

[54] MEDICAL VENTILATORS

[75] Inventors: **George Edward Smythe; Geoffrey Keith Orton**, both of London, England

[73] Assignee: **U.S. Philips Corporation**, New York, N.Y.

[22] Filed: **Apr. 25, 1974**

[21] Appl. No.: 464,511

Related U.S. Application Data

[63] Continuation of Ser. No. 282,587, Aug. 21, 1972, abandoned.

[30] Foreign Application Priority Data

Aug. 19, 1971 United Kingdom..... 38978/71

[52] U.S. Cl..... 128/145.6; 128/DIG. 17

[51] **Int. Cl.²**..... **A62B 7/00**

[58] **Field of Search**..... 128/145.6, 145.5, 145.7,
128/145.8, 188, 142, DIG. 17; 137/63 R

[56] **References Cited**

UNITED STATES PATENTS

3,339,545	9/1967	Burchell.....	128/145.8
3,523,527	8/1970	Foster.....	128/145.8
3,633,576	1/1972	Gorsuch.....	128/145.8
3,729,000	4/1973	Bell.....	128/145.6

Primary Examiner—Richard A. Gaudet

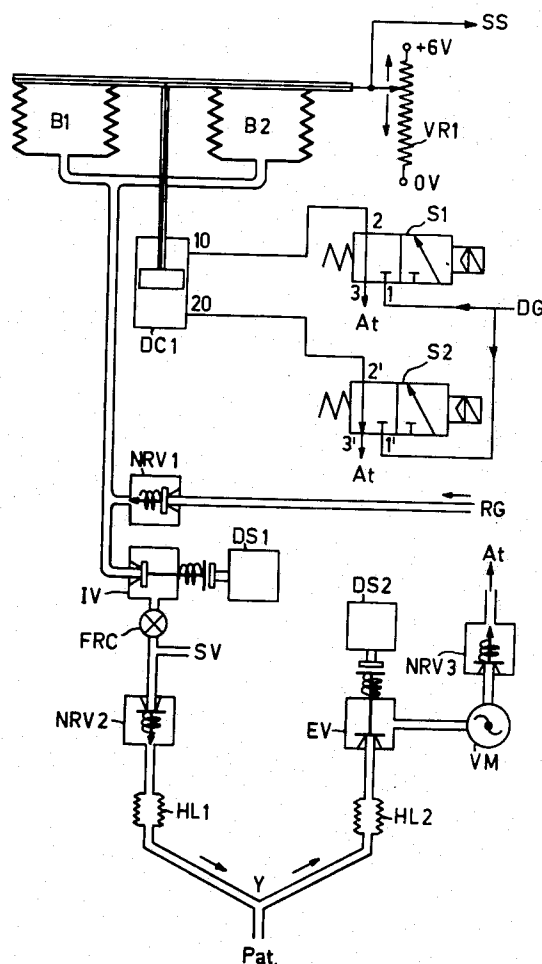
Assistant Examiner—Lee S. Cohen

Attorney, Agent, or Firm—Frank R. Trifari; David R. Treacy

[57] ABSTRACT

A medical ventilator of the constant volume type including a variable-volume reservoir for storing respiratory gas during each expiration period of a repetitive respiratory cycle and from which reservoir gas is passed to a patient during each inspiration period of the cycle, including an electrical position-sensing element associated with the reservoir, and so arranged in relation thereto as to give an indication of the instantaneous volume of the reservoir over the variable range of the latter, an adjustable electrical volume control element settable to the required volume of gas to be passed to the patient, actuating means for expanding and contracting the reservoir so as to perform the storage and passage functions of the latter, and a comparator for comprising the said indication of the instantaneous volume with the setting of the control element, the comparator being arranged to give an output signal when equality of the comparison is achieved, whereby operation of the actuating means to expand the reservoir during each expiration period is terminated when the said output signal is given.

