United States Patent

[11] 3,633,576

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[54] **VOLUMETRIC RESPIRATOR**
7 Claims, 10 Drawing Figs.

[52] **U.S. Cl.** **128/145.8**
[51] **Int. Cl.** **A62b 7/00**
[50] **Field of Search** ..... 128/145.8, 145, 145.5–145.7, 191, 194, 202, 203, 188, DIG. 17

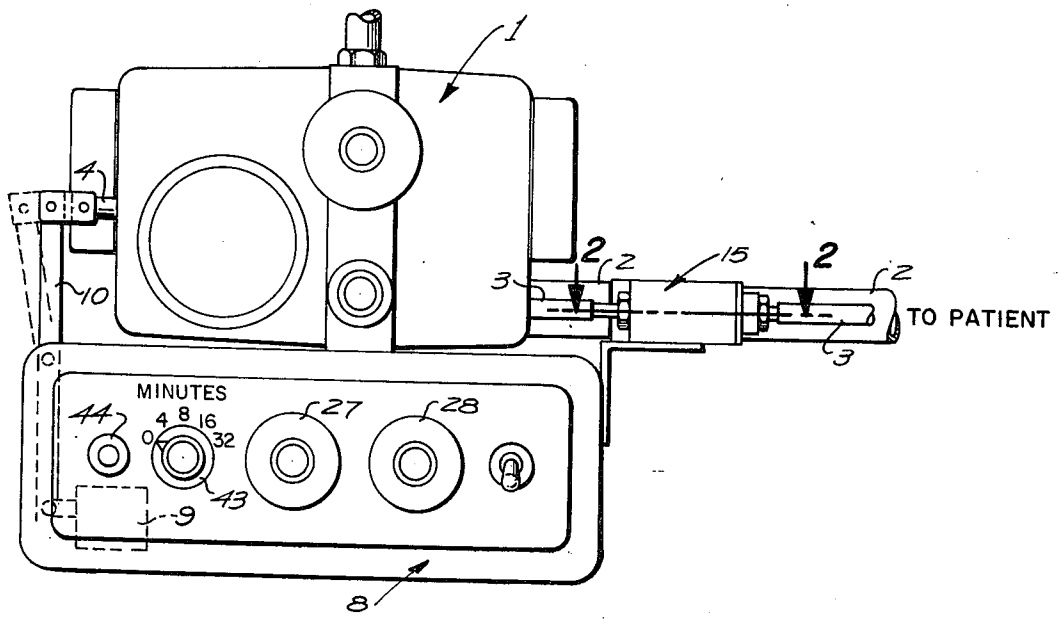
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ABSTRACT: A volumetric respirator which may utilize, as its source of air or life-sustaining gas, a conventional pressure-limited respirator. One or more flow meters, depending upon the selected pressure-limited respirator, are interposed between the respirator and the patient. An adjustable volume control, sensitive to the flow meters, shuts off the supply of air or gas after a selected tidal volume of air has passed. A timer reestablishes flow after a preselected period to permit the patient to exhale. At preselected intervals, the volume control causes a predetermined excess or sigh volume of air or gas to pass.



