United States Patent [19]

Wolter et al.

[11] 3,736,949

[45] **June 5, 1973**

[54] **FLUIDIC RESPIRATOR**

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[22] Filed: **Feb. 8, 1971**

[21] Appl. No.: **113,149**

[52] **U.S. Cl.** **137/102,** 128/145.8

[51] **Int. Cl.** **A62b 7/00**

[58] **Field of Search** 137/102; 128/142.2, 128/145.5, 145.6, 145.8

[56] **References Cited**

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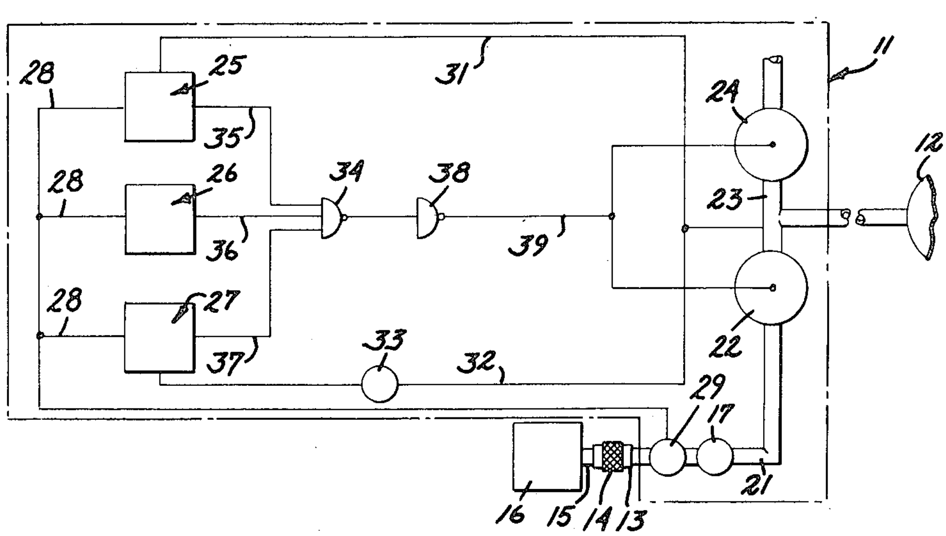
[57] **ABSTRACT**

A respirator as disclosed which is controlled by pneumatic logic components. The respirating apparatus has a first control mode, in which a patient's lung pressure is sensed to control the breathing function. When lung pressure falls below a predetermined low limit air is supplied to the patient, and as lung pressure approaches and exceeds a predetermined high limit, the supply of air is cut off. In a second control mode, respirating air is again supplied on the basis of sensing pressure below the low limit, but air supply cut off is effected after a predetermined volume of air has been delivered to the patient's lungs. Supplemental to either type of control is apparatus which counts the number of output "breaths," and when a predetermined number has been reached a "sigh breath" of increased volume is provided to break the constant breath pattern and thereby preclude lung collapse.

15 Claims, 2 Drawing Figures



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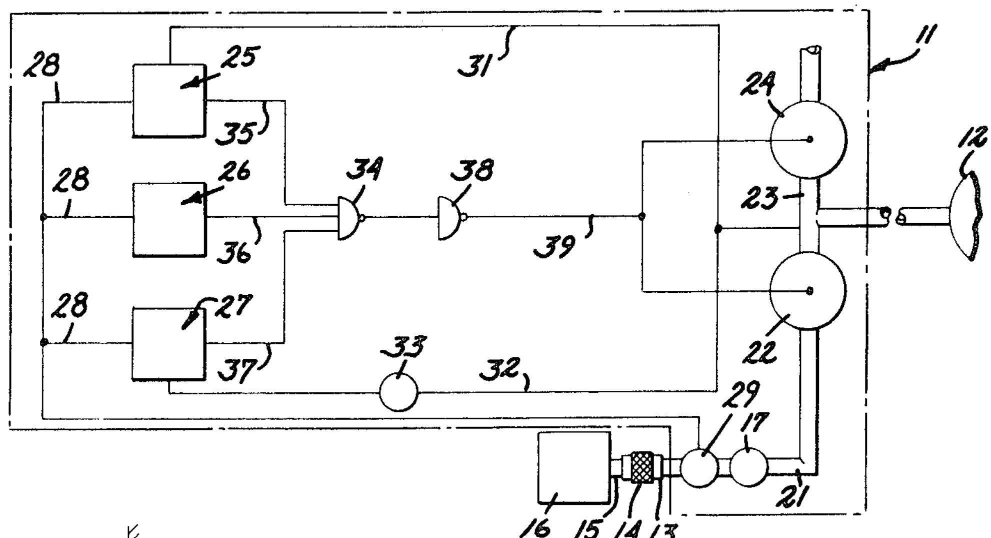