12 Claims, 4 Drawing Figures



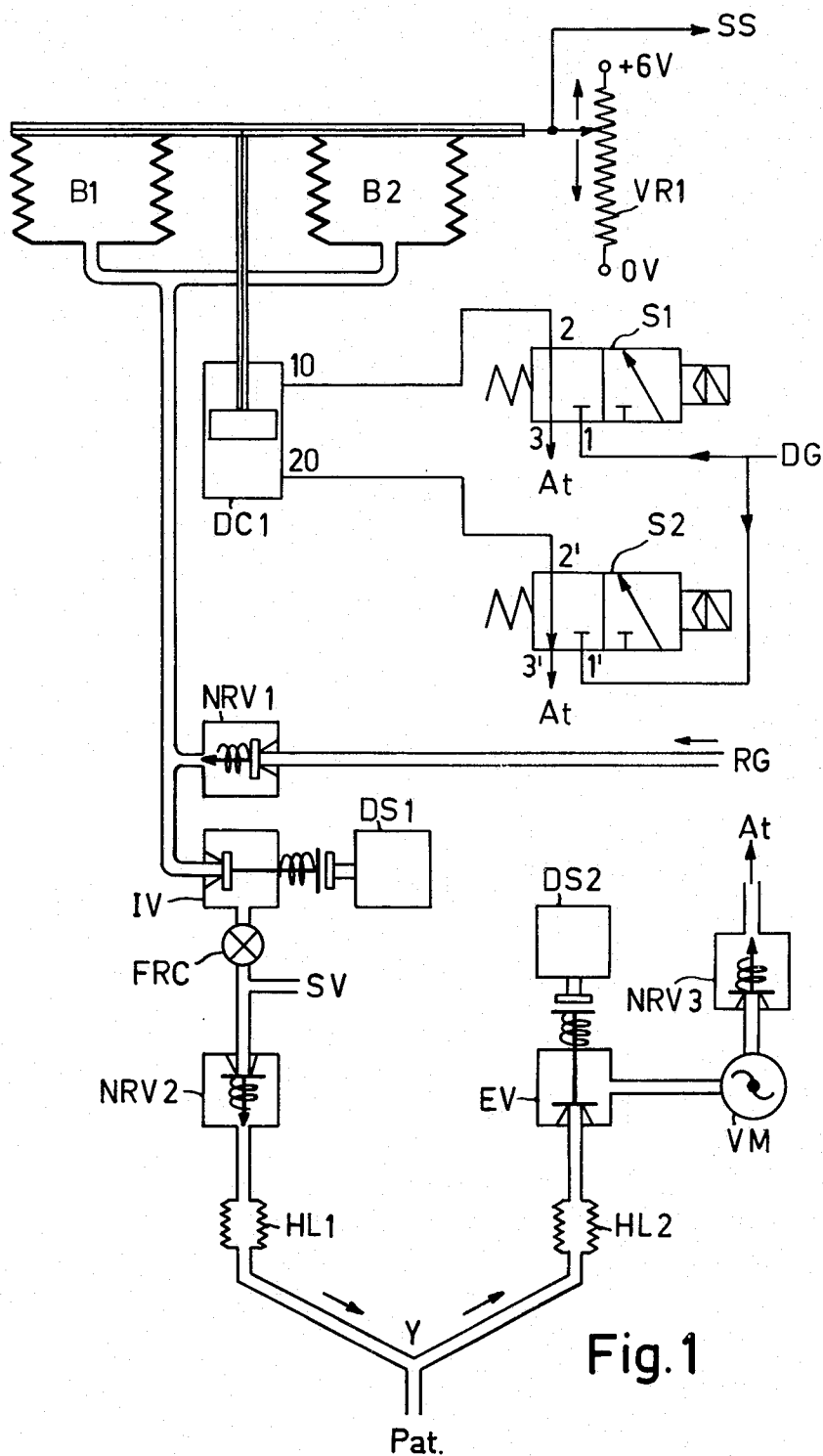


Fig. 1

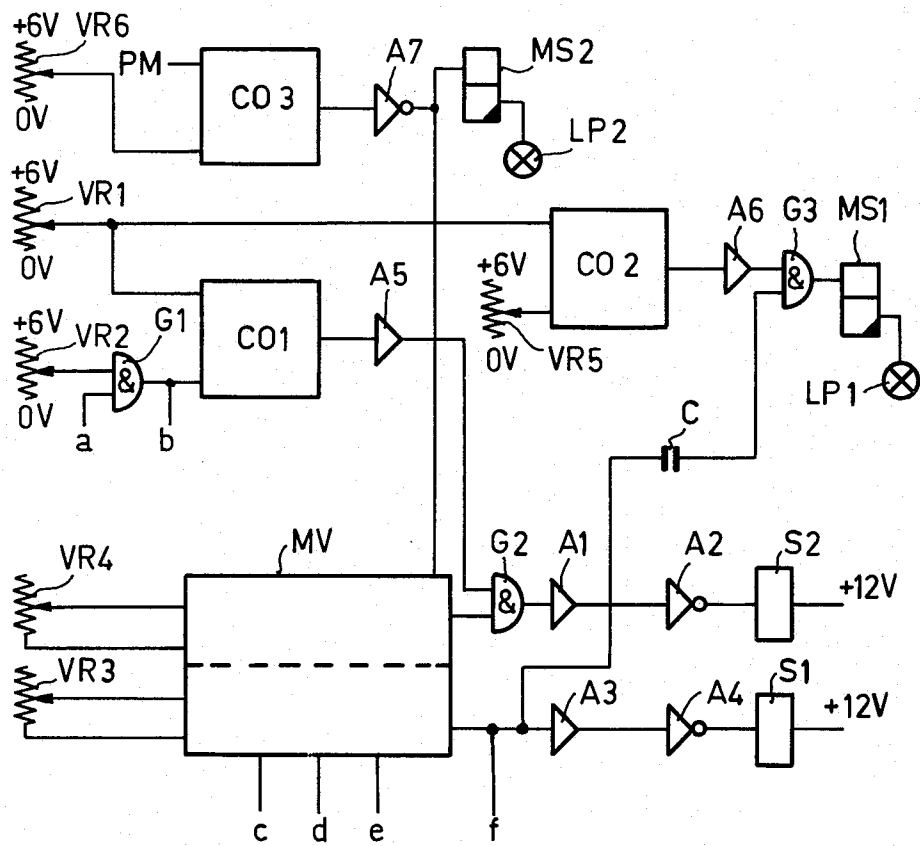


Fig.2

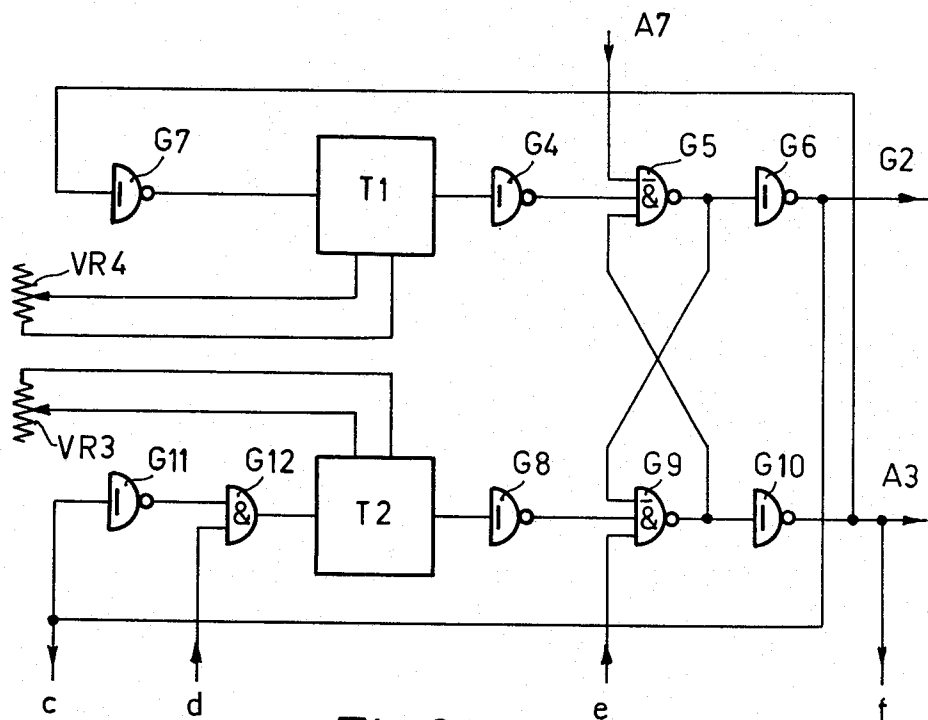


Fig.3

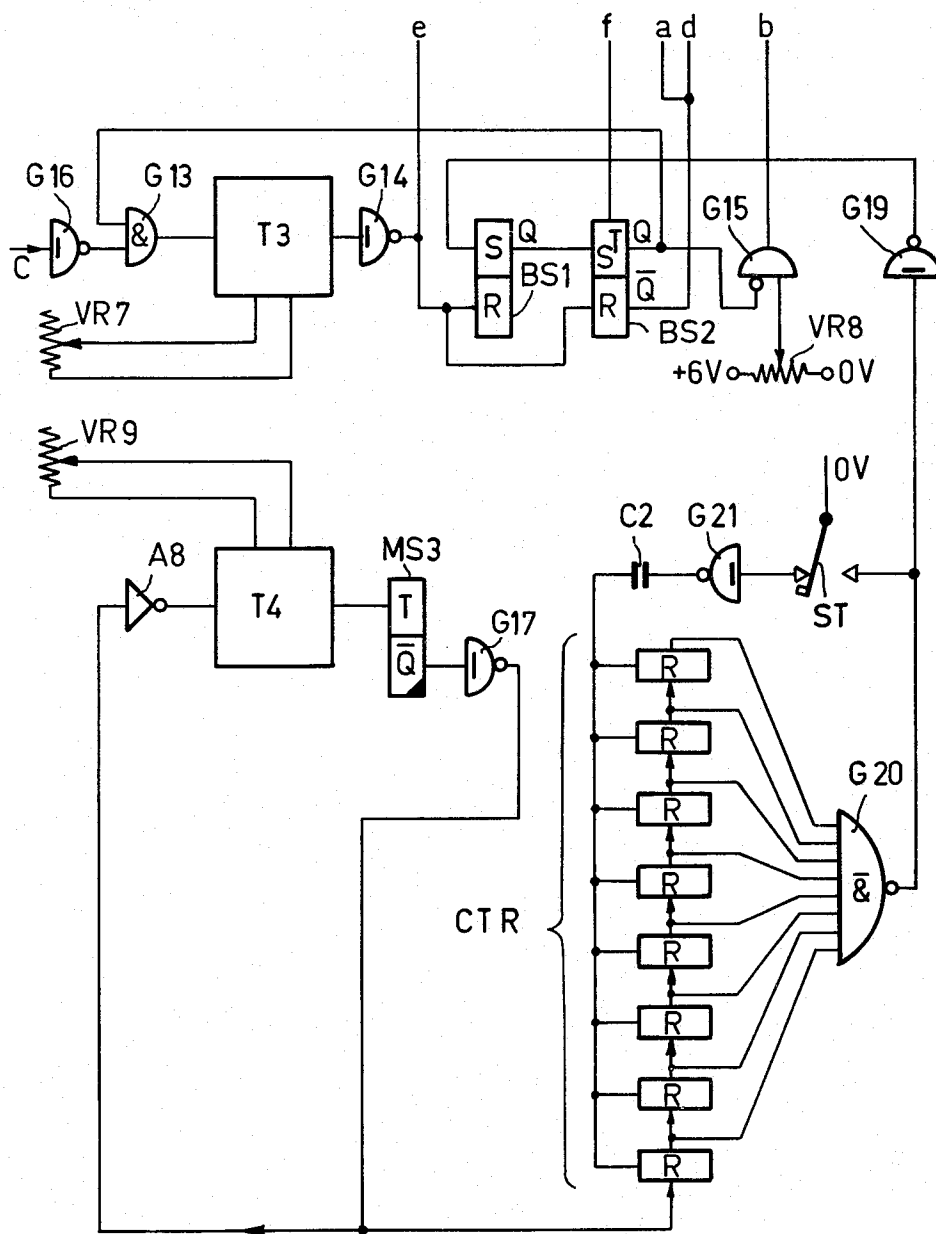


Fig. 4

MEDICAL VENTILATORS

This is a continuation of application Ser. No. 282,587, filed Aug. 21, 1972 now abandoned.

The present invention relates to medical ventilators and more particularly to time-cycled constant volume ventilators. A time-cycled ventilator is one in which the inspiration and expiration periods of the respiratory cycles are adjustable and a constant volume ventilator is one in which a predetermined constant volume of respiratory gas is fed to the patient in each inspiration period irrespective of the respiration rate. The volume of gas fed to the patient in each respiratory cycle is referred to as the "tidal volume" and the total volume of gas fed to or from the patient over a period of one minute is referred to as the "minute volume," i.e., the tidal volume multiplied by the respiration rate (the number of respirations per minute).