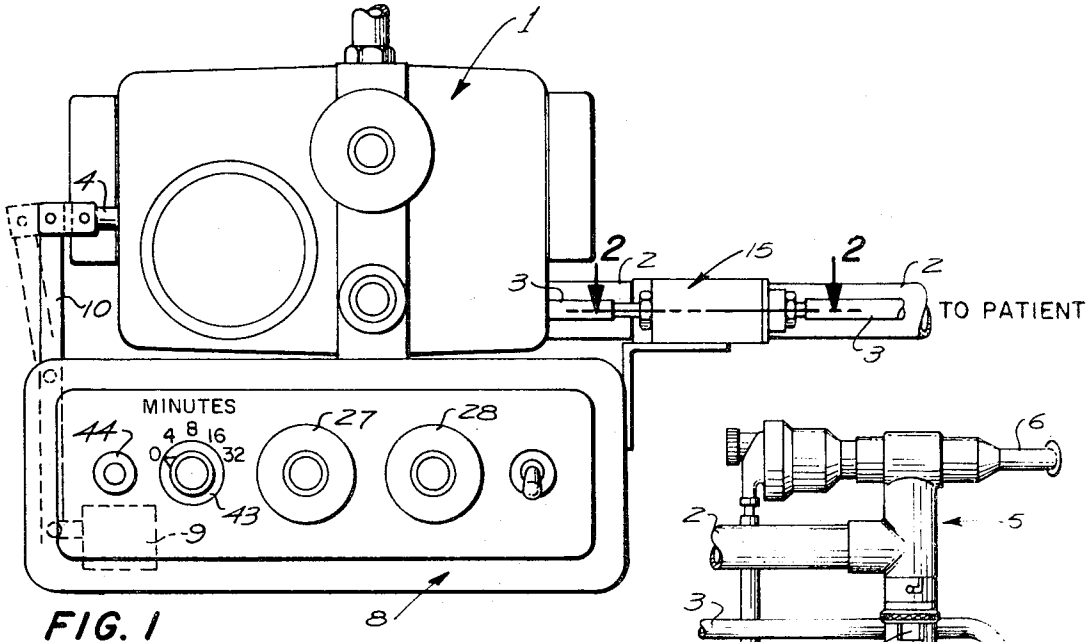


FIG. 1

FIG. 4

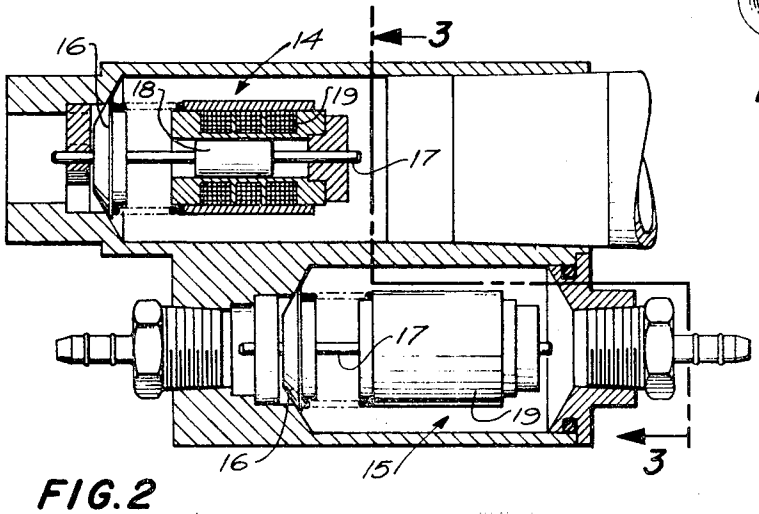


FIG. 2

