

May 8, 1962

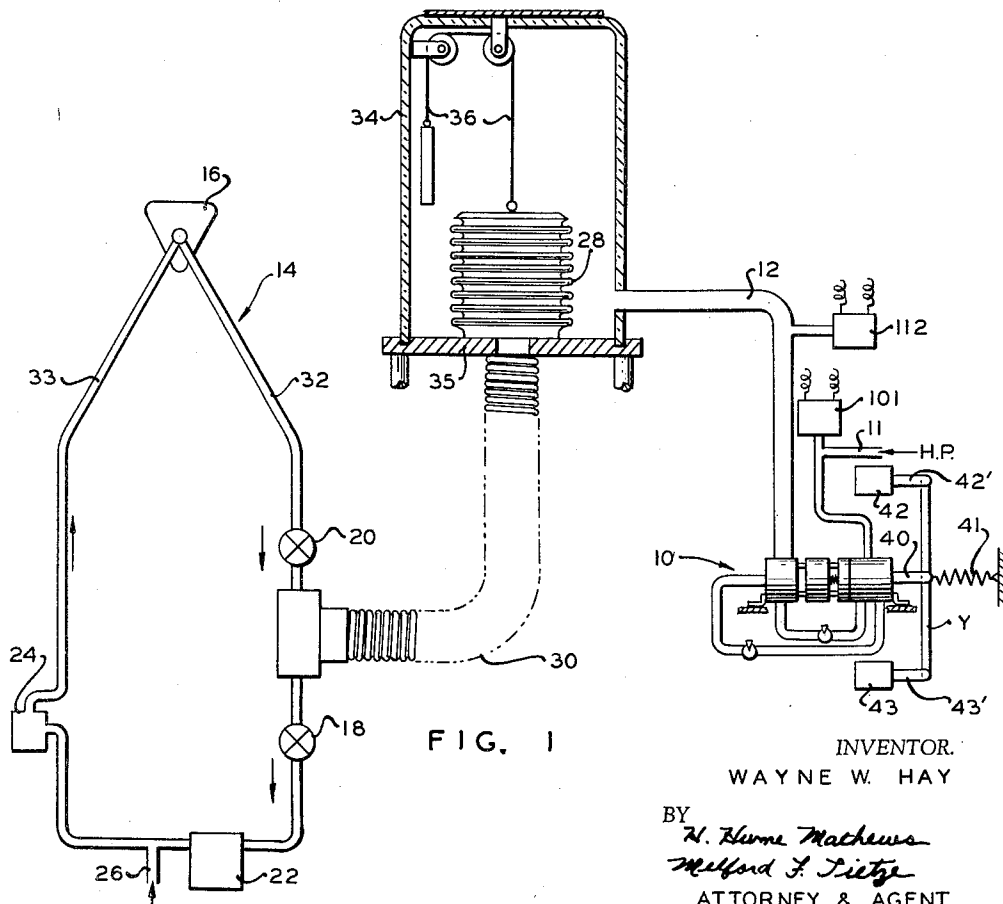
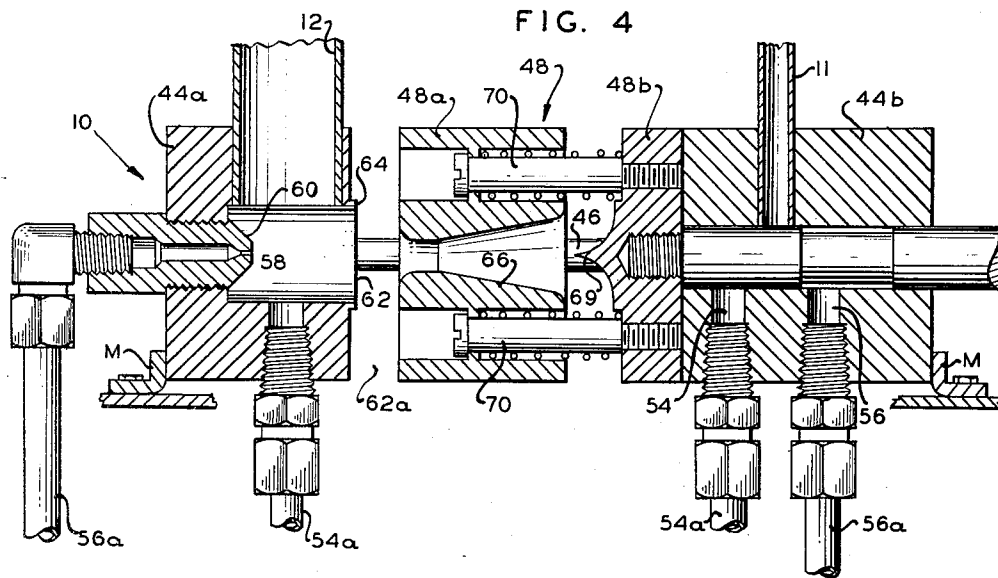
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3,033,196