In ventilators of this type, the inspiration period, the expiration period, and the tidal volume are preset according to the respiratory needs of the patient concerned. In such ventilators it is known to control the inspiration and expiration periods electronically for example by a multivibrator having an individually adjustable dwell time for each of its inspiration and expiration states. The multivibrator output controls gas-switching solenoids which control the passage of gas to and from the patient. Most such ventilators use one or more bellows which are filled with gas during each expiratory period and which are contracted during each inspiratory period to pass the stored volume of gas to the patient; the expansion and contraction of the bellows being controlled by the multivibrator.

The tidal volume is determined by controlling the amount of expansion or contraction of the bellows, for example by means of mechanically adjustable end-stops on the bellows or on the bellows actuating device. The actuating device is usually of the pneumatic type comprising a piston in a cylinder. Alternatively, it is known to provide an electric switch which is operated on expansion of the bellows to the required volume to prevent further expansion by electronic control means. Each of these methods has the disadvantage of requiring mechanical adjustment. In the former case mechanical linkage has to be provided and this tends to be stiff in action from the point of view of the mechanical effort required on the part of the operator and also results in loss of absolute accuracy. In the latter case, the position of the electric switch has to be mechanically adjusted each time a change in the tidal volume is required. This is also cumbersome.

A further disadvantage in the known methods of gas volume control becomes apparent when a so-called "sigh" is required. During normal respiration, it is frequently necessary to fill the patient's lungs at regular intervals, generally in the range of 1 minute to 30 minutes, with a larger quantity of gas over a period longer than the normal cyclic inspiratory period. This extra quantity of gas causes more rapid exhalation during the expiratory period due to the increased expansion of the rib cage and this results in a sighing sound. To produce a sigh inspiration in known respirators, the inspiration period and tidal volume controls have to be readjusted to the sigh levels for one inspiration period only. This, as previously mentioned, is a cumbersome process — particularly in view of the short time available for changing and restoring the time and volume settings.

The object of the present invention is the provision of an improved volume adjustment control.

According to the present invention there is provided a medical ventilator of the constant volume type including a variable-volume reservoir for storing respiratory gas during each expiration period of a repetitive respiratory cycle and from which reservoir gas is passed to a patient during each inspiration period of the cycle. Also included are an electrical position-sensing element associated with the reservoir, and so arranged in relation thereto as to give an indication of the instantaneous volume of the reservoir over the variable range of the latter, an adjustable electrical volume control element settable to the required volume of gas to be passed to the patient, actuating means for expanding and contracting the reservoir so as to perform the storage and passage functions of the latter, and a comparator for comparing the said indication of the instantaneous volume with the setting of the control element. The comparator is arranged to give an output signal when equality of the comparison is achieved, whereby operation of the actuating means to expand the reservoir during each inspiration period is terminated when the said output signal is given.

In this manner, an electrical signal representing the actual volume of the reservoir (e.g. one or more bellows) is compared during expansion with an electrical signal representing the required volume and the resultant parity signal stops further expansion; so ensuring that the exact volume of respiratory gas required for passing to the patient in an inspiration period is stored in the reservoir during the immediately preceding expiration period. Thus the volume control can be a simple potentiometer or variable resistor mounted on the control panel in any suitable position and calibrated in terms of tidal volume. No mechanical linkage is required and the control knob is easily manipulated.

A medical ventilator according to the present invention may be provided with further advantageous features in that the sensing element may also be used to give an indication that the bellows has passed the full tidal volume during an inspiration period — in other words that the bellows has been restored to its minimum volume position.

In an advantageous embodiment of the present invention there is provided a medical respirator including a further comparator having one comparison input connected to the position sensing element and the other comparison input connected to a presettable electrical control set to a position indicative of the empty or minimum contraction condition of the reservoir, the output of the comparator thereby indicating that the reservoir has reached its minimum volume state and, hence, that the required quantity of gas has been passed to the patient during the inspiration period.

The various features and advantages of the present invention will be apparent from the following description of an exemplary embodiment thereof taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows schematically a respiratory gas circuit; FIG. 2 shows a schematic circuit of the electronic control arrangement;

FIG. 3 shows a suitable multivibrator for use with FIG. 2; and

FIG. 4 shows a schematic circuit of a sigh unit.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1 of the drawings two solenoid-operated gas control valves S1 and S2 are shown in the customary symbolic form, the right hand portion representing the solenoid, the zig-zag to the left indicating that it is a spring-returned solenoid, the left-hand square showing the gas passage path with the solenoid in the unoperated condition and the right-hand square showing the gas passage path with the solenoid operated, the right-hand square replacing the left-hand square in this condition. Inlet ports of these solenoids are connected at inlet DG to a source of driving gas at higher than atmospheric pressure, e.g. compressed air. In the Figure, the driving gas paths are shown as single lines and the respiratory gas paths are shown as double lines.

Ports 1 of valves S1 and S2 are connected to the driving gas source DG, ports 2 are connected to ports of pneumatically-operated driving cylinder DG1, and containing an actuating piston and ram, and ports 3 are connected to the atmosphere At via silencing devices (not shown) if required.

The respiratory gas circuit includes, on the inspiratory side, a respiratory gas inlet RG for gas (e.g. clean air) at atmospheric pressure, non-return valves NRV1 and NRV2, an inspiratory valve IV actuated by solenoid DS1, bellows B1 and B2 which can be expanded and contracted by the piston and ram of cylinder DC1, and a flow rate control FRC (a variable constriction, for example). On the expiratory side, gas is passed from the patient via an expiratory valve EV, a volume meter pick-up unit VM which measures the volume of gas passed from the patient, and a non-return valve NRV3 to atmosphere (At).

