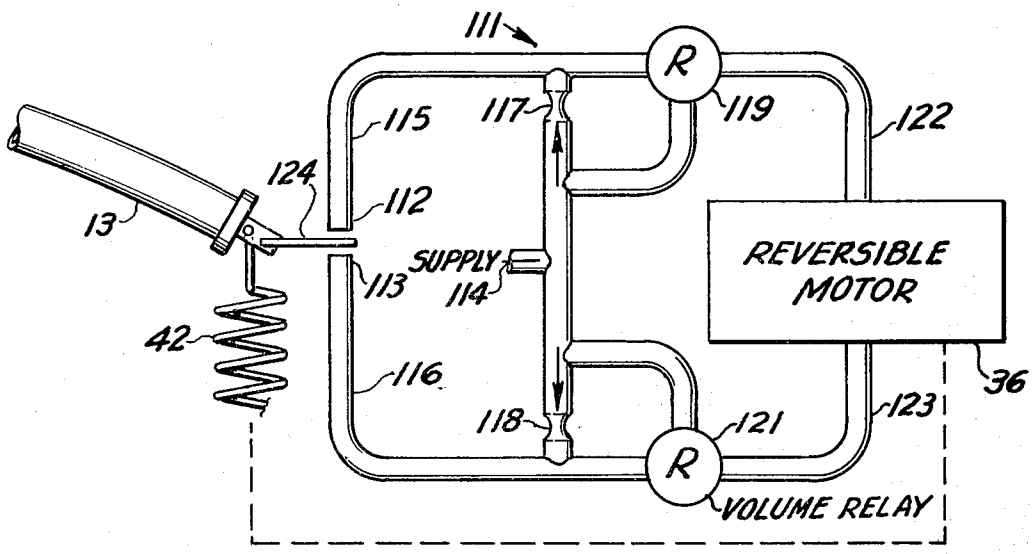



Fig. 6.

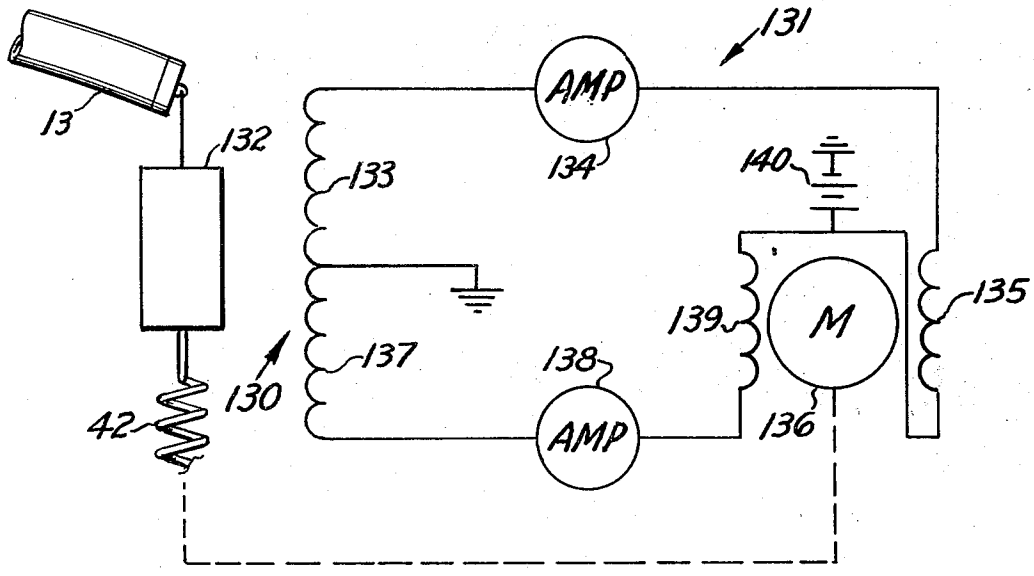



Fig. 7.

INVENTORS:
Joseph E. Gorgens
William A. Heske
Randall Goff
BY John E. Tarpal
ATTORNEY.