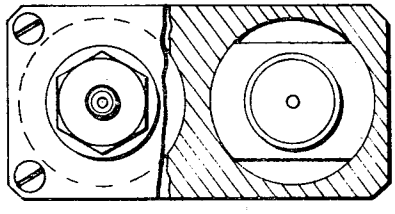


FIG. 3

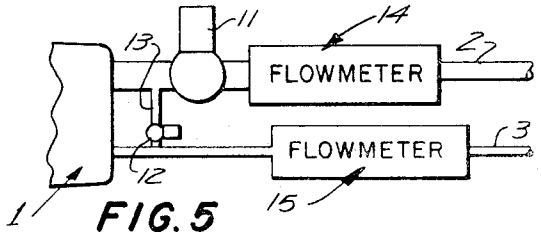


FIG. 5

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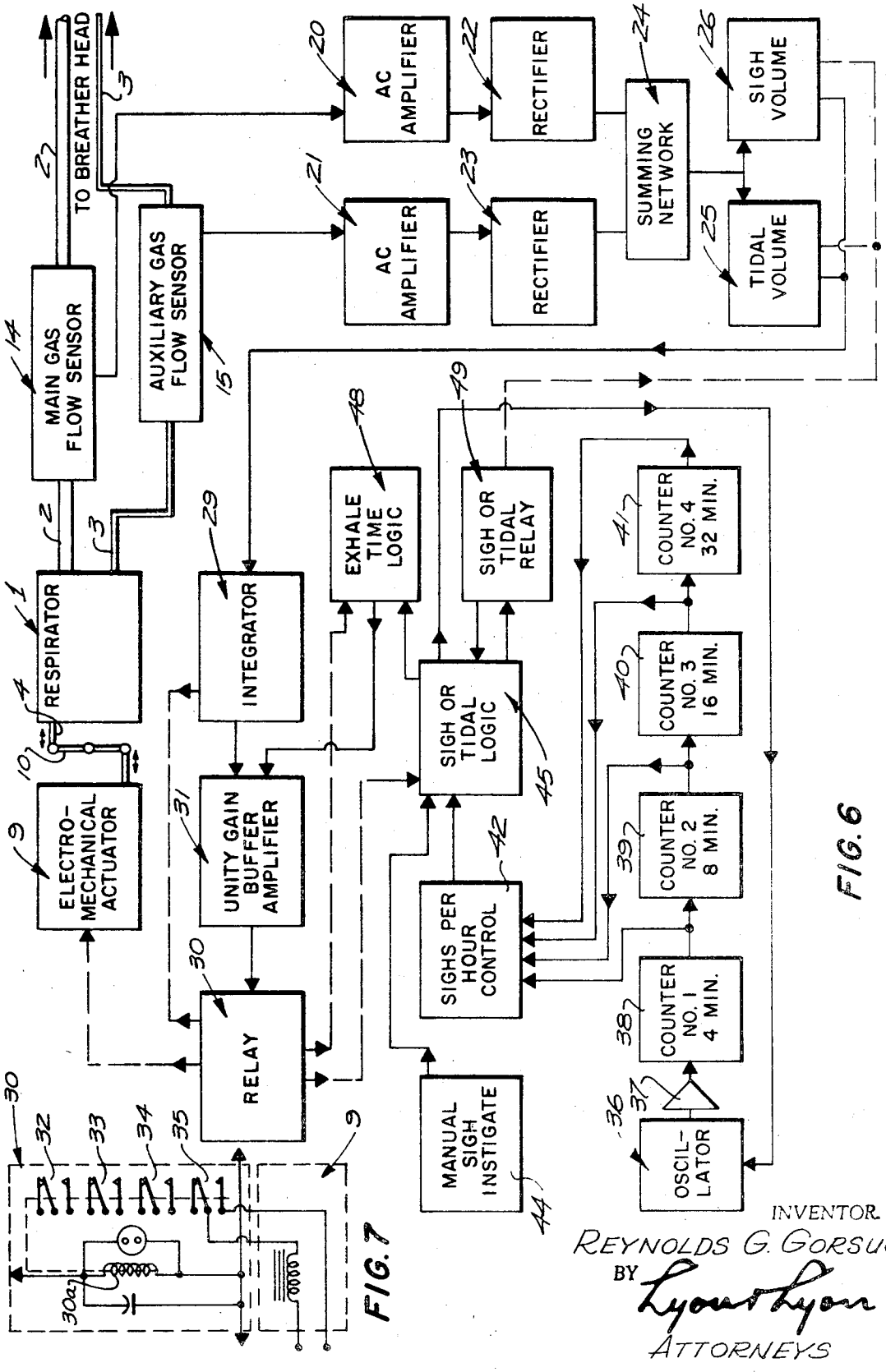
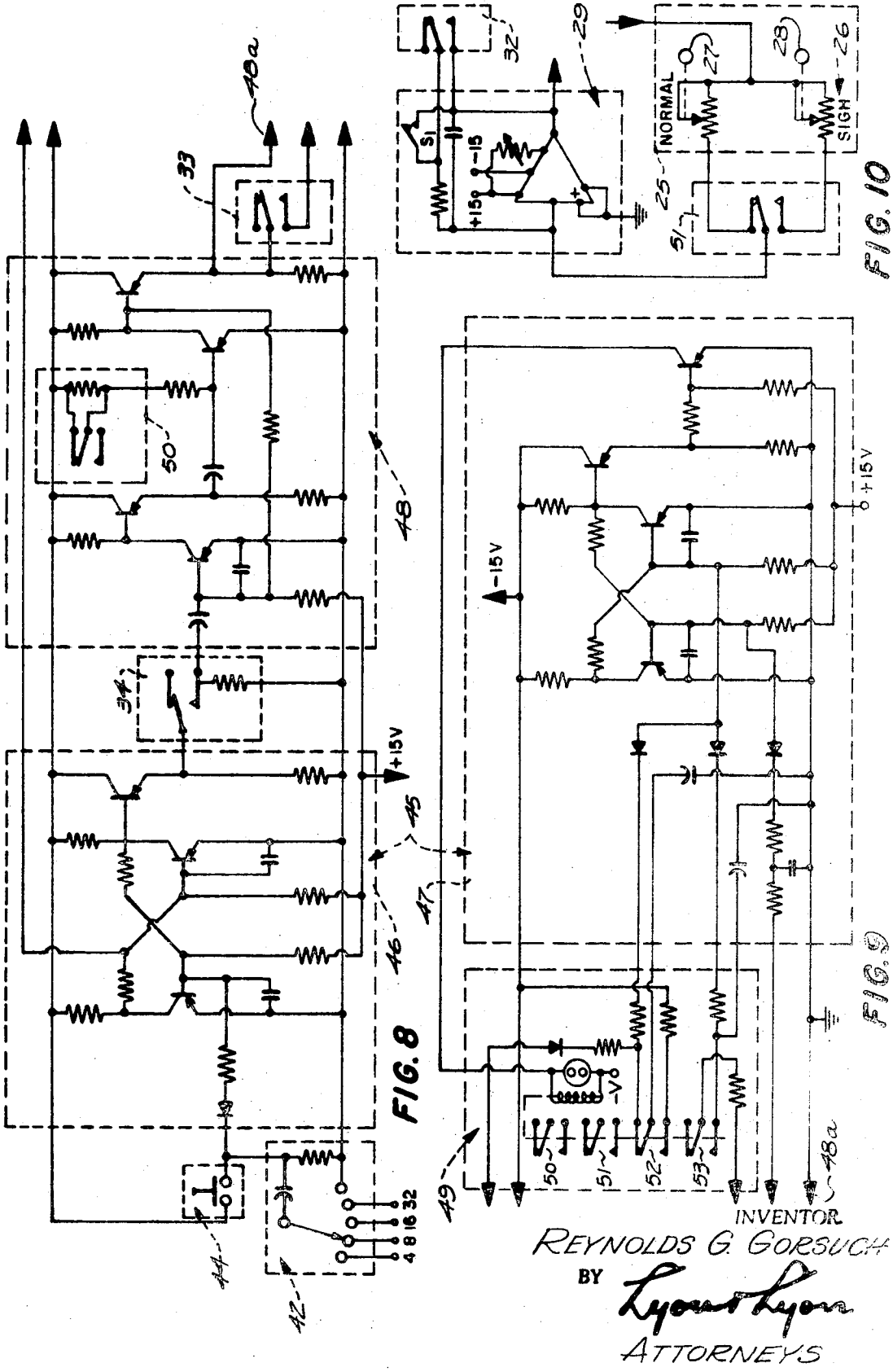