Solenoid valve S1 is operated during the inspiration period and solenoid valve S2 is operated during at least part of the expiratory period. Control circuits for these solenoids will be described hereinafter.

The circuit shown is fairly conventional and its operation is as follows. Assume initially, that valve S1 is operated and that the bellows B1 and B2 are filled with the required volume of respiratory gas to be passed to the patient. Driving gas from inlet DG is passed via ports 1 and 2 of valve S1 (operated) to the upper chamber of driving cylinder DC1 thus forcing the piston and ram downwards and hence contracting the bellows to expel the contained volume of respiratory gas. The solenoid DS1 is de-energized at the same time as S1 is energized, thus opening the inspiratory valve IV. Respiratory gas is now expelled, under pressure of the driving gas, from the bellows at a rate determined by the setting of the flow rate control FRC, thus opening non-return valve NRV2, via hose line HL1 to the Y-piece Y of the face mask or respiratory tube. A safety valve SV (not shown) which guards against excess pressure in the airway, may be connected in the inspiratory airway as shown. A suitable safety valve is shown and described in our copending application Ser. No. 281,720, filed Aug. 18, 1972. The pressure in the inspiratory airway holds non-return valve NRV1 closed, this pressure being higher than the atmospheric pressure of the respiratory gas on the other side of the valve.

During the inspiratory period, expiration valve EV is held closed by the solenoid DS2 which is energized during the inspiratory period. This ensures that none of the inspiratory gas can escape via the expiratory path. An

escape path for the gas driven out of the non-driving chambers of cylinder DC1, during movement of the respective pistons is provided via port 21 in the cylinder and valve S2 (unoperated) to atmosphere.

At the end of the inspiratory period, valve S1 releases and valve S2 is operated. Under this condition, driving gas is fed to port 20 of cylinder DC1, and a venting path to atmosphere is provided via port 3 and valve S1 (unoperated).

The operation of the piston of cylinder DC1 in the upwards direction now causes the pressure in bellows B1 and B2 to be reduced, thus opening non-return valve NRV1 and drawing respiratory gas into the bellows via inlet RG. Inspiratory valve IV is closed by the solenoid DS1 and the expiratory valve EV is opened since the solenoid DS2 has now been moved in the upwards direction by the associated spring.

The pressure in the patient's lungs is higher than atmospheric pressure so non-return valves NRV2 and NRV3 are closed and opened respectively, thus enabling the gas in the patient's lungs to be vented to atmosphere via the Y-piece, hose line HL2, expiratory valve EV (open), volume meter VM, and non-return valve NRV3 (open) to atmosphere.

During the expiration period, the bellows B1 and B2 are filled with respiratory gas, until the required tidal volume has been stored, ready for passage to the patient during the next-following inspiration period.

In accordance with the invention, the bellows are provided with a position-sensing device. This is shown as potentiometer VR1 having its moving contact operated by the bellows. A fixed d.c. voltage is applied to the outer terminals of potentiometer VR1 and the sensing signal output SS is taken from the sliding contact as shown, this output being a d.c. signal proportional to the position of the bellows and, hence, to the volume of the bellows. The way in which this signal is used to control the bellows volume, and hence the tidal volume, to any predetermined value will now be described with reference to FIG. 2 of the drawings which shows a block schematic layout of the electronic control circuitry of a ventilator according to the invention.

A conventional multivibrator MV, shown in detail later in FIG. 3, is used to control the inspiration and expiration periods and the time control resistances are extended as time-calibrated potentiometers VR3 and VR4 respectively, these controls being located on the main control panel of the ventilator. Bellows-sensing potentiometer VR1, which senses the bellows height and hence the contained volume as previously explained, provides an analogue signal to one input of a comparator CO1. Potentiometer VR2 is the gas volume control and this provides an analogue signal, representing the required volume to be stored in the bellows, to the second input of comparator CO1. The comparator output is fed via an amplifier to one input of an AND-gate G2 the second input of which is connected to the expiration period output signal of multivibrator MV. The output of AND-gate G2 is fed via a signal amplifier A1 and an inverting power amplifier A2 to the expiration solenoid S2 previously described with reference to FIG. 1. The inspiration period output signal of multivibrator MV1 is fed via a signal amplifier A3 and an inverting power amplifier A4 to the inspiratory solenoid S1.

It is assumed that the multivibrator is switched to the inspiration period condition and, therefore, there is a logic level "1" at the inspiration output and "0" at the

expiration output. The "1" at the input of amplifier A3 appears as a "0" (earth) at the solenoid S1 and this operates the solenoid. The "0" output of the multivibrator appearing at one input of AND-gate G2 produces a "0" at amplifier A1 input and, hence, a "1" at solenoid S2 which therefore remains unoperated. Thus, during this period, solenoid S1 is operated and, as explained with reference to FIG. 1, the bellows are contracting and respiratory gas is being passed to the patient.

At the end of the inspiration period, as determined by the setting of variable resistor VR3, the multivibrator changes over to the expiration period and its output signals are reversed. Solenoid S1 is therefore released and solenoid S2 is operated via gate G2 which has a "1" on its upper input derived from comparator CO1 via amplifier A5. Comparator CO1 is of a well known type, and gives a "1" output until the two inputs equate when the output signal changes to "0". Thus, as stated, a "1" appears at the two inputs of AND-gate G2 and, hence, a "0" appears at solenoid S2 which operates.