ARTIFICIAL RESPIRATION APPARATUS

Filed Sept. 16, 1957

4 Sheets-Sheet 1



May 8, 1962

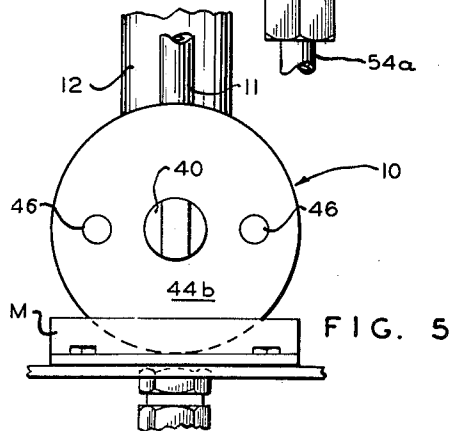
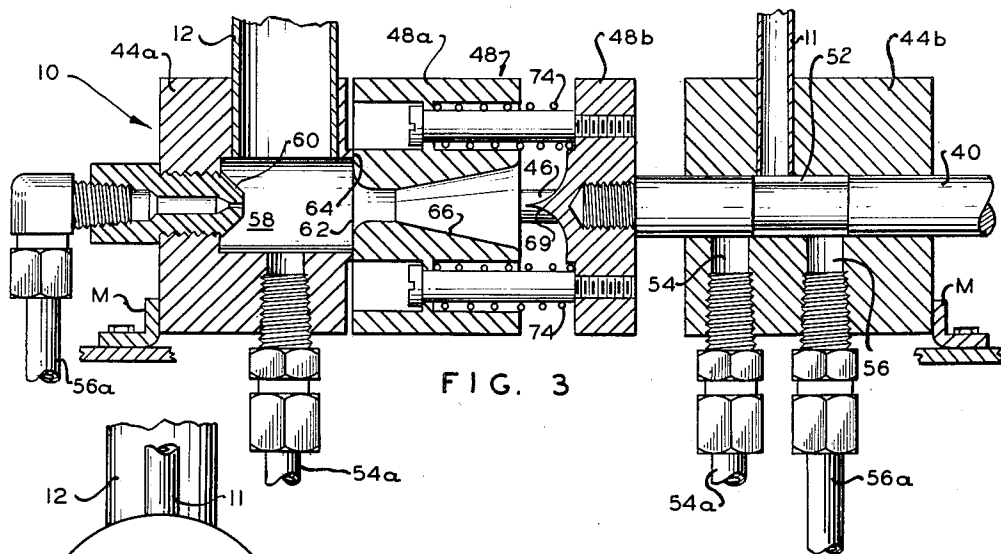
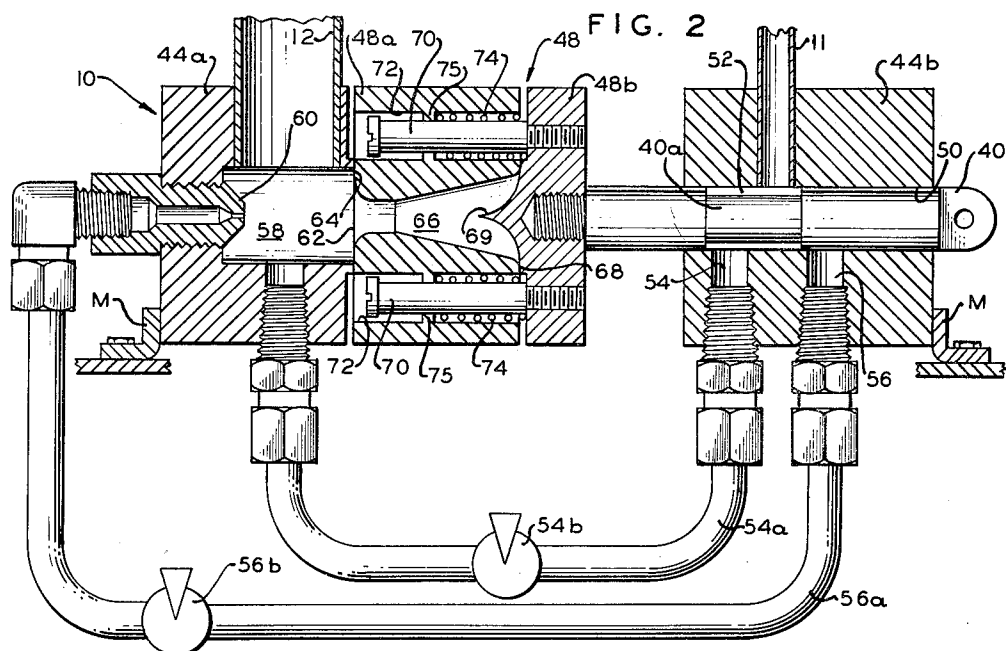
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ARTIFICIAL RESPIRATION APPARATUS

