United States Patent

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[54] **FLUIDIC CONTROL SYSTEMS**
8 Claims, 4 Drawing Figs.

[52] **U.S. Cl.** 137/81.5
[51] **Int. Cl.** F15c 1/12
[50] **Field of Search** 137/81.5

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ABSTRACT: Fluidic control systems having a minimum of moving parts for controlling variables such as liquid level, flow and density in response to low initial pressure signals.

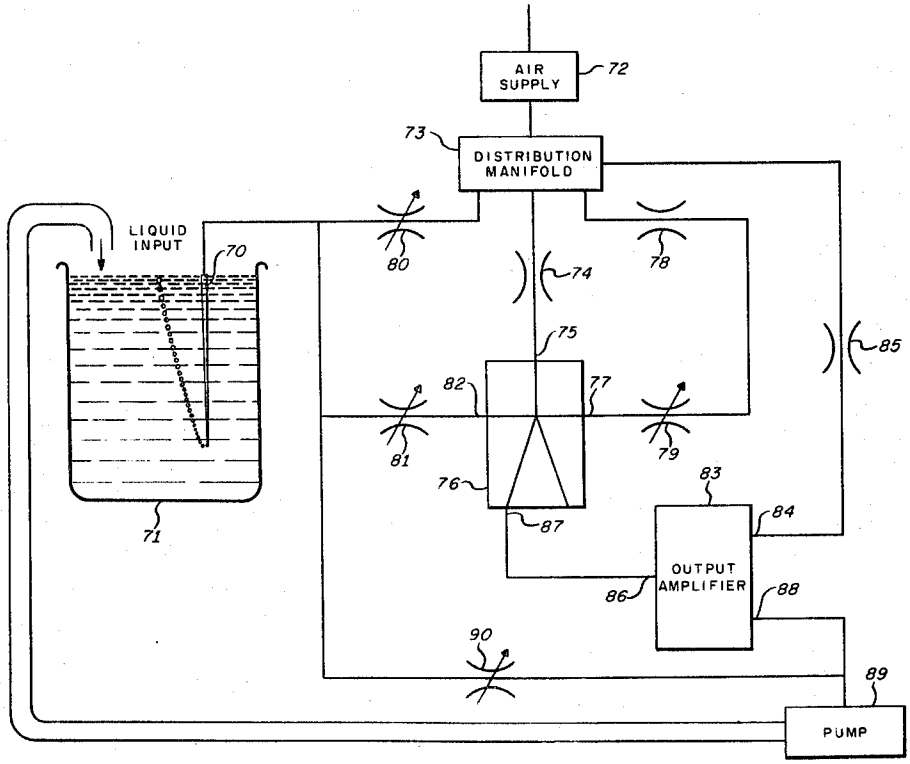
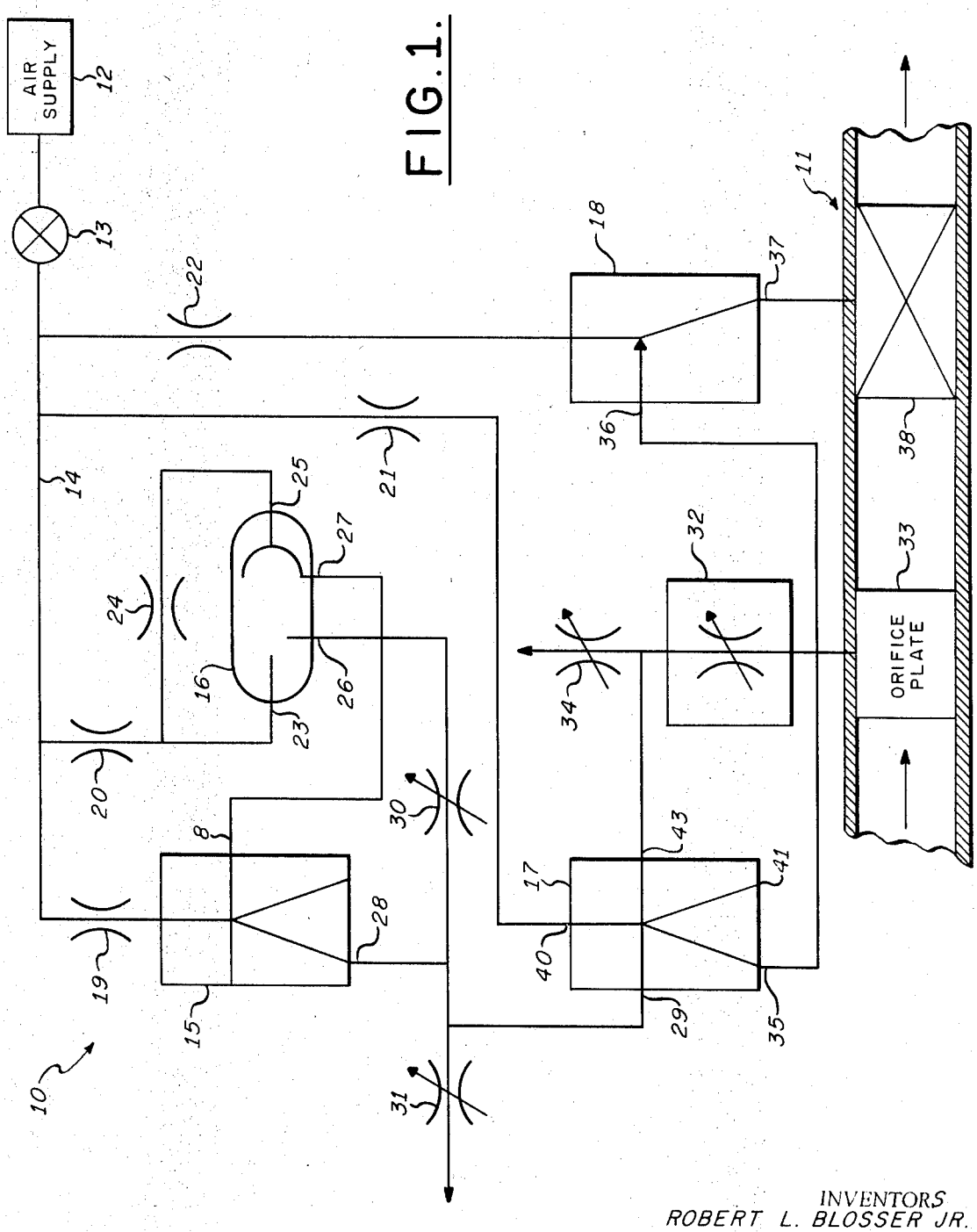