FIG. 1

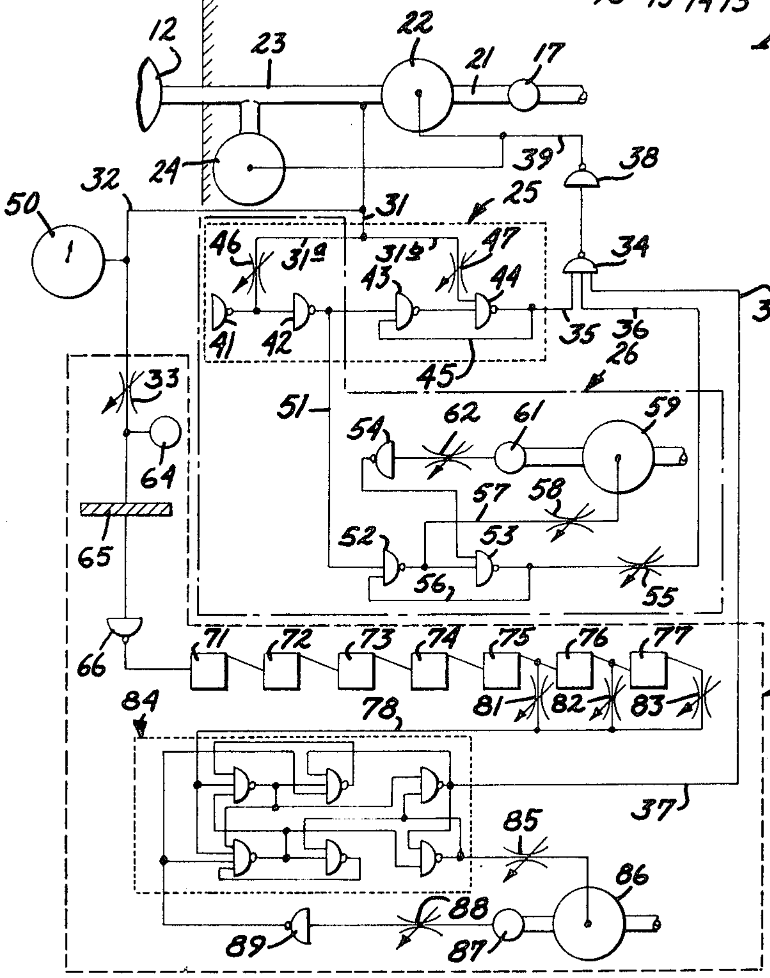

FIG. 2

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FLUIDIC RESPIRATOR

The invention is directed to respirators generally, and specifically to those which are pneumatically controlled.

The function of a respirator is to help persons having respiratory disorders to breath properly, and to restore the breathing process to persons in emergency situations. The manner in which breathing assistance is provided depends on the condition of the patient's lungs; i.e., the load presented to the respirating apparatus. Normal lungs are elastic in nature, and their volume increases and decreases with inhalation and exhalation. Under such circumstances, the respirating apparatus may control breathing as a function of lung pressure. Respirating air is supplied when lung pressure falls below a given low limit and is cut off when lung pressure exceeds a predetermined high limit. Under this mode of control, it may also be desirable to establish the low limit at a negative value (vacuum) to permit the patient to initiate the breathing cycle by inhaling slightly. Supplying respiratory air at the patient's demand prevents excessive oxygen from continuously building up in the patient's blood stream, which results in hyperventilation.