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4 Sheets-Sheet 2



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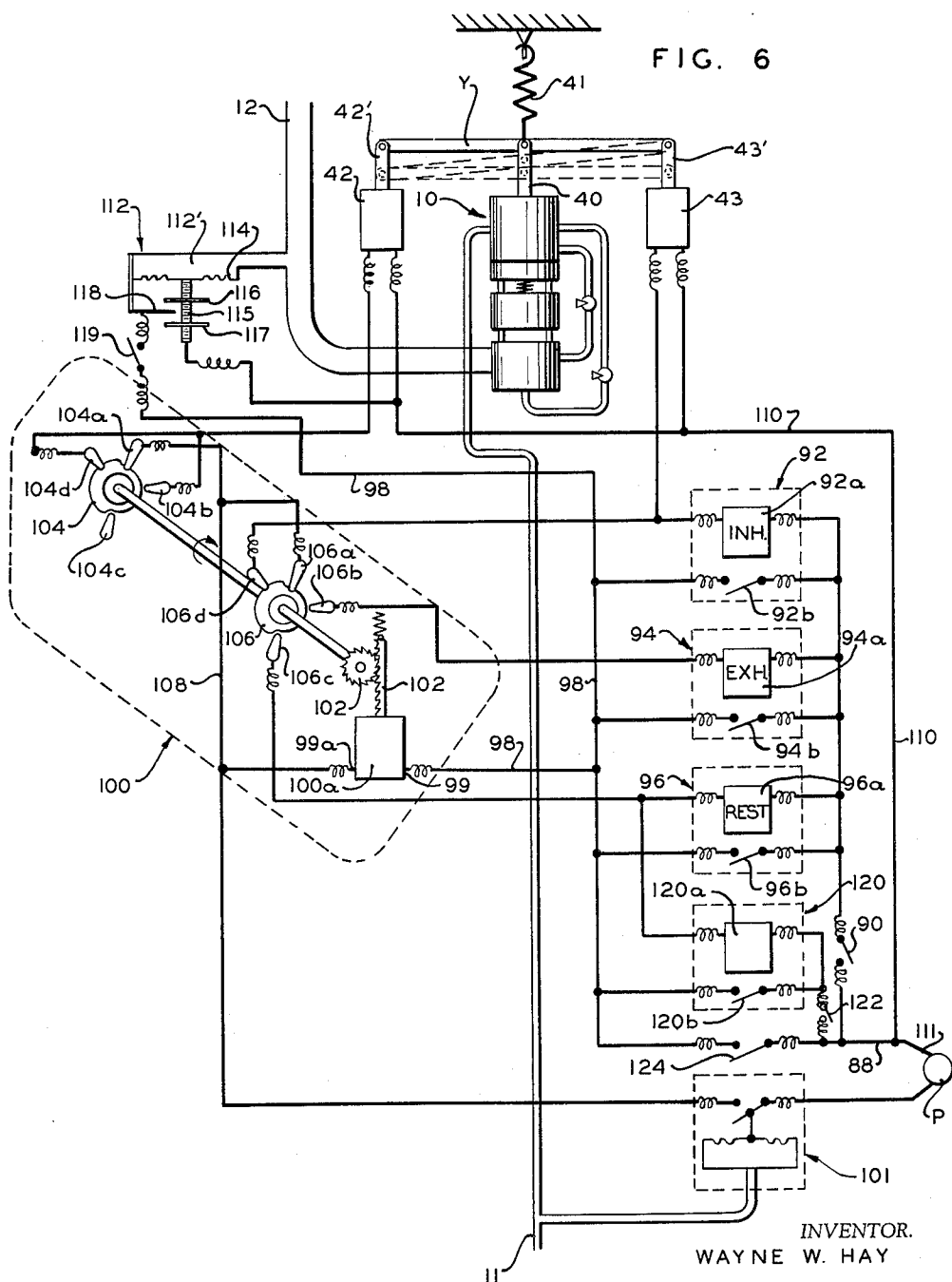
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ARTIFICIAL RESPIRATION APPARATUS