FIG. 1.



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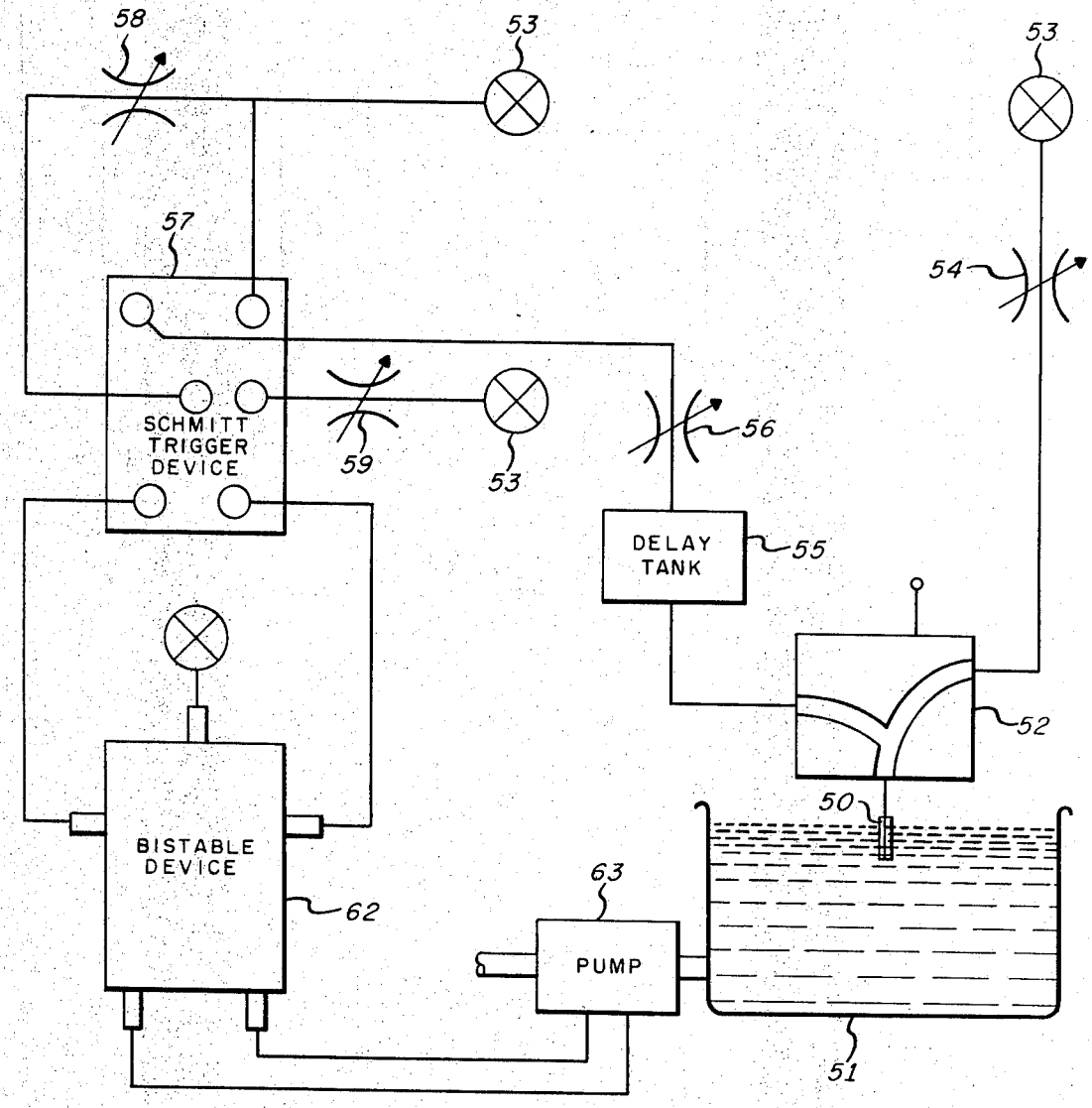