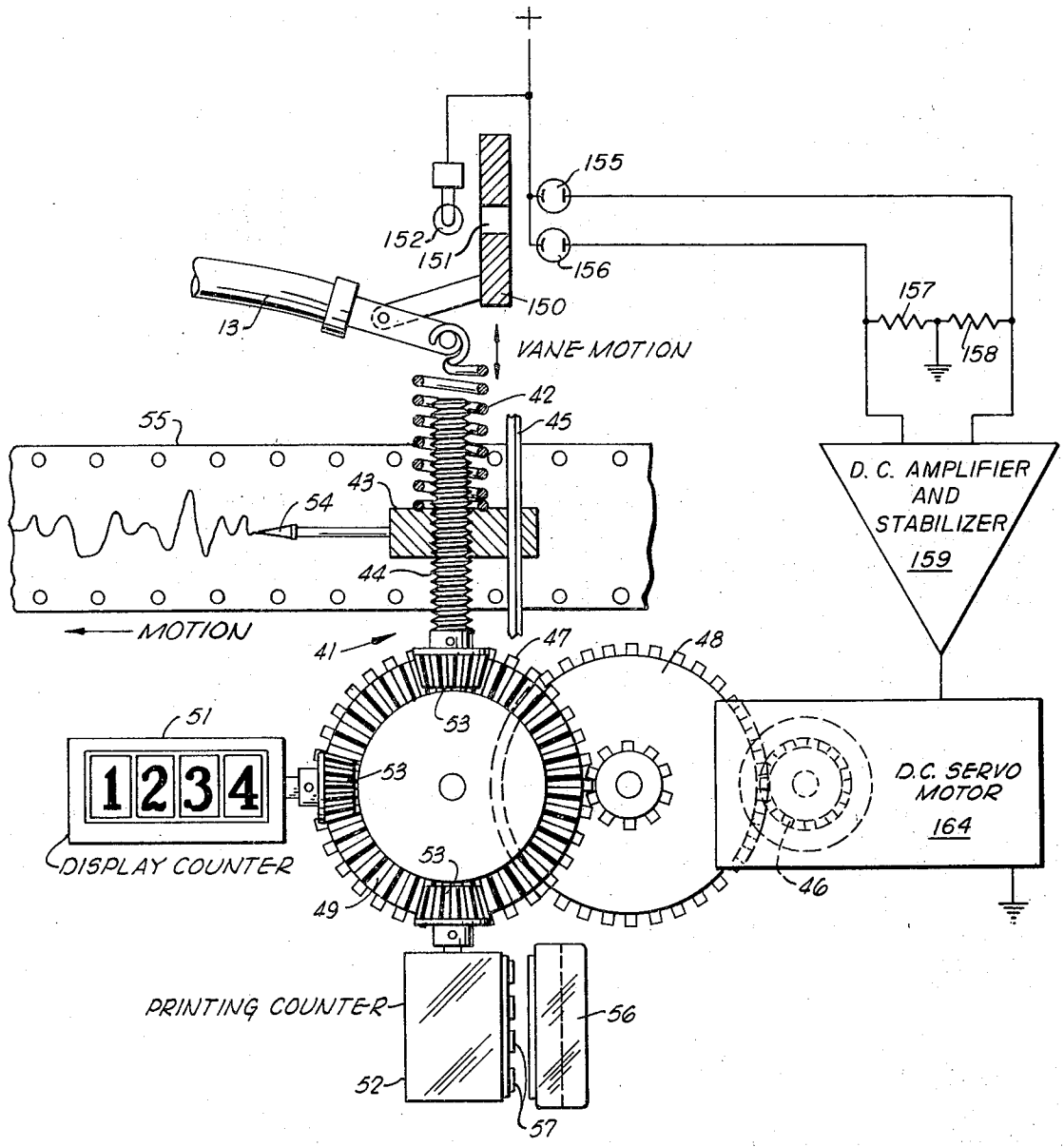



Fig. 8

INVENTORS
JOSEPH E. GORGENS,
WILLIAM A. HESKE &
RANDALL GOFF
BY Daniel Rubin
ATTORNEY

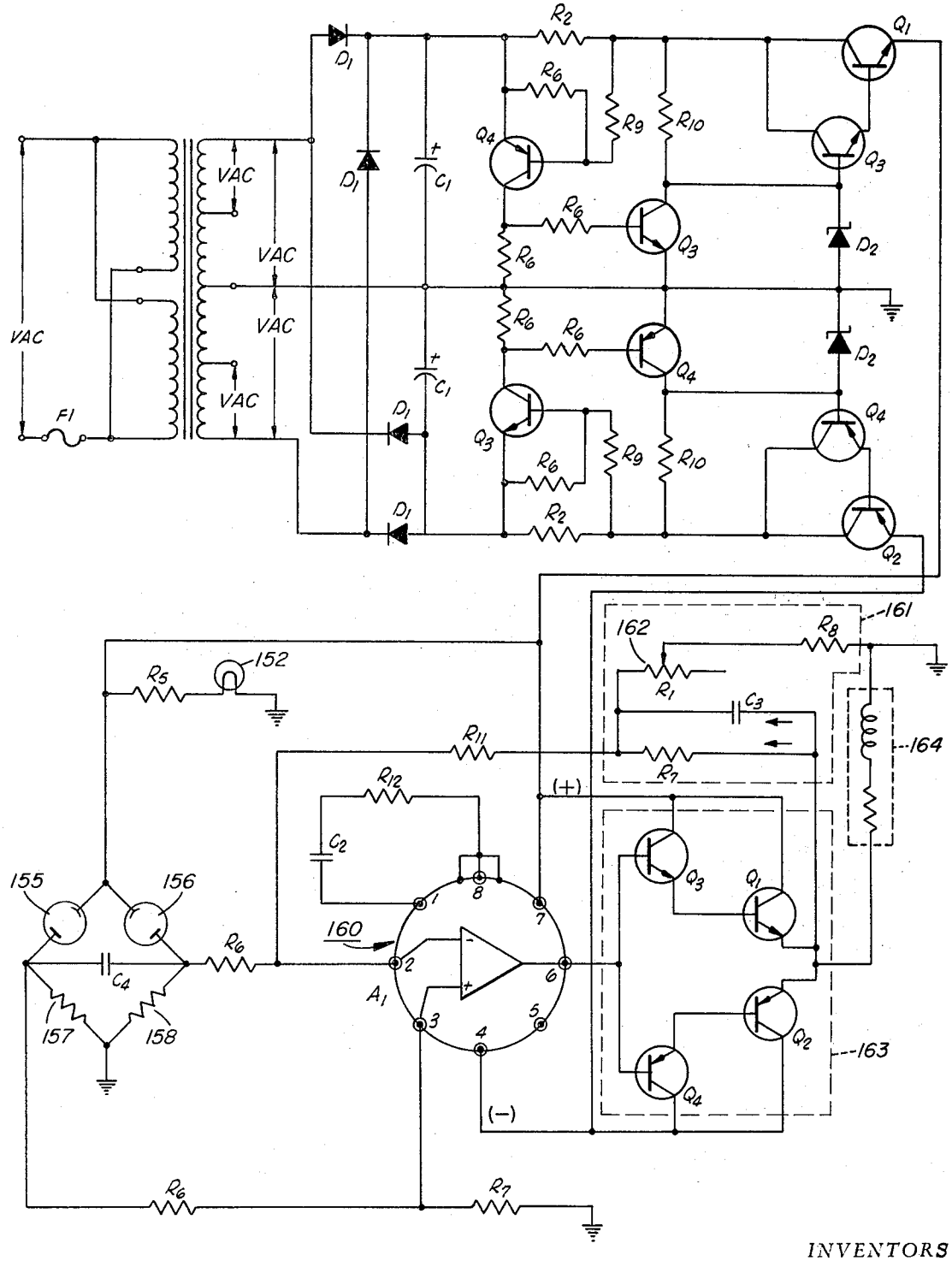



Fig. 9

INVENTORS
JOSEPH E. GORGENS,
WILLIAM A. HESKE &
RANDALL GOFF
BY Daniel Rubin
ATTORNEY

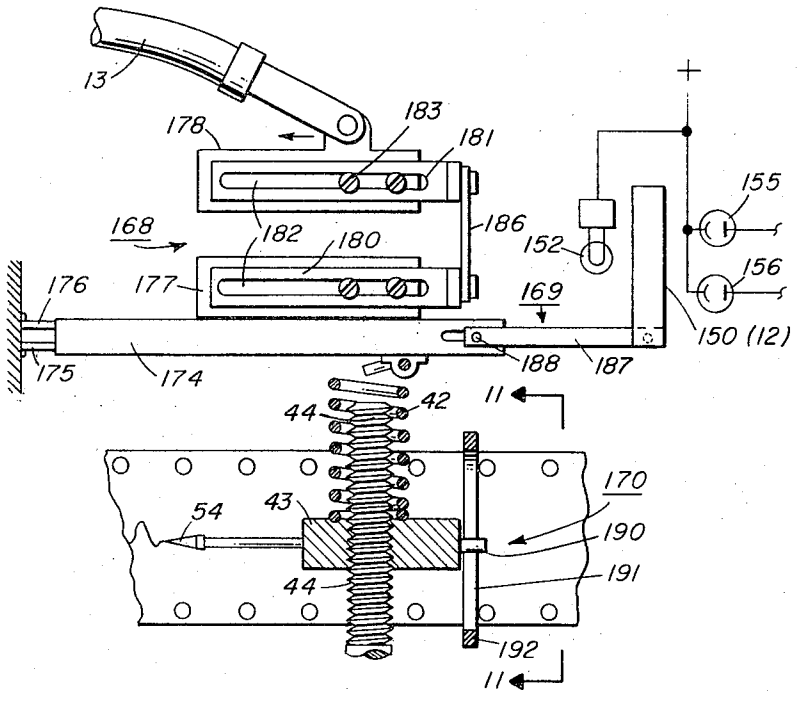



Fig. 10

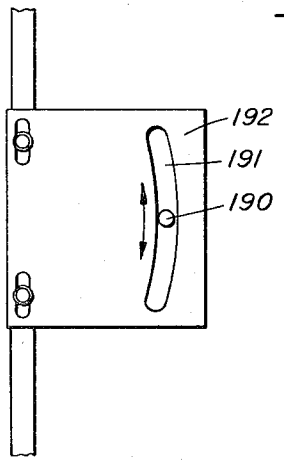



Fig. 11

INVENTORS
JOSEPH E. GORGENS,
WILLIAM A. HESKE &
RANDALL GOFF

BY Daniel Rubin

ATTORNEY

# CONDITION RESPONSIVE APPARATUS

## CROSS-REFERENCES TO RELATED APPLICATIONS

This application is a streamline continuation of application Ser. No. 859,246 filed Sept. 17, 1969, now abandoned, which is a continuation of application Ser. No. 732,472 filed Apr. 12, 1968 now abandoned, which is a continuation-in-part of application Ser. No. 565,857 filed July 18, 1966, titled "Condition Responsive Apparatus," and now abandoned.

## BACKGROUND OF THE INVENTION

The field of art to which this invention relates comprises, for example, devices which provide an indication or control operation in response to a particular variable condition such as fluid pressure, temperature, fluid flow, motion, weight, etc.

It is known in the prior art to employ unidirectional force balance devices for the above purposes which are responsive to an interruption of a signal by whatever means. Exemplifying that type of device in the prior art is U.S. Pat. No. 2,921,595 in which a galvanometer positions a vane or baffle in interrupting relation between a pair of axially aligned nozzles one of which normally discharges and the other of which normally receives a constant air supply. Prior systems of this basic type have suffered from various individual and common disadvantages such as complex construction, high cost, limited useful range, unreliability, inaccuracy, etc.

## SUMMARY

This invention relates generally to apparatus responsive to changes in a given variable condition. As compared to such prior art devices, the apparatus hereof is relatively simple and inexpensive yet will more reliably sense a given variable condition and either furnish accurate indication of the magnitude of the sensed variable condition or effect a desired control function in response thereto.

In accordance with this invention, a primary feature is the provision of a condition responsive apparatus wherein the bidirectional movement of a variable condition responsive control mechanism is acknowledged by a sensing means. When activated, the sensing means provides an amplified signal to selectively energize a bidirectional feedback drive to restore the control mechanism to a given null-position at which the drive is deenergized. Movement of the drive can be used to actuate a suitable readout device which either provides an indication of the variable condition or performs a control function in response thereto. This null-balance and bidirectionally controlled apparatus permits an extremely accurate sensing and/or indication of the variable condition. The apparatus can be operably electronic, electric, fluidic and where of the latter type has the additional advantage of not requiring electrical input or explosion proofing.