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4 Sheets-Sheet 3



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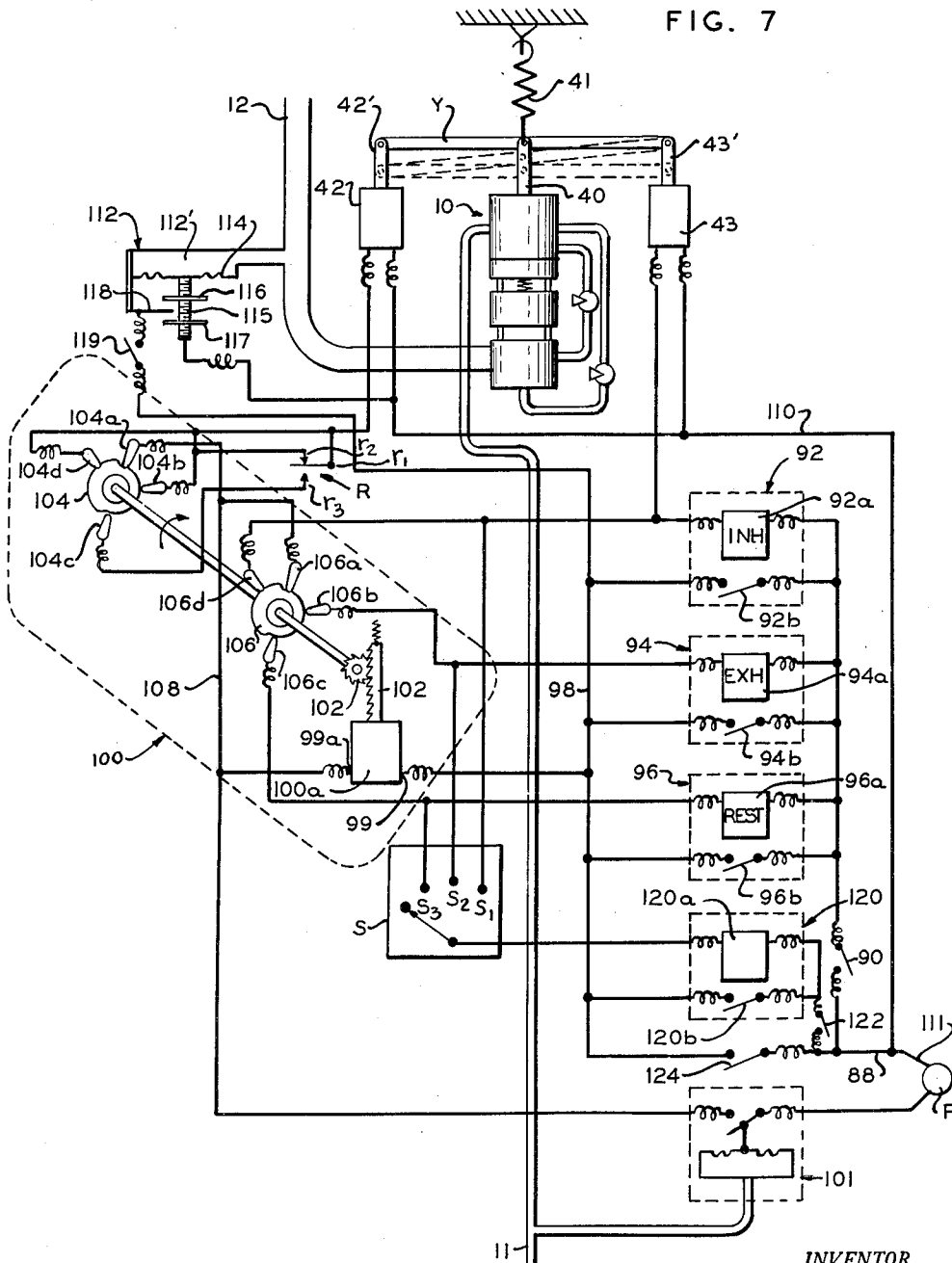
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ARTIFICIAL RESPIRATION APPARATUS