Some respiratory diseases affect elasticity of the lungs, which significantly diminishes the aforementioned volumetric change with inhalation and exhalation. Consequently, the respirating apparatus works under an essentially constant volume load, and if operation is in the pressure sensing mode the upper pressure limit may be reached before the patient receives sufficient respirating air. The solution to this problem is to retain the pressure sensing mode at the lower pressure limit, but to insure the provision of a minimum volume of respirating air to the patient before switching to exhalation. Thus, volume sensing means are incorporated into the respirating apparatus control to switch operation to the exhalation cycle after the patient has received the minimum volume of respirating air.

It is also known that operation of a respirator at a constant breathing rate over a period of time will eventually lead to collapse of the lungs. Accordingly, it is desirable to include a "sigh" control in the respirator which periodically provides a breath of increased volume to the patient. This breaks the constant breathing rate and precludes such lung collapse.

Our invention provides all of the foregoing features in respirating apparatus which employs pneumatic logic elements to effect the various control modes. A portion of the control circuitry consists of fluidic amplifiers which have no moving parts and offer extreme reliability. However, conventional pressure actuating valve means are employed to control the flow of respirating air under flow operating pressure. The air supply valve, for example, is normally closed and permits the passage of respirating air only during the inhalation cycle. Consequently, respirating air is conserved during the exhalation cycle. This is an improvement over existing respiratory control apparatus which employ fluidic amplifiers to control the supply of respirating air. In all such systems of which we are aware, the supply of respirating air is merely dumped to atmosphere during the exhalation cycle.

Our inventive apparatus also permits extremely reliable operation with very low control pressure even though pressure of the respirating air supply is considerably higher. This also represents an air consumption saving, particularly in view of systems in which the control pressure approaches or is equal to the regulated pressure of the respirating air supply.

The combination of fluidic logic elements with conventional valve means results in a unit which is extremely reliable in operation and, by virtue of the simplicity and availability of individual components, can be assembled at low manufacturing costs. The components are sufficiently small to permit complete portability of the unit, particularly when used in conjunction with the respirating air supply of the hospital. Under these circumstances, the respirating air supply may also serve as a source of control pressure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a general schematic representation of respirating apparatus embodying the inventive principle, wherein control means for effecting pressure sensitive, volumetric and sigh control modes are represented by block diagrams; and

FIG. 2 is a detailed schematic representation showing the control circuitry for each of the control means.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring initially to FIG. 1, a respirator is schematically represented by a broken line designated **11**. The output of respirator **11** consists of a mask **12** adapted for patient use, and a pressure coupling **13** serves as the respirator inlet. Coupling **13** is adapted for connection with a mating coupling **14** which, by means of a conduit **15**, communicates with a source of respirating air **16**, usually oxygen enriched. Such sources of respirating air are ordinarily provided in certain hospital rooms, particularly those relating to intensive care.

Internally, coupling **13** is connected to a conduit **21** which communicates through a pressure regulating valve **29** and an on-off valve **17** with the inlet of a pressure operated supply valve **22**. The outlet of supply valve **22** is connected to mask **12** by a conduit **23**, which is also connected to the outlet of a pressure actuated exhaust valve **24**. As is shown, the outlet of exhaust valve **24** communicates with atmosphere.

Respirator **11** includes control means for effecting first and second control modes, which are selectively usable, and a third control mode which may be used in combination with either of the other control modes. In FIG. 1, the control means are designated **25**, **26** and **27**, and each is supplied with pressure through a conduit **28** which communicates with conduit **21** through pressure regulating valve **29**. In the preferred embodiment, the control pressure supplied to control means **25–27** is considerably lower than the pressure of respirating air provided through conduit **21**.

Control means **25** includes sensing apparatus and logic circuitry which permits inhalation and exhalation to be controlled by lung pressure, which is sensed through a conduit **31** connected with conduit **23**. Control means **26** controls the inhalation cycle in a similar manner, but the exhalation cycle is governed by apparatus which automatically supplied a predetermined volume of respirating air to the patient.

Control means **27** effects operation in the "sigh" control mode, in which an increased volume of respirating air is supplied to the patient at periodic intervals. In order to accomplish this function, control means 27 must also communicate with conduit 23 through a conduit 32 which includes an on-off valve 33.

Each of the respective control means 25–27 has an output which serves as an input to a conventional "NOR" logic element 34. The transmission of pressure signals is to conduits 35–37, respectively.