The release of solenoid S1 and the operation of solenoid S2 causes the respiratory gas circuit to switch to the expiration period and the bellows are now expanded. The potential appearing at the upper input of comparator CO1 thus steadily increases until it reaches the value preset on gas volume control VR1, when the comparator detects equality and changes its output from "1" to "0." This inhibits AND-gate G2 and solenoid S2 is therefore released; so preventing further expansion of the bellows. The bellows now contain the tidal volume of respiratory gas as predetermined by the setting of gas volume control VR1. At the end of the expiration period, as determined by the setting of variable resistor VR1, multivibrator MV changes over to the inspiration period and its output signals are reversed.

Gate G1 is an analogue gate which passes the analogue signal from volume control VR2 unchanged unless there is an inhibiting signal "1" at the lower input via lead *a*. For present purposes it is assumed that there is a "0" on lead *a* and the gate is therefore open. The function of leads *a*, *b*, *c*, *d*, *e*, and *f* will be described hereinafter.

The use of an electronic sensing element for sensing the bellows volume enables an advantageous feature to be readily achieved. If, for example, there is a blockage in the airway at any point between the respiratory gas reservoir formed by the bellows B1 and B2, the resulting reduction of the gas flow rate may lead to the full tidal volume not being delivered to the patient in the inspiration period. Thus the bellows will not fully empty during this period. In accordance with an advantageous embodiment of the invention, the use of the sensing element to detect the bellows empty condition in addition to the tidal volume enables an alarm signal to be given, if there is a blockage.

To achieve this, the signal output of sensor VR1 is compared in comparator CO2 with the signal from a preset potentiometer VR5, which potentiometer is preset to the bellows empty state. This preset control is set during initial testing and does not appear on the control panel. The output of comparator CO2 is taken via an AND-gate G3 to the input of timed monostable trigger MS1, a so-called "one-shot multivibrator" of well-known type. The output of monostable provides an alarm signal which, in the present embodiment, is used to light a lamp, other forms of alarm device may of course, be fitted.

While the bellows contain gas, the input signals to comparator CO2 differ and so a "1" output is given. This "1" output, via amplifier A6 enables AND-gate G3 so long as the bellows are not in the empty or minimum volume state. At the end of the inspiration period, the bellows should have passed the tidal volume to the patient and will have reached the minimum volume state. Comparator CO2 recognises this state and its output changes to "0," thus inhibiting gate G3. If, however, the bellows have not discharged by the end of the inspiration period, gate G3 is still enabled. The "0" output appearing at inspiration output of MV on changeover to the expiration period is differentiated by capacitor C to produce a short "0" pulse at the lower input of gate G3 which therefore produces a "0" pulse at its output. This fleeting pulse triggers monostable MS1 which then remains triggered for its one-shot period, for example 1-second and restores. In this way a 1-second alarm signal is provided on changeover from an inspiration period to an expiration period to draw attention to the fact that a fault exists.

Using the same basic comparator principle, a further advantageous feature is incorporated in a further embodiment of the invention, namely a so-called "patient trigger" facility. It is well known that a patient may spasmodically attempt to inhale during an expiration period of the ventilator and the object of the present embodiment is to detect such an event immediately and to change the ventilator from the expiration period to an inspiration period and hence assist the patient in his attempt to inhale. To this end a further comparator CO3 is provided, the output of which is fed, via an inverting amplifier A7, to a further alarm monostable trigger MS2 and to the expiration period portion of multivibrator MV.

A signal, appearing at input PM of comparator CO3 is derived from a pressure meter (not shown) monitoring the lung pressure and providing an analogue signal output proportional to the pressure. Such a pressure meter is disclosed in our previously co-pending application Ser. No. 282,586, now abandoned. Patient trigger potentiometer VR6 is pre-adjusted to a value representing a particular negative pressure value in terms of cms of water suited to the patient being ventilated, the setting being read off from a calibrated dial surrounding the adjusting knob on the control panel. If the patient attempts to draw breath during an expiration period, the pressure in the airway is reduced to a negative value. If this value, as read by the pressure meter, produces a signal at input PM equal to the preset value as determined by the setting of potentiometer VR6, comparator CO2 operates and gives a "1" output. This is inverted to "0" by inverting amplifier A7 and monostable MS2 is triggered to give an alarm signal of fixed duration in the same manner as monostable MS1 previously described. The "0" signal is also fed to the expiration period portion of multivibrator MV to cause it to switch immediately to the inspiration period, and hence, help the patient in his attempt to draw breath.

It will be seen that straight and inverting amplifiers are used in the logic circuitry of the particular embodiment. These are shown because the practical embodiment used diode-transistor logic (DTL), where amplifiers are necessary. It can readily be appreciated, of course, that alternative logic may be used, for example TTL, and that the amplifiers are not required. Also, of course, opposite polarity logic could equally well be used with appropriate changes to the gate. All such

means are very well known to those versed in the art and the invention is not to be taken as limited to the particular embodiment shown.

A suitable circuit for multivibrator MV is shown in FIG. 3 of the drawings. This is a fairly conventional multivibrator, based largely on the use of NAND-gates, and its operation is very well known per se. Timers T1 and T2 of the RC time constant type are provided with external controls VR4 and VR3 respectively for determining their operating conditions. The flip-flop action of the multivibrator is achieved by cross-coupled NAND-gates G5 and G9 forming a bistable trigger and the timer trigger inputs are taken from the complementary outputs of gates G5 and G9 via inverters G11 and G7. As each timer reaches the end of its duration, its change of output signal changes over the bistable trigger, which in turn causes the discharge of the timing capacitor in the timer concerned and starts the charging of the timing capacitor of the other timer.

It can readily be appreciated that, if the multivibrator is in the expiration period state, receipt of a "0" on the input of gate G5 from inverting amplifier A7 of the patient trigger circuit (FIG. 1) will cause the bistable to change the multivibrator to the inspiration state as previously mentioned. It will also be appreciated that lead c, taken from the output of gate G6 can be used to start a separate inspiration period timer, that lead d can be used to inhibit timer T2 by holding its input at "0", and that the separate timer output can control the inspiration period of the multivibrator via lead e.