Filed Sept. 16, 1957

4 Sheets-Sheet 4



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3,033,196

ARTIFICIAL RESPIRATION APPARATUS

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20 Claims. (Cl. 128—29)

This invention relates to apparatus for artificially respirating a patient, or assisting respiration, and particularly to apparatus of this type adapted to be used in conjunction with the administration of inhalant anesthetics to patients.

Typical apparatus employed heretofore for artificial respiration or resuscitation have provided a positive pressure inflationary phase, corresponding to the act of inhalation, in a normal breathing cycle, and, in many instances, a negative pressure phase, corresponding to the act of exhalation in a normal breathing cycle. By successively delivering and exhausting gases in such a manner to and from a patient, between predetermined limits of pressure, ventilation of the patient's lungs and consequent oxygenation of the blood therein may be achieved. When suitable concentrations of anesthetic gases are mixed with the respired gases, anesthetization of the patient may be achieved and/or maintained simultaneously. Certain surgical operative procedures require such respiration of the patient while under the anesthesia.

It has been found, however, that positive and negative pressure phases of respiration may be imposed on a patient in such a way as to have an undesirable effect on the blood circulation in the lungs, thus inhibiting the desired alveolar exchange whereby oxygenation of the blood is achieved. Available apparatus, generally, have either not afforded the desired respiratory phases corresponding to optimum physiological conditions or have not been adapted to facilitate or furnish the desired adjustment or control of such phases of the respiratory cycle. For example, such apparatus have not afforded in any safe and effective manner a flexibility of adjustment of the duration of the respective phases independently of other factors such as gas flow and pressure, or an independently adjustable rest phase corresponding to atmospheric pressure within the respiratory tract. In addition, the apparatus heretofore available frequently involve cumbersome valve and control mechanisms whose physical embodiment is entirely too awkward for efficient use or operation, particularly in operating rooms and the like.

Accordingly, it is an object of the present invention to provide an improved respirator apparatus effective to produce positive pressure inhalation, negative pressure exhalation and atmospheric pressure rest phases of independently adjustable duration.

A further object of this invention is to provide such improved respirator apparatus wherein the timed duration of said respective phases is controlled independently of the rate of gas flow or of the gas pressure therein.

A further object of this invention is to provide a respirator in which the duration of both the inhalation and/or exhalation phases of the respiratory cycle can be limited by the degree of positive and/or negative pressures respectively associated therewith.

A further object of this invention is to provide a respirator which is sensitive to the demands or breathing efforts made by the patient to the extent that the respira-

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tor will respond by eliminating obstruction to, or actually assisting, the patient's own respiratory efforts in the event that these efforts occur out of phase with the automatic operation of the respirator.

5 A further object of this invention is to provide a respirator in which the automatic cycle can be selectively limited at the discretion of the operator to exclude the rest phase or any of the other phases, or to vary the sequence of the phases as they occur in a respiratory cycle induced by the respirator.

10 A further object of this invention is to provide a respirator in which the respiratory efforts of the patient can be used to control the cycling of the device to permit it to assume the burden of the work of respiration.

15 A further purpose of this invention is to provide an electrically actuated respirator which will, in the event of failure of the supply of gas and/or electric power supply "fail safe" to the extent of permitting the patient to breathe under atmospheric pressure without obstruction.

20 A still further object of this invention is to provide an improved respirator embodying sequentially operated valve means having separate, timed phases corresponding to the respective phases of the respiratory cycle.

25 A still further object of this invention is to provide a valve device of unique design, especially adapted for use in a respirator, wherein a single source of actuating fluid may be selectively controlled by said valve to produce each of the respiratory phases.