FIG. 6

FIG. 7

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VOLUMETRIC RESPIRATOR

BACKGROUND OF THE INVENTION

Respirators are frequently used in hospitals and in first-aid treatment to assist or take over the breathing function of the patient. Assuming no effort by the patient, the conventional respirator supplies air or a life-sustaining gas or mixture through a tube to a breather head or mask at a predetermined pressure for a preselected interval. Means are provided, however, to sense incipient inhalation or exhalation on the part of the patient so as to start the supply of gas or to stop the supply of gas. This type of respirator is known as a Pressure Limited Respirator or an Intermittent Positive Pressure Breathing Apparatus.

It is recognized that this type of respirator is not fully compatible with the patient's needs; more specifically:

1. Oxygen transfer to the blood is a function of the volume delivered rather than the pressure in the system.

2. The pressure required tends to repress the right side of the heart and thus tends to increase the workload on the heart.

3. A patient should be permitted to receive periodically an excess volume of gas known as a "sigh volume" as this reduces mental tension and inhibits atrophy of lung tissue which is not ventilated by the normal or tidal volume of air.

Previous attempts to overcome these known defects of the conventional pressure-limited respirator have not met with success.

SUMMARY OF THE INVENTION

The present invention is directed to a volumetric respirator which overcomes the limitations of a pressure-limited respirator, and is summarized in the following objects:

First, to provide a volumetric respirator which may be arranged as an attachment on a pressure-limited respirator to convert the respirator so as to supply the patient with a preselected volume of air during each breathing cycle; or, which may be utilized to control the gas available at a preselected pressure.

Second, to provide a respirator which incorporates a novel means for effecting shutoff of the supply of gas, when the patient has received a preselected volume of gas, and thereupon delays the supply of a next charge of gas for a period calculated to permit the patient to exhale.

Third, to provide a volumetric respirator which, when arranged to incorporate a pressure-limited respirator having a manual shutoff control, may be arranged to effect automatic operation of the normally manually operated control.

Fourth, to provide a volumetric respirator which, when arranged to incorporate a pressure-limited respirator having a pressure-limited gas supply, a breather head assembly, a low-pressure main line and a high-pressure auxiliary line connecting the supply and breather head assembly, incorporates novelly arranged valve means operable to shut off the main line and divert pressure from the auxiliary line to effect a back pressure shutoff of the supply.

Fifth, to provide a volumetric respirator, as indicated in the other objects, which incorporates a novel means for periodically supplying the patient with a predetermined excess volume of gas to simulate the natural sigh which periodically occurs in the course of natural breathing and provides a correspondingly increased off period to permit the patient to exhale the extra volume of gas supplied.

Sixth, to provide a volumetric respirator which permits the use of more than one supply line to the patient; for example, a main line for supplying air at normal breathing pressure and a higher pressure auxiliary line for operation of a nebulizer or other gas-operated device for the introduction of medicine to the patient.

Seventh, to provide a volumetric respirator, as indicated in the preceding object, wherein its volume-measuring means measures the sum of the volumes supplied through both lines.

Eighth, to provide a volumetric respirator which utilizes electronic circuits capable of a wide range of adjustment of, for example: (a) tidal volume selection, (b) sigh volume selection, and (c) sigh frequency selection with attendant shutoff periods so as to be uniquely adjusted to the needs of a particular patient.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a front view of the volumetric respirator, arranged to incorporate a pressure-limited regulator.

FIG. 2 is an enlarged sectional view, taken through 2—2 of FIG. 1, showing a main and auxiliary flow meter interposed in the main and auxiliary lines extending from the respirator.

FIG. 3 is a partially transverse sectional view, partially end elevational view of the flow meters, taken through 3—3 of FIG. 2.

FIG. 4 is a plan view of the breather head, showing fragmentarily the main and auxiliary lines which extend from the respirator.

FIG. 5 is a diagrammatical view, showing a modified construction in which a pair of valves are located between the respirator and the flow meters.

FIG. 6 is a block diagrammatical view, indicating the major components of the volumetric respirator.

FIG. 7 is a wiring diagram, illustrating one of the relays.

FIG. 8 and FIG. 9 are wiring diagrams in which FIG. 9 is a continuation of FIG. 8, these diagrams showing the major components to effect the supply of tidal volume of gas, or the supply of a sigh volume of gas.

FIG. 10 illustrates the circuit which selects the tidal volume of gas and the sigh volume of gas in association with the integrator circuit.

The volumetric respirator requires a source of air or life-sustaining gas which is regulated as to maximum pressure. Conveniently, this may be obtained from a conventional pressure-limited respirator, disclosed in U.S. Pat. No. 3,068,856. This respirator includes a respirator housing 1, from which extends a main output or low-pressure line 2, and an auxiliary output or high-pressure line 3. The respirator is provided with a manual control 4, which is normally used to shut off the operation of the respirator. In one embodiment of the present invention, the manual control 4 is operated automatically to shut off discharge into the output lines after a predetermined volume of gas has been delivered to the patient, and to reactivate the respirator after a predetermined interval calculated to permit the patient to exhale.