In the preferred embodiment, the NOR logic function is provided by turbulent fluid amplifiers similar to the one disclosed in U.S. Pat. No. 3,234,955, issued to Raymond N. Auger on Feb. 15, 1966. Turbulence fluid amplifiers consist of spaced inlet and outlet tubes which are aligned to permit fluid supplied to the inlet tube to form a free stream or jet before it is collected in the inlet tube. The parameters of the free jet are controlled so that under normal conditions a critical Reynolds number is approached; i.e., the jet remains laminar but is easily prompted into a state of turbulence. The fluid amplifier includes one or more control inputs which are positioned to permit a control jet to transversely impinge on the free jet, causing it to become turbulent and preventing further collection at the outlet tube. Thus, whereas the outlet tube initially provides an output signal, the application of one of several control jets reduces the output to zeros and thus performs the NOR logic function. Operation of the turbulence fluid amplifier is monostable, and laminar flow resumes in the absence of a control jet.

The output of logic element 34 is inverted through the use of a second pneumatic NOR element 38. The output of NOR element 38 is commonly received through a conduit 39 by the pressure control portions of valves 22 and 24. Supply valve 22 is normally biased to a closed position whereas exhaust valve 24 is normally opened. From the standpoint of magnitude, valves 22 and 24 are biased for the same range of operation. Accordingly, a positive pressure signal appearing at the output of logic element 38 simultaneously opens supply valve 22 and closes exhaust valve 24. Under this condition, the patient receives respirating air through mask 12 and inhalation is effected. Control means 25 and 26 sense the sufficiency of respirating air to the patient, and the output of logic element 38 is switched accordingly. Under this condition, supply valve 22 closes and exhaust valve 24 opens, permitting the inhaled air to be exhausted to atmosphere.

FIG. 2 discloses the specific pneumatic circuitry which brings about the different control modes. The numeral designation of FIG. 1 carries over to FIG. 2. As is typical in the symbolic notation of logic circuitry, only the control inputs and outputs are shown. The conduits communicating the supply of power pressure are left out for purposes of simplicity and clarity.

Pressure sensitive control means 25 comprises four "NOR" logic elements 41–44 connected output to input as shown. The output of NOR element 44 is connected to conduit 35 and also serves as the input to NOR element 43 through a conduit 45. Internally of control means 25, conduit 31 divides into conduits 31*a* and 31*b*. Conduit 31*a* includes a variable resistor 46 and is connected to the single input of NOR element 42. Conduit 31*b* also includes a variable restriction 47 and serves as the second input to NOR element 44. Variable restrictions 46 and 47 are set so that the NOR elements 41–44 are capable of sensing different levels of lung pressure through conduit 31 to effect the desired pressure control mode.

In operation, NOR element 41 provides a continuous output signal since it has no control inputs. Whether the output signal from NOR element 41 reaches the control input of NOR element 42 with a magnitude sufficient to prompt its laminar supply jet into a state of turbulence depends on how much of the signal is bled through variable restriction 46 into conduit 31. This, of course, is a function of the pressure in conduit 31, meaning that at a particular point a decrease in lung pressure will permit the output pressure of NOR element 41 to bleed through variable restriction 46. With no input signal NOR element 42 is "on" which turns NOR element 43 "off." Assuming that the pressure in conduit 31*b* is too low to have an effect on NOR element 44, it follows that the output occurring at conduit 35 will be "on," or a positive pressure signal. This signal is fed back through conduit 45 to NOR element 43 to maintain a stable state.

After passing through NOR elements 34 and 38, this output signal appears as a positive pressure in conduit 39 and thus opens control valve 22 while closing control valve 24.

As the broken lines of FIG. 2 indicate, control means 26 employs selected circuit components of control means 25 in order that it may receive a desired output signal from NOR element 42 through a conduit 51. Obviously, the circuit components shared, including NOR elements 41 and 42, variable resistor 46 and the innerconnecting pressure conduits, could be duplicated for control means 26. The sharing of elements between control means 25 and 26 eliminates unnecessary parts and conserves valuable space.