It is therefore an object of the invention to provide novel apparatus responsive to changes in a given variable condition.

It is a further object of the invention to provide a novel condition responsive device capable of operating a control function in analogue correlation to condition changes.



It is a further object of the invention to provide a device in accordance with the last recited object in which operational sensitivity can be either fluidic, electric, or electronic.

It is a still further object to provide novel condition responsive apparatus in accordance with the aforesaid objects having a high level of accuracy and reliability as compared to such prior art devices without associated construction complexity and high fabrication costs.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic representation of a preferred pneumatic embodiment of the invention;

FIG. **2** is a graph illustrating the pressure-vane deflection characteristics of the sensing device shown in FIG. **1**;

FIG. **3** is a partial schematic representation of a modified readout device for use with the embodiment of FIG. **1**;

FIG. **4** is a schematic representation of a differential pressure responsive control mechanism for use with the embodiment of FIG. **1**;

FIG. **5** is a partial schematic representation of another invention embodiment utilizing a torsional feedback arrangement;

FIG. **6** is a schematic representation of a modified pneumatic sensor for use with the embodiment shown in FIG. **1**;

FIG. **7** is a schematic representation of another invention embodiment utilizing an electrical sensor and drive means;

FIG. **8** is a schematic representation of another invention embodiment utilizing electronic sensing and drive means;

FIG. **9** is a schematic circuit diagram for the embodiment of FIG. **8**;

FIG. **10** is a fragmentary schematic of optional mechanical features for enhanced performance versatility; and

FIG. **11** is a side illustration of FIG. **10** as viewed from the position **11**—**11** thereof.

Referring now to FIG. **1**, there is shown a pneumatically operative condition responsive apparatus according to the present invention including the controller **11** which includes the vane member **12** connected to the conventional Bourdon tube **13** by the lever arm **14**. Associated with the controller **11** is the sensing device **15** including a first pair of spaced apart, aligned nozzles **16** connected between the low pressure air supply **17** and the pneumatic relay **18** by the air supply tube **19**. The sensing device **15** includes a second pair of spaced apart, aligned nozzles **21** also connected between the air supply **17** and the pneumatic relay **18**.