FIG. 2.

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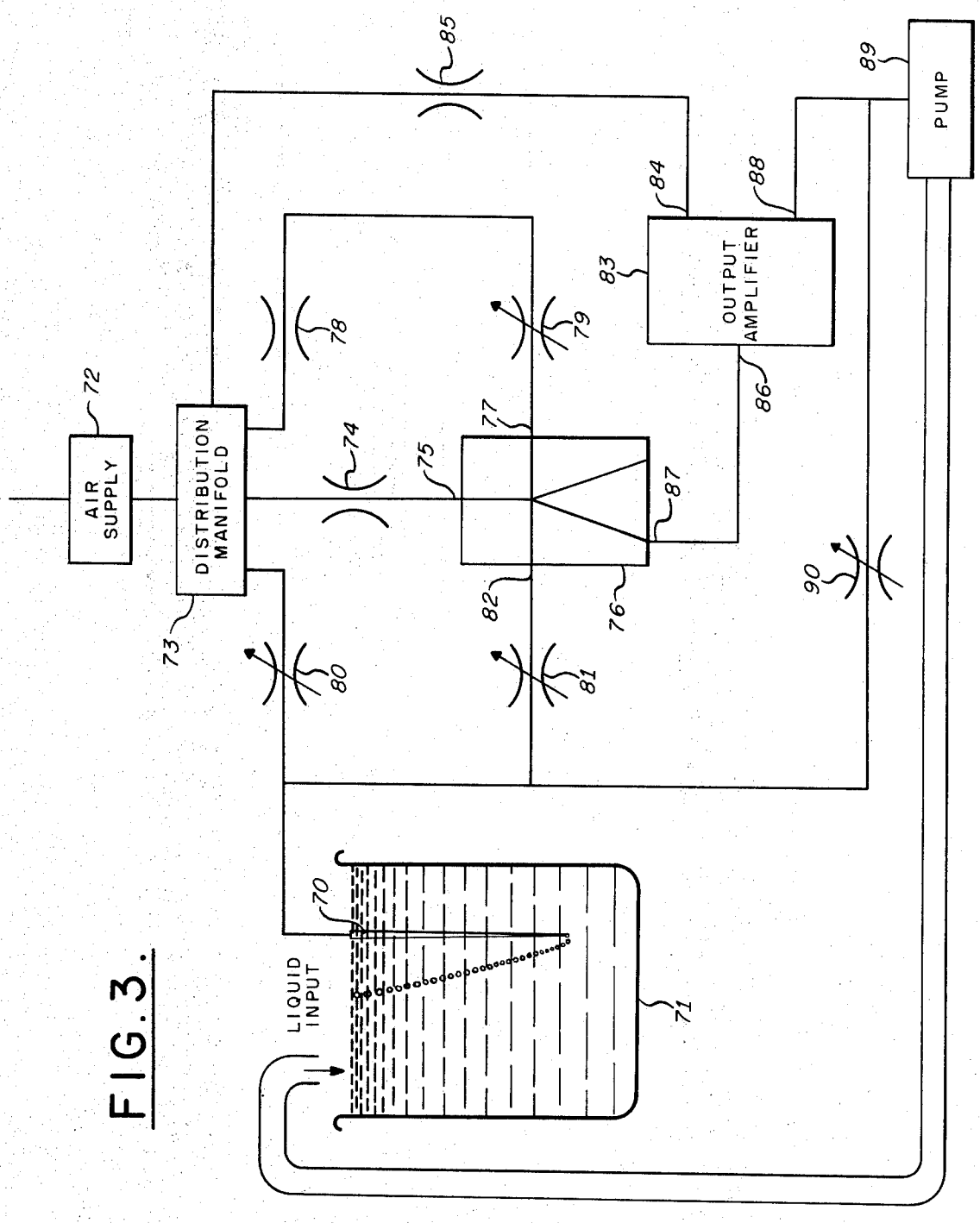