The respirator, shown in the aforementioned patent, also includes a breather head 5, having a mouthpiece 6 and an exhalation port 7. As is more fully described in the aforementioned patent, the breather head includes an exhalation valve which discharges through the exhalation port 7 and is responsive to back pressure exerted by the patient when the patient attempts to exhale. The auxiliary or high-pressure line 3 is utilized to maintain a back pressure on the exhalation valve during the inhalation period so that the exhalation valve is not prematurely opened. The high-pressure line is also used to operate a nebulizer contained within the breather head 5.

The volumetric controller includes a housing 8 on which the housing 1 is mounted and which contains electronic circuitry that may include a solenoid 9, adapted to move an operating arm 10 connected to the manual control 4. Alternatively, the electronic circuitry may be caused to operate a main valve 11, mounted in the main output line 2, and an auxiliary valve 12 mounted in a cross line 13 extending between the auxiliary line 3 and the main line between the respirator housing 1 and the main valve 11, as shown in FIG. 5.

In either mode of control, the main line 2 and auxiliary line 3 are provided respectively with flow sensors 14 and 15, which, if the valves 11 and 12 are used, as shown in FIG. 5, are located downstream therefrom. The flow sensors may be conventional, one type of which includes a target disk 16, secured to a longitudinally movable shaft 17 which carries an armature

18, movable within coils of a differential transformer 19. A sensor power oscillator, not shown, for example, a 400 Hz. sign wave oscillator with a constant amplitude output, is buffered and transformer coupled to the coils of the two flow sensors 14 and 15. The main output line 2 and auxiliary output line 3 extend from the gas flow sensors to the breather head 5.

The AC output from each sensor is proportional to the flow of gas through the sensor and the sum of the two outputs represents the total flow of gas to the patient. The two output signals are routed respectively to AC amplifiers 20 and 21, which amplify the signals to a level useful to actuate other electronic devices. The output signals from the amplifiers 20 and 21 pass through rectifiers 22 and 23, and the outputs from the two rectifiers are fed to a summing network 24 to produce a composite signal representing the sum of the individual signals and, hence, the total gas being delivered to the patient at any instant in, for example, liters per second, or other suitable unit of gas flow.

Considering a person breathing without aid of a respirator, he normally inhales what is designated a "tidal" volume of air, which only partially fills his lungs. At intervals, he will take a deeper and longer breath or "sigh," accompanied by a longer exhalation period. The sigh cycle might occur as seldom as once each 15 minutes or more; or, as often as once each 4 minutes or less. It is intended that the volumetric respirator provide as appropriate times a sigh cycle in which a greater volume of gas is supplied to the patient.

To accomplish this, the output voltage from the summing network 24 is supplied to a pair of potentiometer controls 25 and 26, either one or the other of these controls being selectable. The control 25 constitutes a tidal volume control, and the other control 26 constitutes a sigh volume control, including, respectively, manual adjustment dials 27 and 28 mounted on the front panel of the housing 8.

Either the control 25 or the control 26 selectively forms the series input resistance of an active integrator 29, which charges a low leakage capacitor to a predetermined constant level. The integrator 29 integrates the signal from the summing network 24; that is, it converts from an electrical analog of liters per second to an electrical analog representing a continuous summation in liters or other unit of measurement. Stated otherwise, the integrator performs the function of a comparison circuit in effectively comparing the output of the integrator 29 with the input thereto as determined by the setting of the normal or tidal volume control 25 or the sigh volume control 26, depending upon which has been selected. When the two signals are of like magnitude, a relay 30 is closed which powers the actuator 9 or the solenoid valves 11 and 12, depending upon which is used.