Control means 26 also includes a NOR element 52, one input of which is connected to conduit 51, and NOR elements 53 and 54. NOR element 53 has two inputs which are respectively connected to the outputs of NOR elements 52 and 54. The output of NOR element 53 is connected to conduit 36 through a variable resistor 55, the latter serving merely as part of the on-off control for control means 26. The output of NOR element 53 is also conveyed from a point upstream of variable restriction 55 through a conduit 56 to serve as the second input for NOR element 52. The output of NOR element 52 is also connected by a conduit 57 including a variable restriction 58 to the inlet of a pressure actuated control valve 59. Variable restriction 58 cooperates with variable restriction 55 to complete the on-off switching control for control means 26. Valve 59 is directly supplied with pressure through conduit 21, and its outlet is connected to the input of NOR element 54 through a timing circuit including a volume capacitor 61 and a variable restriction 62.

As mentioned above, a volume sensitive control means provides the necessary mode of operation in cases where the volume capacity of a patient's lungs remains essentially constant during inhalation and exhalation. This mode of operation insures that a sufficient volume of air enters the patient's lungs before the exhalation cycle has begun. However, it is not essential that the control means for switching from the exhalation to the inhalation cycle be a volume sensing device since the problem exists only at the upper inhalation limit. Accordingly, it is possible for volume sensing control means 26 to employ the low limit pressure sensing portion of control means 25 and still accomplish the necessary operation.

Thus, in operation of control means **26**, let it be assumed that the respirator is in the exhalation cycle and that lung pressure has not yet fallen to the low pressure limit. Accordingly, NOR element **51** provides a sufficient output to disrupt the laminar supply jet of NOR element **42**, and no input is received by NOR element **52** through conduit **51.** Since operation is in the exhalation cycle, it follows that the output of NOR element **53** must be "off" in order for supply valve **22** to be in its closed state. Thus, both of the inputs to NOR element **52** are off, which permits it to generate a positive output signal. This signal is carried to the input of normally closed control valve **59**, which holds the valve in an open position. Pressure is therefore continuously supplied to the input of NOR element **54** through volume capacitor **61** and variable restriction **62**, and no output signal is carried from NOR element **54** to the second input of NOR element **53.** Summarizing, NOR element **52** is on, NOR element **53** is off, control valve **59** is open and NOR element **54** is off.

When lung pressure of the patient drops below the low pressure limit, the output signal of NOR element **41** is bled through variable restriction **46** and NOR element **42** turns on. As a result, NOR element **52** turns off, NOR element **53** turns on and control valve **59** closes. This positive output signal of NOR element **53** is carried through conduit **36**, NOR elements **34** and **38**, and ultimately opens supply valve **22** and closes exhaust valve **24** to initiate the inhalation cycle. Since control valve **59** has been closed, the positive input signal to NOR element **54** continues only so long as the timing circuit permits. As soon as the pressure previously built-up in volume capacitor **61** is bled off through variable restriction **62**, NOR element **54** turns on, causing NOR element **53** to turn off and thereby terminate the inhalation cycle and initiate the exhalation cycle. Cyclic operation continues as lung pressure decreases to the low pressure limit.

Control means **25** and **26** are selectively openable, the latter by operation of variable restrictions **55** and **58.** In the preferred embodiment, however, control means **25** operates at all times, whether or not control means **26** has been actuated. In this manner, the high pressure limit portion of control means **25** is capable of acting as a safety feature when the volume sensing mode of operation is selected. Specifically, variable restriction **47** is adjusted to have a resistance value which will permit the flow of air therethrough from having an effect on the normal operation of control means **26.** However, in such case that control means **26** switches the respirator to the inhalation cycle and is incapable of switching to the exhalation cycle, the increase in lung pressure will be sensed through variable restriction **47** and cut the supply of respirating air to the patient's lungs.

Control means **27** is selectively operable with either control means **25** or **26.** Conduit **32**, which communicates with conduit **31**, serves as the inlet to control means **27**, and it includes a variable restriction or on-off valve **33** for enabling or stopping the "sigh" mode of operation. Conduit **32** also includes a pressure gauge **50** which continuously monitors lung pressure. Preferably, a volume capacitor **64** is disposed in conduit **32** to smooth out stray pressure pulses which may be generated in conduit **32**, and an isolator **65** which precludes unwanted interaction of signals between control means **27** and control means **25** and **26.** Isolator **65** is a conventional, commercially available device comprising a single diaphragm relay.