Formed within the pneumatic relay **18** are the hollow actuating chambers **23** and **24** which communicate with the air supply tubes **19** and **22** and are separated from the valve chambers **25** and **26** by the flexible membranes **27** and **28**. Attached to the membranes **27** and **28** are the valve stems **31** and **32** which seat in the valve channel **33** communicating with the high pressure air supply **34**. The compression springs **35** bias the valve stems **31** and **32** away from the valve channel **33** in opposition to the forces applied to the membranes **27** and **28** by the air pressure within the actuating chambers **23** and **24**. Connecting the reversible drive air motor **36** with the valve chambers **25** and **26** are the air supply tubes **37** and **38**.

The feedback mechanism **41** connects the controller **11** with the reversible air motor **36** and includes the linear spring **42** having ends attached to the end of the Bourdon tube **13** and the internally threaded support member **43** which engages the externally threaded lead screw **44**. The stabilizing guide bar **45** passes through an aperture in the support member **43** so as to permit relative vertical movement therebetween. Mounted between the spur gear **46** on the reversible air motor **36** and the spur gear **47** of the feedback mechanism **41** is a speed reduction spur gear assembly **48**. The bevel gear face **49** of the spur gear **47** drives the lead screw **44**, the digital display counter **51** and the digital printing counter **52** through the associated bevel gears **53**. Attached for vertical movement with the support **43** is the transcribing pen **54** positioned for contact with the strip chart **55**. The paper tape **56** is adapted with a conventional actuating mechanism (not shown) for periodic contact with the digital printing counter **52** so as to receive impressions imposed by the raised digital wheels **57**.

For operation of the invention embodiment shown in FIG. **1**, the Bourdon tube **13** is connected so as to be deflected in the well-known manner by changes in a given variable condition such as pressure. The Bourdon tube deflection moves the attached vane member **12** transversely within the gaps between the first and second pair of aligned air nozzles **16** and **21**. Responsive to movement of the vane member **12**, the sensing device **15** actuates the reversible air motor **36** which, through the feedback mechanism **41**, returns the vane member **12** to a given null-position which can be, as shown, symmetrically spaced between the nozzles **16** and **21**. The operation can occur, for example, in the following manner: upon a variable condition change which produces an upward movement of the Bourdon tube **13** and attached vane member **12**, the resultant reduction of air flow from the air supply **17** into the air supply tube **19** will provide a reduced pressure air signal within the actuating chamber **23**. The reduction in air pressure exerted against the flexible membrane **27** will permit the compression spring **35** to actuate the valve stem **31** proving air communication between the high pressure air supply **34** and the air supply tube **37** thus amplifying the original signal provided by the air supply tube **19**. Responsive to the amplified air signal, the reversible air motor **36** will drive the spur gear **46** in a counterclockwise direction causing clockwise rotation of the speed reduction gear **48**. This in turn will produce counterclockwise rotation of the spur gear **47** and bevel face **49** and clockwise rotation of the lead screw **44** thereby causing downward movement of the associated support member **43**. The corrective movement will continue until a sufficient force is exerted via the linear feedback spring **42** to pull the Bourdon tube **13** into a position wherein the attached vane member **12** is again in its null-position. At this time, the air pressure in the supply tube **19** and communicating chamber **23** will again be sufficient to force the valve stem **31** into seating engagement with the valve channel **33** thereby deactivating the air motor **36**. Similarly, a change in the variable condition causing a downward movement of the Bourdon tube **13** and attached vane member will provide a different reduced pressure air signal in the supply tube **22** and activating chamber **24**. In this case, the valve stem **32** is activated to produce air communication between the air supply **34** and the supply tube **38** for driving the reversible air motor and connected spur gear **46** in a clockwise direction. Thus, the speed reduction gear **48** will be driven in a counterclockwise direction, the bevel face gear **49** in a clockwise direction and the lead screw **44** in a counterclockwise direction. The resultant upward movement of the support member **43** will reduce the tension applied to the Bourdon tube **13** by the feedback spring **42** allowing the attached vane member **12** to return to its null-position. Again, the return to null-balance is accompanied by a pressure increase in the supply tube **22** and actuating chamber **24** so as to close the valve **32** and deenergize the air motor **36**.

Because of the force balance system provided by the linear feedback spring **42**, the linear movement of the attached support member **43** required to maintain the null-balance is an analog function of the variable condition which produces movement of the Bourdon tube **13**. Accordingly, the degree of movement experienced by the reversible motor **36**, the reduction gear **48**, the bevel gear **49** and the lead screw **44** are also analog functions of the sensed condition. Thus, the visible indications exhibited by markings of the transcribing pen **54** on the strip chart **55**, the digital display on the counter **51** and the printed illustration pressed on the tape **56** by the printing counter **52** are direct measurements of the variable condition being monitored.

FIG. **2** is a graph illustrating the relationship between the vertical deflection of the vane member **12** and the nozzle pressure of the nozzles **16** and **21** with vane deflection in inches $\times 10^{-3}$ plotted as the abscissa and nozzle pressure in pounds per sq. in. plotted as the ordinate. The particular plotted values shown were obtained utilizing a supply pressure of 20 psi which is a typical instrument air supply pressure. Obviously, the use of other supply pressures would establish different sets of nozzle curves. Curve A represents the vane deflection-nozzle pressure characteristic for the nozzle on supply tube **19**, curve B represents the vane deflection-nozzle pressure characteristic for the nozzle on supply tube **22** and the point C represents the null-balanced position of the vane member **12**. Thus, for example, at zero deflection the vane member **12** is in a position to totally obstruct air flow into the supply tube **22** and to permit transfer of about 10.2 psi pressure into supply tube **19** while at a position about $5.5 \times 10^{-3}$ inches higher the vane member **12** will completely obstruct flow into the supply tube **19** and will permit transfer of about 10.2 psi pressure to the supply tube **22**.

The compression springs **35** are selected to balance an air pressure in the chambers **23** and **24** corresponding to the null-balance point C and deflection of the vane member **12** in either direction will effect a pressure reduction within one of the chambers **23** or **24** thereby actuating the corresponding valve stem, as described above. Thus, the measured movement of the reversible air motor **36** which returns the vane member **12** to the null position C after a change in the variable condition sensed by the Bourdon tube **13** is not a function of the vane deflection-nozzle pressure characteristics of the individual nozzles **16** and **21**. It will be obvious that this allows a substantially greater accuracy of measurement than that obtained by prior art devices

which utilize a vane produced nozzle pressure change to directly actuate an indicator device. In such a system, the accuracy of the measurement is dependent upon the linearity of the vane deflection-nozzle pressure characteristic of the system and, as shown in FIG. 2, nozzle pressure in a typical system is not a directly linear function of vane deflection.