FIG. 3.

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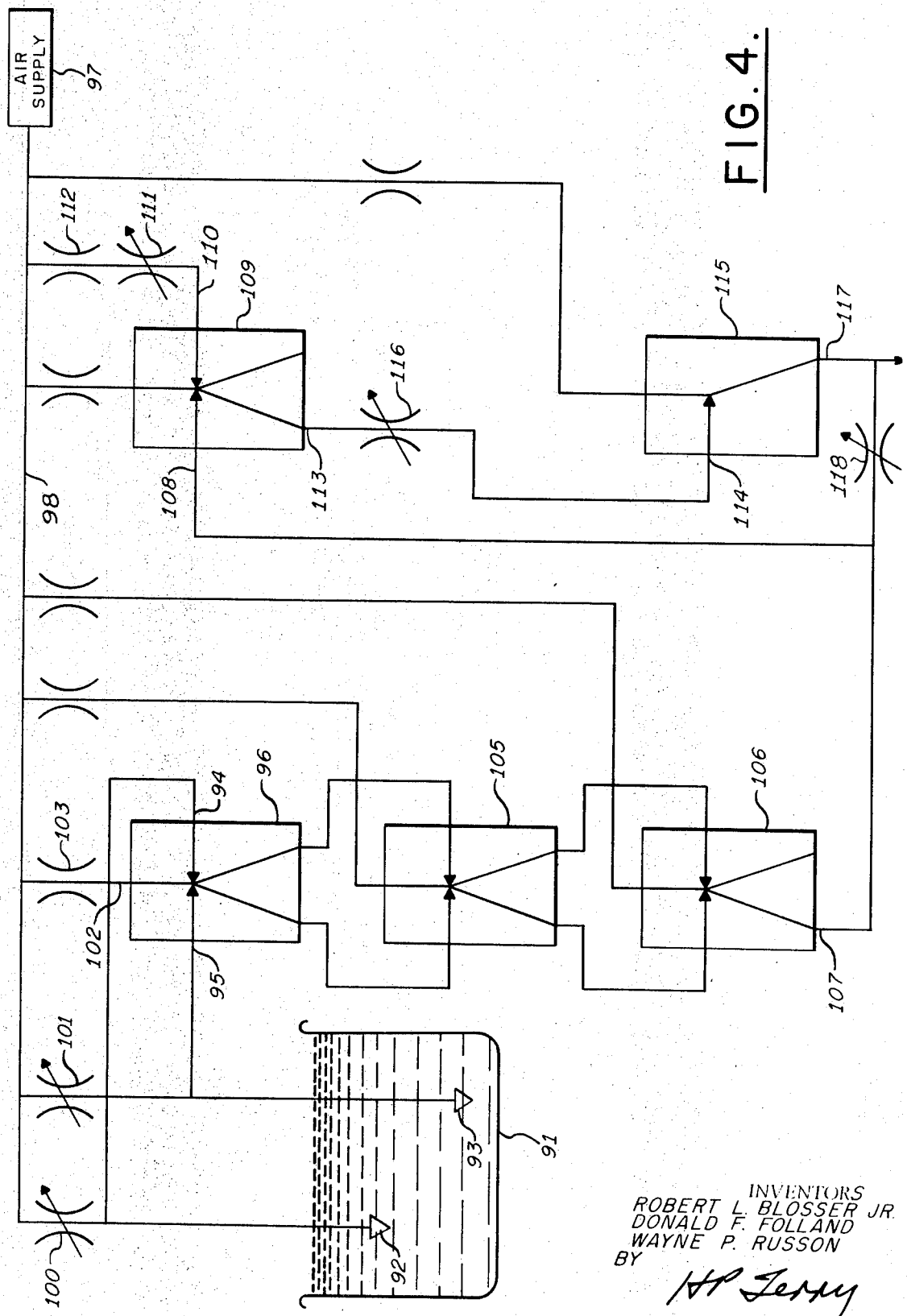