30 Still another object of this invention is to provide a respirator adapted for use during gaseous surgical anesthesia as well as other types of anesthetic procedures and also in the absence of any anesthetic procedure.

35 These and other objects and advantages of the present invention will be better understood by reference to the following description of one embodiment thereof and the accompanying drawings in which:

40 FIG. 1 is a schematic illustration of a respirator in accordance with the invention including an improved control valve means, and having operatively associated therewith a closed anesthetic administering circuit in which the desired, independently controlled, respiratory phases may be applied to a patient;

45 FIG. 2 is a longitudinal sectional view of the control valve illustrating its operative position corresponding to the inhalation phase;

FIG. 3 is the same sectional view as in FIG. 2 but showing the valve in exhalation phase position;

FIG. 4 is the same sectional view as in FIG. 2 but showing the control valve in a rest phase position;

50 FIG. 5 is an end view of the control valve looking at the actuating rod end thereof;

FIG. 6 is a combined schematic illustration of the control valve and solenoid actuating mechanism therefor and stepping switch and electrical control circuit for energizing the solenoids and controlling operation of the valve; and

FIG. 7 is a schematic illustration, similar to FIG. 6, showing certain modifications.

Referring now to FIG. 1, a respirator control valve 60 mechanism designated generally by the numeral 10 is shown having a gas supply conduit 11 for delivering a gas under pressure, such as compressed air or oxygen and a conduit 12 operatively connected to a closed anesthetic circuit shown schematically at 14. The anesthetic circuit embodies conventional elements includ-

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ing a face mask 16, inhalation check valve 18, exhalation check valve 20, and carbon dioxide absorber 22. A typical anesthetic vaporizer 24 is shown connected in the anesthetic circuit in which the vapors of a volatilized agent such as ethyl ether may be admixed with the circuit gases and delivered to the patient. The vaporizer may, however, be disconnected from the circuit and suitable anesthetic vapors supplied in another manner such as by metering from an outside source together with the make-up oxygen, through the delivery conduit 26. An expandable bellows 28 connected in the circuit by a flexible conduit 30 corresponds to the rebreathing bag of a usual closed cycle anesthetic circuit. The check valves 18 and 20 function to maintain a unidirectional, circulating flow of the respiratory gases, the exhalation gases passing from the mask through the exhalation side 32 and the returning gases being supplied to the mask through the inhalation side 33 of the circuit. It will be seen that, as in the conventional closed breathing circuit, the exhalation volume is accommodated by expansion of the bellows 28 which then collapses or returns to its original size as the volume of gas is delivered therefrom upon inhalation.

In such an anesthetic circuit it is common to assist the respiration of the patient by physically compressing and/or expanding the bellows, which then functions as a pump whereby volumes of gas determined by the displacement of the bellows are circulated to and from the patient corresponding to the phases of an artificial respiration cycle. For this purpose, the bellows is encased in a transparent shell 34 which is sufficiently large to accommodate the desired displacement of the bellows from the fixed end support 35. The bellows are preferably arranged vertically therein and provided with a counterweight mechanism 36 which compensates for the weight of the bellows. By means of the connecting tube 12, the control valve 10 selectively controls the pressure within the shell 34, thereby governing the operation of the bellows and controlling or assisting the respiration of the patient.

The control valve 10 has three operative positions: inhalation position in which gas under positive pressure is delivered to the shell 34; exhalation position in which suction is applied to the conduit 12 causing evacuation of the shell 34 and expansion of bellows 28; and, rest position in which conduit 12 and shell 34 are opened directly to the atmosphere. The three operative positions are obtained by longitudinal displacement of the actuating, or push, rod 40 of the control valve, which is shown in FIG. 1 in its normal, extreme-rightmost, rest position to which it is biased by a tension spring 41. The rod 40 is adapted to be retracted to two successive positions, corresponding respectively to exhalation position and inhalation position by the energization of solenoids, 42 and 43, whose plungers, 42' and 43', respectively, are pin connected to a transverse yoke Y which, in turn, is connected at its center, by means of a pin, to the rod 40. The solenoids are energized by means of an electrical control circuit, shown in FIG. 6 and hereinafter described in detail whereby the control and adjustment of the respective phases of respiration is achieved in accordance with the advantageous features of the present invention.