Thus facilities are provided in the basic multivibrator for controlling its inspiration period from a separate timer. Such a separate timer can be used as part of an add-on sigh unit having the sigh function discussed earlier. Such an add-on unit will now be described with reference to FIG. 4 of the drawings, the connections of this unit into the basic ventilator control circuitry described in relation to FIGS. 2 and 3 being shown as a, b, c, d, e, and f on the Figures concerned.

Referring now to FIG. 4, the sigh unit is divided into two main parts, an inspiration timer unit of the same form as the multivibrator inspiration period timing circuitry and an interval timer comprising a pulse generator (a further timer unit) and a counter.

The inspiration timer unit comprises a timer T3 having its operative duration controlled by adjustable time constant resistor VR7, input AND-gate G13, an output inverter G14, and an input enabling inverter G16. The output of inverter G14 feeds the reset inputs of two bistables BS1 and BS2 and also, via lead e, NAND-gate G9 in the inverter (FIG. 3). The Q output of bistable BS2 is fed to the inhibiting input of gate G12 (FIG. 3) via lead d and also to the inhibiting input an analogue gate G15. This gate is of the same type as gate G1 (FIG. 2) and, in fact, effectively replaces it during a sigh period. The gate passes the analogue signal derived from the sigh volume control potentiometer VR8 to lead b so long as there is a "1" on the upper input and the gate is inhibited if there is a "0" on the inhibiting input.

The clock pulse generator of the sigh interval timer comprises a timing unit T4 (the same as the previous timing units) adjustable for example from 0.25 seconds to 7 seconds, a monostable MS3, an inverter G17 and an inverting amplifier A8, all arranged in a loop. The generated pulses are fed from the output of inverter G17 to the input of an eight stage binary counter (i.e., total count of 256) CTR. The output of all eight stages are combined in a NAND-gate G20, which detects the

"all-1's" state of the counter (i.e., the maximum count state before resetting to zero on the next input pulse). The output of NAND-gate G20 is inverted by inverter G19 and fed to the set input of bistable trigger BS1.

For the purposes of explanation, of the operation of the clock pulse generator, it is assumed that monostable MS3 is in its untriggered state, i.e., a "1" on the Q output. This is inverted to "0" by inverter G17, and back to a "1" by inverting amplifier A8. The "1" on the input of the timer T4 starts the charging of the timing capacitor. At the end of its RC time constant, the timer gives a "0" signal at its output. This triggers monostable MS3, which has a one-shot duration of, for example 1 mS, and the Q output goes to "0" for this period. This is inverted to a "1" to provide a clock pulse to counter CTR and back to a "0" in inverting amplifier A8. This "0" pulse discharges the timing capacitor and, at the end of the pulse, the timer starts its time period again. In this way, a train of 1mS duration clock pulses is generated and fed to the input of counter CTR. When the counter reaches its full count (of 256 pulses in the present example) the "all-1's" state operates NAND-gate G20 to produce a "0" at its output and this is inverted to a "1" by inverter G19 and fed to the set input of bistable BS1 which then sets to a "1" at its Q output. This bistable acts as a memory, recording the fact that the counter has reached the full count state and that a sigh is therefore due.

Obviously, the sigh inspiration period has to start at the instant the multivibrator switches from the expiration period to the inspiration period, and so the sigh control must wait for the instant. In the meantime, the counter resets and begins its count again, the all-1's state has passed and it is therefore necessary to store the full count information until the next inspiration period commences. The "1" output of bistable BS1 is fed to the set input of bistable BS2 but this bistable does not set until it receives a trigger pulse at its T input over lead f.

When multivibrator MV next changes from an inspiration period to an expiration period, (FIG. 3), a "0" appears at the output of gate G10 and, hence, bistable BS2 is now triggered via lead f and produces a "1" at its Q output and a "0" at its Q output. The "1" at the control input of gate G15 now enables the gate to pass the analogue signal representing the required sigh tidal volume set by potentiometer VR8 via lead b to the input of comparator CO1 (FIG. 2). The same "0," on lead d, inhibits AND-gate G12 (FIG. 3) and so suppresses the multivibrator inspiration period timer. The "1" on the Q output of bistable BS2 enables gate G13 and, via lead a, the "0" on the Q output inhibits analogue gate G1 (FIG. 2). In this way, the normal gas volume control VR2 is replaced by a sigh volume control VR8 at the input of comparator CO1. The bellows now fills with the sigh volume instead of the normal volume. The "0" which appeared on lead c at the changeover instant is inverted by inverter G16 to a "1" and AND-gate G13 is now enabled. The "1" at the input of sigh timer T3 causes the timer to commence its time constant period. At the end of its time constant period, as determined by the setting of sigh inspiration period control potentiometer VR7, a "1" appears at the timer output, which is inverted to a "0" by G14 and this resets bistables BS1 and BS2 and is fed over lead e to the multivibrator, causes the multivibrator to change over to the expiration period.

In this way, at periodic intervals determined by the setting of the time constant of timer T4, a sigh volume of gas is passed to the patient for the duration of a sigh inspiration time; the normal controls being over-ridden for this one period. At the end of the sigh period, the multivibrator changes back to the expiration period. This reverses the switching process just described and the over-ride controls are removed from the circuit, which now returns to normal cyclic operation until the sigh interval counter again reaches its full count, i.e., in any predetermined interval from about one to thirty minutes according to the setting of time constant resistor VR9.