In addition to providing measuring accuracy, the embodiment of FIG. 1 has the particular advantages of requiring neither an electrical power input nor an explosion proofing. Furthermore, the arrangement wherein the vane 12 is mounted for transverse movement between the nozzles reduces the possibility of vibration-produced contact and associated mechanical wear of these parts.

It will be appreciated that a conventional Bourdon tube, as shown in FIG. 1, has a relatively low spring rate enabling it to be restored to a null-position. Also, the spring rates of conventional Bourdon tubes are in a magnitude range that can be balanced by reasonably sized feedback springs. In other applications and embodiments, however, one may utilize a control element, such as a large diaphragm motor valve, having an extremely high spring rate. For these cases, it can be desirable to use between the control member and sensing means an additional spring member (not shown) for converting movement of the control device into a suitable force which could be balanced with a feedback spring of reasonable size. Also, in the embodiment of FIG. 1, it will be understood that the described operation simply requires relative movement between the vane member 12 and nozzle pairs 16 and 21. Thus, one could adopt an analogous arrangement wherein the vane is stationary and the nozzle pairs mounted for movement in response to changes in the variable condition.

FIG. 3 shows a modified invention embodiment wherein components identical to those shown in FIG. 1 are given the same reference numerals. As in the embodiment of FIG. 1, the reversible air motor 36 drives the lead screw 44 and the digital display counter 51. However, in this embodiment the angular displacement $\theta_i$ of the display counter drive shaft 61 is fed into the differential gear 62 which also receives through the bevel gears 63 the angular displacement $\theta_s$ of the drive shaft 64 connected to the reference counter 65. Attached to the drive shaft 64 is the handle 66 with which the counter 65 can be set to a desired reference point. The output shaft 67 of the differential gear 62 delivers an output angular displacement of $(1/100)(\theta\beta - \theta)$ to the actuator spring 68 via the pulley 69 and connecting belt 70.

The actuator spring 68 can be used to actuate a variety of conventional control devices (not shown) such as valves, rheostats, switching arrays, etc. Typically, such control devices can be actuated in response to a change in a sensed condition, as indicated by the display counter 51, to restore the condition to a given reference value set by the reference counter 65.

FIG. 4 shows another modification wherein components identical to those shown in FIG. 1 are given the same reference numerals. As in the embodiment of FIG. 1, movement of the vane member 12 is sensed by a sensing circuit (not shown) which drives a reversible motor (not shown) operatively connected to the lead screw 44 and linear feedback spring 42. However, the controller 11 of FIG. 1 is replaced by the controller 71 which includes as its primary element the differential pressure cell 72. Separating the high pressure chamber 73 and the low pressure chamber 74 is the center support 75 straddled by a pair of flexible membranes 76 spaced apart by the spacer rod 77. Pivotally connected to the differential pressure cell 72 at a fulcrum point 78 is the lever arm 79 having at one end a notch 81 which seats the end of the force pin 82 attached to the lower flexible membrane 76. The opposite end of the lever arm 79 is attached to the vane member 12 by the support arm 83 which is pivoted at 84 and adjustably secured by the slot and screw assembly 85 so as to allow vertical positioning of the vane member 12. Supported by the lever arm 79 between the fulcrum point 78 and the vane member 12 is the internally threaded collar 86 which engages the spindle 87 at an externally threaded mid-portion 88. The spindle 87 has one end rotatably attached to the feedback spring 42 and an opposite end connected to the handle 89. The supply tubes 91 provide fluid communication between the differential pressure chambers 73 and 74 and the high and low pressure regions on opposite sides of the flow restrictor 92 within the fluid transmission pipe 93.

Except for the controller 71, the operation of this embodiment is identical to that described for the embodiment of FIG. 1. After setting a desired null-position for the vane member 12 with the adjusting assembly 85 and providing a desired tension for the feedback spring 42 by adjustment of the spindle 87 within the collar 86, the controller 71 functions in the following manner: an increased flow rate in the fluid transmission pipe 93 will increase the pressure differential across the membranes 76 by increasing the pressure in the chamber 73. This will cause a downward movement of the membranes and attached force pin 82 causing clockwise rotation of the lever arm 79. The resultant upward movement of the vane member 12 will produce the control operations described in connection with the embodiment of FIG. 1. As above, the actuated reversible air motor 36 will, through the feedback spring 42, increase the downward force applied to the lever arm 79 by the shoulder 90 of the collar 86. Consequently, the vane member 12 will be moved downwardly until it reaches the set null-position at which time the control operations will stop. Similarly, a reduced flow rate in the transmission pipe 93 will reduce the pressure in chamber 73 permitting the force exerted by the feedback spring 42 to cause counterclockwise rotation of the lever arm 79. The resultant downward movement of the vane member 12 will again produce energization of the reversible air motor in a direction which reduces the tension applied to the feedback spring 42 and thereby again restores the vane member 12 to its null-position.

The readouts obtained in this embodiment by, for example, the display counter 51, the printing counter 52 or the strip chart 55 will bear a non-linear dependency to the flow rate in the transmission pipe 93. However, a linear measurement of flow can be obtained by extracting the square root of the sensed differential pressure with suitable feedback devices such as tapes and contoured drums or a non-linear screw pitch on the lead screw. It will be apparent that input controllers other

than the Bourdon tube 13 shown in FIG. 1 and the differential pressure cell 72 shown in FIG. 4 can be effectively utilized with the present invention. Other examples of suitable control elements include differential pressure diaphragms for flow measurements, magnetic drag cups for speed measurements, weight through-springs for load or weight measurements, displacement through-springs for position measurement, bellows and diaphragms for pressure and temperature measurements, bimetal elements for temperature and flow measurements, etc. One can also sense changes in electrical current by using as a control device an electrical coil mounted for movement in a constant magnetic field.

FIG. 5 shows another invention embodiment wherein components identical to those shown in FIG. 1 are again given the same reference numerals. This embodiment is similar to that shown in FIG. 1 except that the linear feedback mechanism 41 is replaced by a torsional feedback arrangement 95. The controller comprises the control shaft 96, supported for rotation by the bearing surfaces 97, and the arm 98 which is adapted to sense a given variable condition, for example weight W. Also secured to the shaft 96 is an oppositely directed arm 99 which terminates with the vane member 12. The inner end of the torsional feedback spring 103 is attached to the control shaft 96 while the outer end thereof is secured to the feedback arm 102 which rotates with the output shaft 101 of the reversible air motor 36.