The signal emanating from isolator **65** is inverted by means of NOR element **66**, from which point it is transmitted to a plurality of serially arranged binary counters numbered **71–77**, respectively. The output signals generated by binary counter **75, 76** and **77** are selectively transmittable to a conduit **78** through variable restrictions **81-83.**

Conduit **78** serves as one of two inputs to a flip-flop logic circuit represented generally by the numeral **84.** Flip-flop **84** has two outputs, one of which communicates with conduit **37**, the other being connected to a variable restriction **85** to the input of a pressure actuated control valve **86.** Variable restriction **85** performs a second on-off function for control means **27.**

Control valve **86** receives a supply from conduit **21**, and its outlet is connected to a timing circuitry comprising a volume capacitor **87** and a variable restriction **88.** The signal issuing from the timing circuitry is inverted by a NOR element **89** before passing on to the second input of flip-flop **84.**

Flip-flop **84** is conventional in design, comprising six NOR elements interconnected as shown. Being conventional, the detailed operation of each NOR element need not be described. Generally speaking, a positive signal received through conduit **78** will generate an output signal in conduit **37** while turning the output connected to control valve **86** off. A positive signal issuing from NOR element **89** has the opposite effect; i.e., there is no signal in conduit **37** whereas a positive signal is applied to normally closed control valve **86.**

Each of the binary counters **71–77** is identical to flip-flop **84** with the exception that each has but a signal input (corresponding to conduit **78**), and only a single output is used. The resulting operation is such that each application of a positive pulse causes an output signal to shift from one output to the other.

From their serial arrangement, it is evident that binary counters **71–77** are capable of counting the number of breaths that respirator **11** has supplied to the patient. This arrangement of binary counters is conventional in design, and a description of operation is not necessary. It suffices to say that opening of variable restriction **81** will permit a positive output signal in conduit **78** at the end of **32** breaths. Selective operation of variable restrictions **82** or **83** permits the generation of an output signal in conduit **78** after **64** or **128** breaths, respectively.

Reception of a signal through conduit **78** causes flip-flop **84** to shift to an output state wherein a positive output pressure signal is supplied through conduit **37** to open valve **22.** Simultaneously, the positive signal emanating from the other output maintaining valve **86** in an open position is cutoff, thereby closing valve **86.** The positive signal applied at the input of NOR element **89** continues, however, as long as the pressure buildup in capacitor **87** continues. This time period is determined by the capacity of capacitor **87** and the fluid resistance of variable restriction **88**, the latter of which is adjusted to establish the desired volume of air necessary to generate a proper "sigh." Generally, the sigh breath is one and one-half to two times the length of a normal breath.

After the pressure capacitor **87** has bled down through variable restriction **88**, the output signal of NOR element **89** turns on. This input signal to flip-flop **84** causes the output signals thereof to revert to the initial state to close valve **22** and reopen valve **86.** The binary counter begins to count again, and operation reverts to the pressure sensing or volume sensing mode until a requisite number of breaths have again been supplied.

What is claimed is:

1. Respirator apparatus for controlling the flow of respirating air to a user, comprising:

a. pressure actuated valve means having an inlet adapted for connection to a source of respirating air, an outlet and a control pressure inlet;

b. conduit means connected to the outlet of the valve means and terminating in a respirator outlet for the user;

c. and control means for sensing pressure in the conduit means, for effecting opening of the valve means when the pressure falls below a first limit and for effecting closing of the valve means when the pressure exceeds a second limit, comprising

i. first and second variable restriction means each communicating with the conduit means;

ii. first switching means responsive to the first restricted pressure for providing a signal pressure of a first or second state;

iii. second switching means responsive to the second restricted pressure and to the signal pressure for providing a control pressure of a first or second state to said control pressure inlet to effect opening and closing of the valve means;

iv. the first and second variable restriction means being adjusted to establish the first and second limit pressures, respectively.

2. The respirator apparatus as defined by claim **1,** wherein the first switching means comprises:

first and second pneumatic NOR gates;

the output of the first gate communicating with the downstream side of the first variable restriction and with the input of the second gate;

the output of the second gate serving as said first signal pressure.