FIG. 4.

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FLUIDIC CONTROL SYSTEMS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention pertains to fluidic control systems for industrial and aerospace process control.

2. Description of the Prior Art

Generally, the prior art control systems are electromechanical devices which are subject to failures due to radiation, shock, dirt and temperature conditions. Further, the prior art devices contain moving parts which not only tend to become inaccurate with use but they are also subject to jamming or sticking. In addition, it is particularly difficult to design proportional systems. They are sensitive to in-line pressure changes and therefore must be carefully compensated. Another problem is that they require complex interface apparatus. Generally, the prior art systems are substantially more expensive than the fluidic control systems of the present invention.

SUMMARY OF THE INVENTION

The present invention utilizes a plurality of interconnected fluidic components having no moving parts except the fluid itself moving therethrough. Generally, the fluidic control systems of the present invention compare the actual conditions by means of fluid signals with a reference condition also defined by means of fluid signals and any difference therebetween provides a control signal which may be amplified to drive a load member in a manner to tend to eliminate the aforementioned difference.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of a fluidic flow control system;

FIG. 2 is a schematic diagram of a fluidic liquid level control system;

FIG. 3 is a schematic diagram of an alternative fluidic liquid level control system; and

FIG. 4 is a schematic diagram of a fluidic density control system.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, the fluidic control system **10** shown controls the flow of fluid in a conduit **11** which may, for example, in a gold extraction process be in the neighborhood of 600 gallons per minute of gold bearing solution. The fluidic flow control system **10** establishes a reference signal representative of the desired flow through the conduit **11** between zero and 100 percent of flow and by means of the fluidic servoloop, to be described, controls the flow through the conduit **11** with respect to the desired flow.

An air source **12** is connected through a precision regulator **13** to a distribution manifold **14** which supplies air under pressure to an amplifier **15**, a transverse impact modulator **16**, a proportional amplifier **17** and a control amplifier **18** via conduits including respective fixed fluidic restrictors **19**, **20**, **21** and **22**. The restrictor **20** determines the proper flow rate for one power input jet **23** of the transverse impact modulator **16** while another restrictor **24** defines the flow rate for the balancing power input jet **25**. The output conduit **27** of the transverse impact modulator **16** is connected to a control stream port **8** of the proportional amplifier **15**. Normally, an output is provided through the output conduit **28** which is connected to a control stream port **29** of the proportional amplifier **17**. The output port **28** also connects through a variable fluidic restrictor **30** to the control stream port **26** of the modulator **16**. The output port **28** is further connected to atmosphere through a set point variable restrictor **31**, the setting of which establishes the desired reference flow signal. The function of the proportional amplifier **15** and modulator **16** is to automatically compensate for pressure variations in the air supply through the manifold **14** in order that the reference set point established by adjustment of the variable restrictor **31** is maintained constant. The other control stream port **43** of the proportional amplifier **17** is connected via a fluidic differential pressure cell **32** to an orifice plate **33** in the conduit **11** through which the flow is being controlled. The cell **32** may be of the type shown in U.S. Pat. application Ser. No. 631,957 entitled Fluidic Diode or Sensor Device of R.L. Blosser, Jr. filed Apr. 19, 1967. The actual flow signal through the diode **32** is attenuated by means of a variable restrictor **34** which permits a portion of the pressure to be bled off to properly match the signal from the diode **32** with the characteristics of the amplifier **17** in order that the actual flow signal via control port **43** can be accurately compared with the reference signal via the control port **29**. The output port **35** of the amplifier **17** is connected to the control port **36** of the power amplifier **18**. The output port **37** of the power amplifier **18** is connected to control a valve **38** such as a Mason Neilan valve disposed in the conduit **11** to control the flow therethrough.