The integrator 29 performs the function:

$$V_0 = \frac{-\int V_i dt}{R_i C}, \text{ where}$$

V_o is the output of the integrator 29, V_i is the input voltage to the integrator (which appears at the output of the summing network 24), R_i is the selected series input resistance (potentiometer 25 or potentiometer 26), and C is the feedback capacitor of the integrator. From the equation it will be apparent that V_i represents gas flow from the respirator in liters per second. C is a constant representing the triggering level of the relay 30. When V_o reaches the triggering level, the relay 30 is triggered. R_i is a variable which controls the integration time rate of the integrator, and V_o also is a variable dependent on V_i and R_i and is limited by the value of C. Hence, there is a value of R_i which will cause the output V_o to reach the limit determined by C. Thus, functionally V_o is compared to R_i, and R_i can be calibrated in terms of demand such that the control dials 27 and 28 may be readily adjusted as desired.

In order to operate the relay 30, the DC output of the integrator 29 is fed through a unity gain buffer amplifier 31, which lowers the impedance of the signal and is capable of supplying a high current output. It is this output which is fed to the actuator coil 30*a* of the relay 30.

The relay, when closed, performs several functions, as follows:

A. A contact set 32 shorts out the integration capacitor and readies it for the next cycle.

B. A contact set 33 triggers the controlled expiration period, to be described, during a sigh cycle.

C. A contact set 34 supplies a logic circuitry, to be described, with a voltage indicating the end of an inhalation period.

D. A contact set 35 supplies power to the solenoid or actuator 9, or to the valves 11 and 12, which shuts off flow to the lines 2 and 3.

In order to accomplish at appropriate intervals a sigh cycle, a unijunction transistor oscillator 36 produces pulses at equally spaced intervals; for example, every 2 minutes. These pulses are fed into a shaping amplifier 37 which broadens the pulses and feeds them to the first of a set of bistable multivibrators. In the construction illustrated, four such multivibrators 38, 39, 40 and 41 are provided. The bistable multivibrators are conventional and are low frequency units such that they are not affected by high frequency noise pulses. Preferably, the output of each multivibrator is half the frequency of the previous one, so that an input pulse every 2 minutes gives output pulses every 4, 8, 16 and 32 minutes, respectively. The pulses from the multivibrators are selected by a switch 42, including a dial 43 on the face of the housing 8. It is also desirable to produce a sigh cycle manually, therefore, a pushbutton 44 is provided to instigate a sigh cycle at any time.

The pulses from the sigh selector switch 42 are routed to a DC latch circuit 45, which has a high AC noise rejection. The pushbutton 44 is also connected to the input of this latch circuit. The DC latch circuit 45 comprises two DC latches 46 and 47; the first latch 46 triggers a monostable multivibrator 48, which provides a timed exhale period following the sigh. The latch 46 triggers the multivibrator 48 through the third set of relay contacts 34 of the relay 30. This triggering of the multivibrator 48 produces an exhalation period of length determined by the time constant of the multivibrator 48. The output 48*a* of the multivibrator 48 is fed back to the relay 30 through the amplifier 31. The relay 30 thus is held on for a period determined by the time constant of the multivibrator 48. The output of the multivibrator 48 is also switched through the second set of contacts 33 on the relay 30 to the input of the second latch 47.

The output of the second latch 47 is buffered by a transistor 47*a* and is used to actuate a sigh-normal relay 49. This relay performs multiple functions as follows:

A. A contact set 50 is used to change the time constant of the monostable multivibrator 48. A longer time is allowed for sigh exhalation.

B. A contact set 51 is used to switch the potentiometer control at the input of the integrator 29 from the normal cycle to the sigh cycle.

C. A contact set 52, when the contact arm thereof moves to the lower position, allows a capacitor 47*b* to charge to the supply voltage. When the relay 49 is released, this capacitor causes the two latches 46 and 47 of the DC latch circuit 45 to return to their original state so as to be ready for the next sigh cycle.

D. A contact set 53 permits the second latch 47 of the DC latch circuit 45 to be turned off at the end of the sigh exhalation period.

Operation of the volumetric respirator is as follows:

If a conventional pressure-limited respirator is used, its manual control is modified for connection to the operating lever 10, as shown in FIG. 1. Alternatively, the valves 11 and 12 are installed in the output lines 2 and 3, as shown in FIG. 5. In either case, the flow meters 14 and 15 are interposed in the output lines 2 and 3.