It is sometimes required that a sigh inspiration is required on demand, for example for physiotherapy to clear the lungs by manual pressure applied after a deep inspiration. For this purpose a push button is provided which, in effect, provides an output equivalent to the full count signal of counter CTR. The momentary operation of the sigh trigger push-button ST causes a "0" to appear at the input of inverter 20, whereafter the operation is identical with that already described for periodic operation. On release of the push button ST, the "0" is inverted to "1" by inverter G21 and differentiated by capacitor C2 to produce a short "1" pulse to the reset inputs of all the counter stages. The counter is thus reset to the zero count state, thus ensuring that the full interval passes before a further sigh inspiration is delivered. This prevents the possibility of a sigh inspiration being effected by the counter very shortly after a manually triggered sigh.

What we claim is:

1. In a medical ventilator of the constant volume type including a variable volume reservoir for storing respiratory gas during each expiration period of a repetitive respiratory cycle and from which reservoir gas is passed to a patient during each inspiration period of the cycle, an electrical position-sensing element operable with the reservoir to give an indication of the instantaneous volume of the reservoir over the variable range of the latter, an adjustable electrical volume-control element settable to the required volume of gas to be passed to the patient, actuating means for expanding and contracting the reservoir so as to perform the storage and passage functions of the latter, and a comparator for comparing the said indication of the instantaneous volume with the setting of the control element, the comparator being arranged to give an output signal when equality of the comparison is achieved, the improvement comprising means for terminating operation of the actuating means to expand the reservoir during each expiration period when said output signal is given and further comprising an electronic multivibrator having two states and individual adjustment means for determining the dwell times of each of said two states, and having respective signal outputs, and means for operating the actuating means to initiate the expiratory and the inspiratory periods in response to said respective outputs.

2. A medical ventilator according to claim 1 wherein the actuating means comprises a pneumatically operated piston and cylinder arrangement, the piston being mechanically connected to the reservoir, a first gas control solenoid means for passing actuating gas to one side of the piston during each inspiratory period so as to cause the piston to move in such a direction as to decrease the volume of the reservoir, and a second gas control solenoid means for passing actuating gas to the

other side of the piston during each expiratory period so as to cause movement of the piston in the opposite direction and, hence, to increase the volume of the reservoir; and means for operating the first and second gas control solenoid means by the multivibrator outputs corresponding to the inspiratory and expiratory periods respectively.

3. A medical ventilator according to claim 2 including an AND-gate and wherein the expiratory period signal output of the multivibrator is connected to one input of the AND-gate and the comparator output is connected to a further input of the AND-gate, and wherein the output of the AND-gate is connected to and controls the said second gas control solenoid means.

4. A medical ventilator according to claim 1 comprising a second presettable electrical control set to a position indicative of the empty or minimum-volume condition of the reservoir, a second comparator having one comparison input connected to the position sensing element and the other comparison input connected to the second presettable control, the output of the comparator thereby indicating that the reservoir has reached its minimum volume state and, hence, that the required quantity of gas has been passed to the patient during the inspiration period.

5. A medical ventilator according to claim 4, further comprising means, operable if the patient tries to inhale during an expiratory period, for switching the multivibrator immediately from its expiration signal state to its inspiration signal state thereby causing the ventilator to revert to the inspiration period.

6. A medical ventilator according to claim 5 wherein said means for switching comprises detecting means for detecting the reduced pressure, in the airway connecting the ventilator to the patient, caused by the attempted inhalation.

7. A medical ventilator according to claim 4 comprising a third settable volume control element settable to an alternative volume of gas to be passed to the patient, adjustable timing control means for setting the inspiration period to any desired value, and gating means, operative at the next instant of changeover from an inspiratory period to an expiratory period after receipt of an over-ride signal, for over-riding the existing setting of the volume and inspiration time by settings dependent on the set position of the third volume control element and of the timing control means.

8. A medical ventilator according to claim 7 comprising pulse generator means for providing the over-ride signal at regular intervals.

9. A medical ventilator according to claim 8 wherein the pulse generator means comprises a counter and a clock pulse source feeding the counter which gives an over-ride pulse after receipt of a predetermined number of clock pulses, after which the counter resets to zero.

10. A medical ventilator according to claim 9 comprising means for providing a manual over-ride signal to said gating means, which signal becomes operative on the next subsequent changeover from an expiratory period to an inspiratory period.

11. A medical ventilator according to claim 10 comprising means for resetting the counter to zero on release of the manual over-ride signal.

12. In a medical ventilator of the constant volume type including a variable-volume reservoir for storing respiratory gas during each expiration period of a re-

11

petitive respiratory cycle and from which reservoir gas is passed to a patient during each inspiration period of the cycle, an electrical position sensing element operable with the reservoir to give an indication of the instantaneous volume of the reservoir over the variable range of the latter, an adjustable, electrical volume-control element settable to the required volume of gas to be passed to the patient, actuating means for expanding and contracting the reservoir so as to perform the storage and passage functions of the latter, a comparator for comparing the said indication of the instantaneous volume with the setting of the control element, the comparator being arranged to give an output signal when equality of the comparison is achieved, the improvement comprising means for terminating operation of the actuating means to expand the reservoir during

12

each expiration period when the said output signal is given and further comprising a further comparator having one comparison input connected to the position sensing element and the other comparison input connected to a presettable electrical control set to a position indicative of the empty or minimum-volume condition of the reservoir, the output of the further comparator thereby indicating that the reservoir has reached its minimum volume state and, hence, that the required quantity of gas has been passed to the patient during the inspiration period, and gating means whereby an alarm signal is given at the commencement of the next subsequent expiration period if no output signal indicating that the reservoir has returned to its minimum volume state is given by the said further comparator.

* * * * *

20

25

30

35

40

45

50

55

60

65