In operation, the reference signal applied to the control stream port **29** is determined by adjustment of the variable restrictor **31**. Any variations in the air pressure from the manifold **14** are applied through the restrictor **19** and if there is an increase in pressure, for example, an increased flow via the output port **28** of the amplifier **15** will be introduced at the control port **26** to cause increased flow from the control stream which deflects the power stream emanating via the power stream port **23** causing less flow to occur via the output port **27**. This reduces the control stream flow emanating from the input port **8** in the proportional amplifier **15** and reduces the output flow from the output port **28** proportionately to maintain the reference pressure signal constant at the control stream port **29** of the amplifier **17**. The opposite will occur on reduced pressure in the manifold **14** thereby tending to maintain the reference pressure signal constant.

The actual flow signal from the orifice plate **33** in the conduit **11** is attenuated by the cell **32** and variable restrictor **34** and then applied to the control stream port **43** of the proportional amplifier **17**. If the actual flow signal at the control port **43** is equal to the reference signal at the control port **29**, the power stream provided at the power input port **40** of the amplifier **17** will divide equally and the output pressure at output ports **35** and **41** will be equal with the output port **41** vented to atmosphere and there will be no change in the actuation of the valve **38**. If the flow through the conduit **11** is too high, the signal appearing at the control port **43** will be greater than that at the control port **29**. The power jet will then be deflected so that more of the flow goes through the output port **35** providing a control signal at control port **36** which is amplified in the power amplifier **18** to cause the valve **38** to restrict the flow in the conduit **11** until there is no difference between the desired flow and the actual flow.

Assuming that the flow is less than the desired flow through the conduit **11**, the signal at the control port **29** will exceed that at the control port **43** thereby causing less fluid to flow through the output port **35** and reducing the signal to be amplified in the power amplifier **18** to cause the valve **38** to permit more flow through the conduit **11**.

Referring now to FIG. **2**, a fluidic liquid level control system is shown in which a liquid level sensing probe **50** is disposed in a tank **51** to sense the level of a liquid within the tank in order to maintain the liquid at a predetermined height. A fluidic diode or differential pressure cell **52** is provided with air from a regulated pressure source **53** via a fluidic variable restrictor **54**. One output of the diode **52** is connected to the probe **50** while its alternative output is connected to a capacitance or delay tank **55**. The output of the delay tank **55** is connected through a variable restrictor **56** to an input port of a fluidic Schmitt trigger device **57**. The other input ports of the Schmitt trigger device **57** are connected to the pressure source **53** via variable restrictors **58** and **59**. The output ports of the Schmitt trigger device **57** are connected to the input control ports of a fluidic bistable flip–flop **62** which has its outputs connected to a hydraulically operated pump **63** for controlling the liquid level in the tank **51**.

In operation, with the liquid level below the lower extremity of the probe **50**, the air will flow through the diode **52** and out the probe **50** thereby providing no output signal to the delay tank **55** which causes no change in the actuation of the pump **63**. When the level of the liquid in the tank **51** reaches the lower extremity of the probe **50** which is located at the desired height of the liquid, the air is prevented from going through the probe **50** and is diverted within the diode **52** to enter the delay tank **55**. The function of the delay tank **55** is to prevent a single spurious signal from accidentally activating the Schmitt trigger **57** in the event the probe **50** is disposed in a tank where the liquid is agitated or turbulent. The delay tank **55** provides an integrating or capacitive effect. When the capacitive effect has taken place, a fluidic signal from the delay tank **55** is provided to the Schmitt trigger device **57** which is then energized to provide a signal to the bistable flip–flop **62**. The bistable flip–flop **62** energizes the pump **63** to cause it to extract liquid from the tank **51** until the bottom of the probe **50** is again exposed. This permits air to exhaust through the probe **50** thereby maintaining the liquid in the tank at a predetermined level defined by the lower extremity of the probe **50**.