The operation of this embodiment is again similar to that described for the embodiment of FIG. 1. A change in the variable condition produces rotation of the shaft 96 and connected arm 99 to move the vane member 12 transversely in the gaps between the nozzles 16 and 21. This energizes the reversible air motor 36 via the pneumatic amplifier relay 18 and the produced direction of motor rotation is such as to change the torque applied to the shaft 96 by the feedback spring 103. The corrective operation continues until the vane member 12 has been returned to an original null-position. Thus, feedback arrangements other than those provided by a linear feedback spring such as that shown in FIG. 1 are possible. Still other suitable feedback mechanisms will include lead-screw cams, tape drives, arrangements utilizing non-linear screw pitches or equivalent means to provide a non-linear measurement of movement, etc.

FIG. 6 shows another embodiment of the invention in which elements identical to those shown in FIG. 1 are again given the same reference numerals. In this embodiment the sensing device 15 of FIG. 1 is replaced by a modified pneumatic sensor 111 which includes only a single pair of spaced apart, aligned nozzles 112 and 113. Each of the nozzles 112 and 113 is connected to a high pressure air supply 114 by supply tubes 115 and 116 having flow restrictors 117 and 118. Also connected to the supply tubes 115 and 116 on both sides of the flow restrictors 117 and 118 are the pneumatic volume relays 119 and 121 which communicate with the reversible air motor 36 via the actuating air tubes 122 and 123. The vane member 124 is attached to the Bourdon tube 13 so as to be moved thereby longitudinally in the gap between the aligned nozzles 112 and 113.

During typical operation, the vane member 124 will assume a null-position mid way between the nozzles 112 and 113 establishing equal given pressures within the supply tubes 117 and 118. At this given pressure the volume relays 119 and 121 will remain closed and the reversible motor 36 deenergized. However, upon a change in the variable condition, the Bourdon tube 13 will, for example, move upwardly causing the vane member 24 to move toward the nozzle 112 thereby raising the pressure in the supply tube 117. The increased pressure will open the volume relay 119 and energize the reversible motor 36 for rotation in a direction which will cause, as described in connection with FIG. 1, the application of an increased tension on the feedback spring 42. This restoring operation will continue until the vane member 124 is returned to its null-position. Similarly, an opposite change in the variable condition will produce a downward movement of the Bourdon tube 13 causing the vane member 124 to move toward the nozzle 113. The resultant pressure increase in the supply tube 118 will open the volume relay 121 and energize the reversible motor 36 for rotation in an opposite direction thereby reducing the tension applied to feedback spring 42 and allowing the vane member 124 to again return to its null-position.

FIG. 7 shows still another embodiment of the invention wherein components identical to those shown in the preceding figures are given the same reference numerals. In this embodiment, the pneumatic sensors are replaced with the electrical sensor 131 and the vane control members are replaced by the magnetic slug 132 connected between the Bourdon tube 13 and the linear feedback spring 42. The electric sensor 131 includes a voltage divider 130 magnetically coupled with the slug 132 and having a first inductive coil 133 connected between ground and the alternating current voltage supply 140 by an amplifier 134 and the windings 135 of the reversible electric servo motor 136. Also connected between voltage supply 140 and ground are the second inductive coil 137 of the voltage divider 130, the amplifier 138 and a second set of motor windings 139 which are wound oppositely to the windings 135. The electric servo motor 136 is connected to the feedback spring 42 with suitable mechanisms (not shown) similar to those shown in the preceding figures.

During operation of this embodiment, the magnetic slug 132 will normally assume a null-position wherein the inductive impedances of the coils 133 and 137 are balanced, the oppositely wound windings 135 and 139 are equally energized and the motor 136 deactivated. A movement of the Bourdon tube 13 and attached magnetic slug 132, caused by a change in a sensed variable condition, will introduce a relative impedance change in the coils 133 and 137 to unbalance the electrical sensor circuit 131. Thus, for example, a relative impedance increase of the inductive coil 133 will reduce the current flow in the first winding 135 relative to that drawn by the oppositely wound winding 139.

This will produce rotation of the servo motor 136 in a direction causing the mechanically connected feedback spring 42 to exert a restoring force on the slug 132 and attached Bourdon tube 13. The operation will continue until the magnetic slug 132 has been returned to its null-position. Similarly, a movement of the magnetic slug 132 which causes a relative impedance increase of

the inductive coil **137** will result in a relatively higher current flow through the winding **135** and produce an opposite direction of motor rotation. This rotation will again effect a return of the magnetic slug **132** to null-position and balancing of the electrical sensing circuit **131**. Obviously, other types of electrical error detectors such as strain gauges, semi-conductor devices, differential transformers, etc. could be utilized in this embodiment.

FIGS. **8** and **9** show still another embodiment of the invention wherein components identical to those shown in the preceding figures are given the same reference numbers. In this embodiment the pneumatic sensors are replaced with components adapted for electronic operation.

The error detector for this embodiment includes a vane here designated **150** and having an intermediately located transverse slit **151** with a width dimension in the direction of movement of about 0.005–0.015 inch. When in the null-balance position, the slit is in optical alignment between constantly energized lamp **152** and an intermediate position relative to dual photocell elements **155** and **156** producing a constant but minimal illumination on each. By virtue of the balanced bridge circuit formed by resistors **157** and **158** intermediately biased to ground, a zero voltage differential exists across the inputs to the amplifier-stabilizing network generally designated **159** that includes a high gain amplifier **160**. Moving the light beam off center in either direction by a position shift of slit **151** unbalances the bridge causing the amplifier to drive D.C. servo motor **164**. The motor direction is effective through lead screw **44** and feedback spring **42** to return the slit to its null-position at which the light beam rebalances the bridge.

In order to provide smooth operation of the device and avoid mechanical instability as a result of increased system sensitivity from high gain setting of the amplifier **160**, a stabilizer circuit **161** is provided as shown in FIG. **9** that includes an adjustable potentiometer **162** for shunting feedback current to ground for gain adjustment. Also provided as part of this network is booster current circuit **163** for the amplifier. This instability sought to be avoided usually takes the form of lead screw oscillation or resonance in the feedback spring. By electrically compensating the system for the dynamic response characteristics of these elements, high apparatus sensitivity with good stability is obtained.