In the course of connecting the volumetric respirator to the patient, the controls of the pressure-limited respirator component are adjusted. The tidal and sigh volume controls 27 and 28 are set and the sigh interval control 43 is adjusted.

The patient may be supplied with life-sustaining gas through a face mask or through the breather head **5**, or other device. Gas is supplied during each tidal cycle until the predetermined volume is delivered. However, if the type of pressure-limited respirator component shown is used, and should the patient attempt to exhale before completion of the supply period, the supply is cut off and resumed at the beginning of the next cycle.

At selected intervals the patient is subjected to a sigh cycle.

The present embodiments of this invention are to be considered in all respects as illustrative and not restrictive.

I claim:

1. A respirator for converting a positive pressure respirator to a volumetric respirator to permit volumetric control of gas supplied to a patient, said respirator comprising:

first means, including a positive pressure respirator comprising means for supplying a life-sustaining gas to a patient via a breather head;

second means, connected to said first means, including means for sensing and measuring the rate of flow of gas supplied and time-integrating the same to provide a measure of the volume of gas being supplied;

third means, connected to said second means and including means responsive to the said sensing and measuring means for terminating the supplying of gas after a predetermined volume of gas has been supplied to the breather head; and

fourth means, connected to said third means and including time delay means for reestablishing the flow of gas to the breather head after a predetermined interval, thereby to permit the exhalation of the previously delivered volume of gas.

2. A respirator as defined in claim **1**, wherein said sensing and measuring means includes a flow meter which produces an electrical signal of magnitude proportional to the rate of flow of gas therethrough and integrating means effective to integrate said electrical signal to produce a signal representing the volume of gas passing through the flow meter.

3. A respirator as defined in claim **2** wherein said means for supplying gas include a shutoff handle; and said means for terminating supplying of gas includes an actuator engageable with the shutoff handle when supplying of gas is to be terminated.

4. A respirator as defined in claim **1**, wherein said means for supplying gas includes a main supply line and an auxiliary supply line and said sensing and measuring means senses and measures the total volume of gas passing through both of said lines.

5. A respirator as defined in claim **4** wherein said sensing and measuring means includes a respective flow meter for each of said main and auxiliary supply lines, each flow meter producing an electrical signal of magnitude proportional to flow in its respective line; a means connected to said sensing and measuring means and responsive to the signals from both flow meters to produce a signal proportional to total rate of gas flow; and means for integrating the latter signal over a period of time to produce a signal representing the total volume of gas passing through the flow meters during that period of time.

6. A respirator as defined in claim **1**, including means connected to said first and second means and operable at preselected intervals to provide a predetermined increase in the volume of gas supplied to said breather head, said latter means further including means operable to increase the next following period of the said time delay means thereby to permit exhalation of the previously delivered increased volume of gas.

7. The combination with a pressure-limited respirator including a pressure-regulating means and a source of life-sustaining gas connected thereto; a breather head having means for connection to a patient and an exhalation valve; a low-pressure and a high-pressure line connecting the pressure-regulating means and breather head, the high-pressure line being operable, during supply of gas to a patient, to close the exhalation valve; said pressure-regulating means being responsive to back pressure in the low-pressure line exceeding a predetermined value to shut off the pressure-regulating means; of apparatus for converting the pressure-limited regulator to a volume-limited respirator, said apparatus comprising:

first means, connected to said respirator, for sensing the volume of gas being supplied through the low-pressure line;

a first valve connected to said first means and responsive to the sensing means for closing the low-pressure line intermediate the pressure-regulating means and the breather head;

c. a second valve, connected to said first means and responsive to the sensing means for diverting gas from the high-pressure line into the low-pressure line between the first valve and the pressure-regulating means to raise the back pressure at the pressure-regulating means to a shutoff valve;

and second means, including time-delay means, connected to said respirator, for delaying resumption of flow of gas to the breather head for an interval predetermined to permit complete exhalation of gas supplied to the breather head.

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