An alternative liquid level control system is shown in FIG. **3** in which a bubbler tube or sensing probe **70** is inserted a predetermined distance below the level of the fluid in a tank **71**. Air is supplied from a regulated pressure source **72** to a manifold **73** and thence through a fixed restrictor **74** to the power stream port **75** of a proportional amplifier **76**. The manifold **73** also provides the reference level control signal to the control stream port **77** of the amplifier **76** via a fixed restrictor **78** and a set point variable restrictor **79**, the setting of which establishes the desired liquid level signal. The manifold **73** further provides air to the bubbler probe **70** via a variable restrictor **80**. The probe **70** is also connected via a variable restrictor **81** to provide a signal representative of the actual level of the fluid in the tank **71** to the control stream port **82** of the proportional amplifier **76**. A power amplifier **83** has its power stream port **84** connected to be provided with air from the distribution manifold **73** via a fixed restrictor **85** and has its control stream port **86** connected to the operative output port **87** of the proportional amplifier **76**. The output port **88** of the power amplifier **83** is connected to a variable speed pump or valve **89** to control the level of the liquid in the tank **71**. The output port **88** is also connected in feedback fashion via a variable restrictor **90** effectively to the control port **82** of the amplifier **76**.

In operation the material to be controlled is flowing into the tank **71** and the control of the level of the liquid in the tank **71** is accomplished by means of the variable speed pump **89** whose speed is controlled by the fluidic level control system. As the level in the tank **71** increases, the back pressure signal in the bubbler probe **70** is compared at port **82** with the reference pressure signal at port **77**. The difference in pressure, if any, appearing at the ports **77** and **82** of the proportional amplifier **76** causes a proportionately greater or lesser output flow from the output port **87** as a function of the relative difference as explained above. The fluidic output signal from the proportional amplifier **76** is amplified in the power amplifier **83** to control the speed of the pump **89** to maintain the liquid in the tank **71** at the desired level. The feedback connection from the output of the power amplifier **83** to the input of the proportional amplifier **76** can be adjusted by means of the variable restrictor **90** to provide the desired stability and sensitivity for any specific application.

Referring now to FIG. **4**, a fluidic density control system will be described which measures and controls the density of a material in a tank **91**. The density sensor may comprise two probes **92** and **93** mounted one above the other such that the probes **92** and **93** measure the head of material at different depths in the material. The basic purpose of the density control system is to detect small changes in the differential head pressure when comparing the pressure seen by the two probes since changes in this differential are proportional to the change in density of the material. The output from each of the probes **92** and **93** is connected to respective control stream ports **94** and **95** of a proportional amplifier **96**. The probes are provided with air from a regulated air supply **97** connected to a manifold **98**. The probes **92** and **93** are connected via respective variable restrictors **100** and **101** to the manifold **98**. The power stream port **102** of the amplifier **96** is connected to the manifold **98** via a fixed restrictor **103**. The output signal from the proportional amplifier **96** is further amplified in cascaded amplifiers **105** and **106**. Each of the amplifiers **105** and **106** has its respective power stream port connected via respective fixed restrictors to the manifold **98** for providing increasingly higher pressure at each stage. For example, a supply pressure of 3 p.s.i. may be provided to the power port **102** of the amplifier **96**; 16 p.s.i. to that of the amplifier **105**, and 30 p.s.i. to that of the amplifier **106**.