Many techniques are known for stabilizing servo systems including a phase lead network, a phase lead-lag network, motor velocity feedback, a phase lag network and the like. In a preferred embodiment there is employed as shown a per se convention phase lag network which is frequency sensitive with high overall amplifier gain. This was found to provide superior stability with less criticality of component values.

As a further operating refinement in connection with this embodiment, the gearing in the feedback loop can be completely eliminated. In accordance herewith, this is effected by employing a frameless direct drive servo motor **164** placed operatively around the lead screw **44** selected of fine pitch. The counter drives under these circumstances is taken directly from lead screw **44** via an appropriate coupling or timing belt connection as most suitably accommodates the particular counter employed. Other refinements and/or variations should be apparent including the substitution of A.C. components for the D.C. components shown. Likewise while the error detector is shown as a dual element photocell, it can be any motion sensing device such as a linear variable differential transformer, a strain gauge transducer, a potentiometric type transducer, or the like.

Referring now to FIGS. **10** and **11**, there is illustrated further operative mechanical features which singularly or collectively can optionally be employed on any of the aforementioned embodiments hereof. These features include a span adjustment designated **168**, a temperature compensator designated **169**, and a linearized rotator **170** for lead screw **44**.

Span adjustment permits change in the effective force exerted by the Bourdon tube **13** in response to a given change in condition pressure. This is achieved by the adjustment mechanism **168** interposed between the sealed end of the Bourdon tube and spring **42** permitting axial displacement of the tube end relative to the axis of screw **44** and to the theoretical rotational center of the tube. The mechanism includes an elongated vane span arm **174** supporting vane **12** or **150** and having a flexure pivot support at one end via leaf springs **175** and **176**. At an intermediate location along the arm length it receives feedback spring **42** secured thereto. Integrally extending upward from the span arm is a fold-over flange **177** having an elongated adjustment slot extending generally parallel to the arm length. Spaced from the latter flange is a comparable flange **178** secured to the end of Bourdon tube **13**. Supported in slidable overlying relation to each of these flanges are span slides **180** and **181** joined by flexure leaf spring **186** and having elongated adjustment slots **182** overlying the corresponding flange slots through which to be secured in presettable position to their respective flanges via screws **183**. By this means, transverse relocation of the tube end relative to the axis of screw **44** can be easily and simply set for any appropriate and plausible operative span response.

Since Bourdon tube motion cannot always be constructed precisely parallel to the feedback spring axis, some motion perpendicular to that axis occurs which, of course, is not balanced by the feedback spring. The flexure therefore provided by spring **186** assures that the Bourdon tube returns to its starting position without imposing undue and unwanted strain on the other components.

Temperature compensation via compensator **169** may be desired where the apparatus is subject to wide temperature variations. For these purposes, it is preferable at the onset to minimize compensation requirements by using a feedback spring having a spring rate substantially unaffected by temperature changes. This is accomplished by employing spring materials such as Ni-Span C and ISO-Elastic being trademarks respectively of International Nickel Co. and John Chatillan & Sons.

To temperature compensate for indication shift-requiring a "zero" position change of the servo, there is as provided herein interposed between span arm **175** and vane **150** a bimetallic strip **187** which compensatingly reorients the null-position of slit **151** relative to

photocells **155** and **156**. Strip motion with temperature can be adjusted by an appropriate resetting of the clamping screw **188**. It is obvious that a thermistor could be used in place of one of the bridge resistors **157** or **158** to also compensate for temperature changes occuring there.

The use of the linearizing rotator **170** is necessary where lead screw rotation and consequently spring rate is required to reflect a highly precise more exact linear function of pressure in the Bourdon tube or other sensing element. This is operative in accordance herewith by providing guided angular displacement of support member **43** as it advances vertically in response to lead screw rotation. Guide **45** is eliminated such that as the support member moves vertically, a guide pin **190** extending laterally from the side of support **43** engages a vertical contoured cam slot **191** in a stationary cam plate **192**. This provides compensation to the spring rate by adding or subtracting from the affect of lead screw rotation offsetting spring nonlinearity occasioned by a changing helix angle. The precise required cam pitch is of course dependent on the spring geometry characteristics.

Obviously, many modifications and variations of the present invention are possible in light of the above teachings.

What is claimed is:

**1**. A fluid pressure sensitive condition responsive apparatus comprising; control means adapted for movement in one direction from a null-position in response to a force change from an increasing fluid pressure and adapted for movement in another direction from a null-position in response to a force change from a decreasing fluid pressure, sensing means comprising a pair of spaced apart sensing elements located defining a null-position therebetween for said control means to move relative thereto and operable to provide a first differential signal in response to movement of said control means in said one direction away from said null-position and a second differential signal in response to movement of said control means in said another direction away from said null-position, differential amplifier means receiving signals from said sensing means to emit an amplified signal correlated and proportional thereto, bidirectional drive means receiving signals from said amplifier and adapted to generate a motion force in a first direction in response to a received signal correlated with said first signal of said sensing means and a motion force in an opposite direction in response to a received signal correlated with said second signal of said sensing means, feedback means including substantially linear spring means connected between said bidirectional drive means and said control means, said feedback means being responsive to said generated motion forces to return said control means to said null-position in opposition to the force change incurred thereby, and output means operable in conjunction with said feedback means for connection to external means to be operative thereby.

**2**. A condition responsive apparatus according to claim **1** wherein said control means includes a variable condition responsive Bourdon tube connected to produce movement thereof in response to changes in the variable condition.

**3**. A condition responsive apparatus according to claim **1** wherein said sensing means comprises a linear differential transducer energized to its respective signal providing levels in response to the respective movement of said control means.

**4**. A condition responsive apparatus according to claim **1** wherein said sensing means comprises dual elements separately energized to their signal providing levels in response to the respective movement of said control means.

**5**. A condition responsive apparatus according to claim **4** wherein said control means comprises a slitted vane movable interposed between a light source and said dual elements which comprise photoelectric cells.

**6**. A condition responsive apparatus according to claim **1** wherein said sensing means comprises a pneumatic detector means and said bidirectional drive means comprises a reversible air motor.