3. The respirator apparatus as defined by claim **1,** wherein the second switching means comprises:

first and second pneumatic NOR gates;

one input of the first gate communicating with said first signal pressure;

the output of the first gate communicating with one input of the second gate;

the downstream side of the second variable restriction communicating with a second input of the second gate;

the output of the second gate serving as said second signal pressure and further communicating with a second input of the first gate.

4. The respirator apparatus as defined by claim **1,** wherein the first and second switching means comprise fluidic components.

5. The respirator apparatus defined by claim **1,** wherein the pressure actuated valve means is normally closed.

6. The respirator apparatus defined by claim **5,** and further comprising normally open valve means having an inlet communicating with said conduit means, an outlet serving as an exhaust for the respirator apparatus, and a control pressure inlet for receiving the control pressure, the normally open valve means being constructed and arranged to open when the normally closed valve means is closed and to close when the normally closed valve means is opened.

7. The respirator apparatus defined by claim **1,** and further comprising second control means for counting the number of breaths supplied to the user and for increasing the duration of a selected breath upon completion of a predetermined number of breaths.

8. Respirator apparatus for controlling the flow of respirating air to a user, comprising:

a. normally closed pressure actuated valve means having an inlet adapted for connection to a source of respirating air, an outlet and a control pressure inlet;

b. conduit means connected to the outlet of the normally closed valve means and terminating in a respirator outlet for the user;

c. and control means for sensing pressure in the conduit means, for opening the normally closed valve means when the pressure falls below a first limit and for effecting closing of the normally closed valve means when the pressure exceeds a second limit, comprising

i. first adjustable means responsive to pressure in the conduit means for providing a first signal pressure corresponding to the first limit pressure;

ii. second adjustable means responsive to pressure in the conduit means for providing a second signal pressure corresponding to the second limit pressure;

iii. and switching means responsive to the first and second signal pressures for providing a control pressure of a first or second state to the control pressure inlet to effect opening and closing of the valve means.

9. Respirator apparatus for controlling the flow of respirating air to a user, comprising:

a. pressure actuated valve means having an inlet adapted for connection to a source of respirating air, an outlet and a control pressure inlet;

b. conduit means connected to the outlet of the valve means and terminating in a respirator outlet for the user;

c. and control means for sensing pressure in the conduit means, for effecting opening of the valve means when the sensed pressure falls below a predetermined limit and for effecting closing of the valve means a predetermined time after said valve means has been opened, comprising

i. variable restriction means communicating with the conduit means;

ii. first switching means responsive to the restricted pressure for providing a first signal pressure of a first or second state;

iii. pneumatic timing means responsive to the second state of the first signal pressure for providing a second signal pressure of predetermined duration;

iv. and second switching means responsive to the first and second signal pressures for providing a control pressure of first or second state to said control pressure inlet to effect opening and closing of the valve means.

10. The respirator apparatus as defined by claim **9,** wherein the first switching means comprises:

first, second and third pneumatic NOR gates;

the output of the first gate communicating with the downstream side of the variable restriction and with the input of the second gate;

the output of the second gate communicating with the input of the third gate;

and the output of the third gate serving as said first signal pressure.

11. The respirator apparatus as defined by claim **9**, wherein the pneumatic timing means comprises:

a second normally closed, pressure actuated valve means adapted for connection with a source of fluid pressure;

and third conduit means connected downstream of the second valve means, the third conduit means including a fluid capacitor and a variable fluid restriction.

12. The respirator apparatus as defined by claim **9**, wherein the second switching means comprises a pneumatic NOR gate having first and second inputs communicating with the first and second signal pressures, respectively, and an output for providing said control pressure, the output further communicating with the first switching means to maintain said first signal pressure in one of said first or second states.

13. The respirator apparatus defined by claim **9**, wherein the valve means is normally closed.

14. The respirator apparatus defined by claim **13**, and further comprising normally open valve means having an inlet communicating with said conduit means, an outlet serving as an exhaust for the respirator apparatus, and a control pressure inlet for receiving said control pressure, the normally open valve means being constructed and arranged to open when the normally closed valve means is closed and to close when the normally closed valve means is opened.

15. The respirator apparatus defined by claim **9**, and further comprising second control means for counting the number of breaths supplied to the user and for increasing the duration of a selected breath upon completion of a predetermined number of breaths.

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