The output port **107** of the amplifier **106** is connected to the control stream port **108** of the amplifier **109**. The other control stream port **110** of the amplifier **109** is is connected via a variable restrictor **111** and a fixed restrictor **112** to the manifold **98** to provide a reference or desired density signal to the control stream port **110**. The signal representative of the actual density the material is applied to the control stream port **108**. Any difference between the reference and actual density signals provides an output signal via the output port **113** which is coupled to the control stream port **114** of a power amplifier **115** via a variable restrictor **116**. The amplified output signal from the output port **117** of the amplifier **115** is utilized to vary the density of the material in the tank **91** until the actual density signal appearing at control port **108** is equal to the desired density signal appearing at control port **110**. A feedback connection for stability and sensitivity purposes may be provided from the output port **117** via a variable restrictor **118** to the control port **108**. The output signal from the amplifier **115** may be used to control a pump, for example, to add dilutant to the tank **91**.

It will be appreciated that suitable meters and indicators may be provided in the systems to accurately adjust and measure the various pressures but have not been shown for purposes of simplicity.

We claim:

1. A fluidic control system comprising condition sensing means responsive to actual conditions for providing fluidic signals in accordance with said actual conditions, fluidic threshold defining means responsive to said fluidic actual condition signals for providing fluidic control signals when said actual condition signals deviate from a desired condition, fluidic amplifying means responsive to said control signals for providing amplified control signals, and controllable load means responsive to said amplified control signals for controlling said actual conditions to tend to return said actual conditions to said desired condition; said fluidic threshold defining means includes fluidic flow path defining means having a preferred flow path coupled to said condition sensing means and a nonpreferred flow path that becomes operative to provide said fluidic actual condition signals when said preferred flow path becomes inoperative, and fluidic switch means coupled to said nonpreferred flow path and responsive to said fluidic actual condition signals when said preferred flow path becomes inoperative for providing said fluidic control signals; and fluidic delay means coupled between said fluidic flow path defining means and said fluidic switch means for delaying the effectiveness of said fluidic actual condition signals to prevent spurious signals from becoming effective.

2. A fluidic control system of the character recited in claim **1** in which said fluidic delay means is a delay tank.

3. A fluidic control system of the character recited in claim **1** in which said fluidic switch means is a fluidic Schmitt trigger means.

4. A fluidic control system comprising condition sensing means responsive to actual conditions for providing fluidic signals in accordance with said actual conditions, fluidic threshold defining means responsive to said fluidic actual condition signals for providing fluidic control signals when said actual condition signals deviate from a desired condition,

fluidic amplifying means responsive to said control signals for providing amplified control signals, and controllable load means responsive to said amplified control signals for controlling said actual conditions to tend to return said actual conditions to said desired condition; said fluidic threshold defining means having a fluidic reference signal generating means for providing fluidic reference signals in accordance with said desired condition and comparison means responsive to said actual signals and said reference signals for providing a comparison therebetween; said fluidic reference signal generating means having a means for compensating for undesired pressure fluctuations to provide substantially constant fluidic reference signals, and said compensating means includes a proportional amplifier means and transverse impact modulator means interconnected to each other and coupled between a fluid pressure source and said comparison means for compensating for undesired pressure fluctuations of said fluid pressure source thereby to provide substantially constant fluidic reference signals.

5. A fluidic control system comprising condition sensing means responsive to actual conditions for providing fluidic signals in accordance with said actual conditions, fluidic threshold defining means responsive to said fluidic actual condition signals for providing fluidic control signals when said actual condition signals deviate from a desired condition, fluidic amplifying means responsive to said control signals for providing amplified control signals, and controllable load means responsive to said amplified control signals for controlling said actual conditions to tend to return said actual conditions to said desired condition; said fluidic threshold defining means having a reference signal source and a proportional fluid amplifying means having a pair of input control nozzles associated therewith, one of said input control nozzles being coupled to said reference signal source, the other of said control nozzles being coupled to said sensing means and a variable restrictor means coupling the output of said fluidic amplifying means to the said other control nozzle whereby the stability and sensitivity of the system can be controlled.

6. A fluidic control system of the character recited in claim 5 in which said proportional amplifying means includes a plurality of cascaded proportional amplifiers having successively higher pressure power streams.

7. A fluidic control system of the character recited in claim 5 in which said condition sensing means includes probe means disposed with respect to the substance being measured such that the location of said probe means defines a desired condition at least in part.

8. A fluidic control system of the character recited in claim 7 in which said probe means is responsive to pressure heads of a substance at two different levels for providing a measure proportional to the density of said substance.