**7**. A condition responsive apparatus according to claim **6** wherein said pneumatic detector means comprises a first pair of aligned spaced apart nozzles adapted for connection to an air supply, and said control means comprises a vane member adapted for movement in the gap between said spaced apart aligned nozzles.

**8**. A condition responsive apparatus according to claim **7** wherein said vane member is adapted for longitudinal movement between said aligned nozzles and said pneumatic means further comprises pneumatic relay means responsive to pressure changes in said nozzles produced by movement of said vane member and adapted to provide said first signal for driving said reversible air motor in one direction and said second signal for driving said reversible air motor in the opposite direction.

**9**. A condition responsive apparatus according to claim **7** wherein said feedback means comprises a linear spring connected between said vane member and said reversible air motor.

**10**. A condition responsive apparatus according to claim **9** wherein said linear spring is attached to a threaded support member which threadedly engages a threaded drive member connected for rotation with said reversible air motor.

**11**. A condition responsive apparatus according to claim **7** wherein said pneumatic detector means further comprises a second pair of spaced apart aligned nozzles adjacent said first pair of aligned nozzles and adapted for connection to an air supply, said vane member is adapted for transverse movement in the gaps between said first and second pairs of aligned nozzles and said pneumatic means further comprises pneumatic relay means responsive to pressure changes in said nozzles produced by movement of said vane member and adapted to provide said first signal for driving said reversible air motor in one direction and said second signal for driving said reversible air motor in the opposite direction.

**12**. A condition responsive apparatus according to claim **11** wherein said pneumatic detector means comprises a pneumatic amplifier means for amplifying said first and second signals before application to said reversible air motor.

**13**. A condition responsive apparatus according to claim **1** wherein said control means comprises

bidirectional rotational means and said feedback means comprises a torsional spring means connected between said control means and said bidirectional drive means.

14. A condition responsive apparatus according to claim 1 wherein said sensing means comprises an electrical detector means and said bidirectional drive means comprises a reversible electric motor.

15. A condition responsive apparatus according to claim 14 wherein said control means comprises a magnetic element adapted for movement in response to the variable condition, and said electrical detector means comprises a normally balanced circuit adapted in response to movement of said magnetic element to provide said first signal for driving said reversible electric motor in one direction and said second signal for driving said reversible electric motor in the opposite direction.

16. A condition responsive apparatus according to claim 1 wherein said control means comprises a differential pressure responsive device adapted for fluid communication connection with regions of different pressure, and a movable member adapted to provide said bidirectional movement in response to changes in the differential pressure existing in the connected regions.

17. A condition responsive apparatus according to claim 16 wherein said sensing means comprises a pneumatic detector means and said bidirectional drive means comprises a reversible air motor.

18. A condition responsive apparatus according to claim 17 wherein said pneumatic detector means comprises a first pair of aligned spaced apart nozzles adapted for connection to an air supply, and said movable member comprises a vane member adapted for movement in the gap between said spaced apart aligned nozzles.

19. A condition responsive apparatus according to claim 18 wherein said vane member is adapted for longitudinal movement between said aligned nozzles and said pneumatic means further comprises pneumatic relay means responsive to pressure changes in said nozzles produced by movement of said vane member and adapted to provide said first signal for driving said reversible air motor in one direction and said different signal for driving said reversible air motor in the opposite direction.

20. A condition responsive apparatus comprising; a light source, a vane having slit and adapted for bidirectional movement from a null-position past said light source in response to a variable condition, dual photoelectric cells separately energized to their signal providing levels by light received from said source through said vane slit in response to appropriate movement of said vane, said cells providing a first signal in response to movement of said vane in one direction from said null-position and a second signal in response to movement of said vane in the other direction from said null-position, bidirectional drive means actuated by said cell signals and adapted to generate one motion in response to said first signal and a different motion in response to said second signal, feedback means comprising a linear spring connected between said bidirectional drive means and said vane, said feedback means being responsive to said generated motion to return said vane to said null-position, and output means actuated concomitantly with said feedback means for connection to external means to be operative thereby.

21. A condition responsive apparatus according to claim 20 including compensating means to offset spring non-linearity through changes in the helix angle thereof.

22. A condition responsive apparatus according to claim 20 wherein said output means is connected to a digital counter readout means adapted to record movement of said drive means.

23. A condition responsive apparatus according to claim 20 in which the signals provided by said cells are differential signals and there is included a differential amplifier to receive said cell signals and emit an amplified signal correlated and proportional to said received signals for actuating said bi-directional drive means.

24. A condition responsive apparatus according to claim 23 including compensating means to offset spring non-linearity through changes in the helix angle thereof.

25. A condition responsive apparatus according to claim 23 wherein said output means is connected to a digital counter readout means adapted to record movement of said drive means.

26. A condition responsive apparatus comprising; a light source, a vane having a slit and adapted for bidirectional movement from a null-position past said light source in response to a variable condition, dual photoelectric cells separately energized to their signal providing levels by light received from said source through said vane slit in response to appropriate movement of said vane, said cells being connected in a normally balanced circuit and providing a first signal in response to movement of said vane in one direction from said null-position and a second signal in response to movement of said vane in the other direction form said null-position, an amplifier including a conjoined stabilizer circuit and receiving said cell signals to emit amplified signals thereof, bidirectional drive means actuated by said amplifier signals and adapted to generate one motion in response to an amplified second signal, feedback means connected between said bidirectional drive means and said vane, said feedback means being responsive to said generated motion to return said vane to said null-position, and output means actuated concomitantly with said feedback means for connection to external means to be operative thereby.

26. A condition responsive apparatus according to claim 26 in which said stabilizer circuit comprises a phase lag network.

28. A condition responsive apparatus according to claim 26 in which said stabilizer circuit comprises a phase lead network.

29. A condition responsive apparatus according to claim 26 in which said stabilizer circuit comprises a phase lead-lag network.

30. A condition responsive apparatus according to claim 26 in which said amplifier emits an amplified signal correleated and proportional to the signal differential from said photoelectric cells.

31. A condition responsive apparatus according to claim 26 wherein said output means is connected to a digital counter readout means adapted to record movement of said drive means.

32. A condition responsive apparatus according to claim 26 in which the signals provided by said cells are differential signals and said amplifier is a differential amplifier to emit amplified signals correlated and proportional to the cell signals received thereat.

33. A condition responsive apparatus according to claim 32 in which said stabilizer circuit comprises a phase lag network.

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