The construction of the control valve 10 is illustrated in greater detail in FIGS. 2, 3, 4 and 5. Referring thereto, it may be seen that the valve comprises two, fixed body sections 44a and 44b in which are received, respectively, the conduit 12 communicating with the respirator shell chamber 34 and the gas delivery conduit 11. The body sections are interconnected by dual slide rods 46, FIGS. 3, 4 and 5, on which a composite valve block 48, comprising two relatively movable sections 48a and 48b, is slidably mounted. The valve may be mounted, as may be desired, by means of mounting fixtures M.

The rod 40 is threadedly connected to the plate 48b at its inner end and extends through a bore 50 in body por-

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tion 44b wherein it is slidably received in a substantially gas-tight manner. A reduced section 40a of the actuating rod forms an annular manifold chamber 52 and is arranged, selectively, to close off the inlet conduit 11, or alternatively interconnect said inlet through the chamber 52 with either of two outlet passages 54 and 56. It will be seen that these passages receive connecting tubes 54a and 56a respectively which extend to and are received in the body section 44a. The tube 54a is received in a fitting which opens directly into a chamber 58 and the tube 56a is received in a fitting which opens into the chamber 58 through a venturi nozzle 60. The chamber 58 connects directly with the conduit 12 and has an opening 62 confronting the nozzle 60. The tubes 54a and 56a are provided with needle valves 54b and 56b respectively which afford adjustment of the gas flow therethrough.

The body section 48a is adapted to be placed flush against the annular seating surface 64 surrounding the chamber outlet 62 and is provided with a venturi passage 66 which is thereby placed in communication with the chamber 58 and venturi nozzle 60. At its opposite end the venturi passage is adapted to be occluded by the plate 48b having a shoulder 68 which seats around the terminal opening thereof. A conical protrusion 69 in the inner face of the plate 48b is provided to reduce the turbulence in the gas discharged through the venturi passage when the plate 48b is spaced away therefrom as hereinafter described. It will be seen that two screws 70 threadedly seated in the plate 48b project inwardly therefrom and are received in longitudinal bores 72 in the block 48a. Compression springs 74 disposed on the shanks of the screws are compressed between shoulders 75 in the bores and the face of plate 48b, thus producing a bias tending to separate the sections 48a and 48b of the valve block 48. The separation of these members is limited to a predetermined extent by the heads of the screws 70 which engage the shoulders 75 and effectively cause the section 48a to move toward the right with the section 48b in response to outward movement of rod 40, after such allowable relative displacement between the members 48a and 48b has taken place.

In the position shown in FIG. 2, gas is delivered through conduit 11 and the annular space 52 around the reduced section of push rod 40 into conduit 54 where the rate of flow is adjusted by needle valve 54b and delivered through conduit 54a to chamber 58 from which egress is provided by conduit 12 to the shell 34 thereby inflating the patient's lungs. Inflation will progress until the valve is shifted to another phase of the respiratory cycle, or until a suitable pressure relief valve (not shown in this figure) would prevent further increase in pressure.

After inflation of the lungs has been achieved to the desired extent, the volume of gas thus injected is removed by the application of a suitable degree of negative pressure. As shown in FIG. 3, this is accomplished by moving rod 40 to the right with relation to the valve body 44b. This occludes the passage between conduit 11 and conduit 54 and opens the passage between conduit 11 and conduit 56 through which the compressed air or other gas is delivered to needle valve 56b (FIG. 2) by means of which pressure delivered to venturi nozzle 60 is adjustably limited. Valve section 48b moving simultaneously with rod 40 opens up passage 66 through which the compressed air from venturi nozzle 60 together with the gas which it aspirates from chamber 58 and conduit 12 is exhausted to atmosphere, providing the aforesaid application of negative pressure and the consequent deflation of the lungs. It will be noted that in the position shown, shoulder 64 surrounding the opening 62 remains in substantially gas-tight relation with the engaging face of the section 48a, under the bias of springs 74.

When the lungs have been sufficiently evacuated, they may be brought to pressure equilibrium with the atmosphere by moving rod 40 still further to the right with respect to valve body 44b to the limits of its travel as shown

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in FIG. 4. In this position, the plate section 48b stops against the end of valve body 44b and the full cross sectional area of rod 40 occludes conduit 11 preventing flow of gas into either conduit 54 or conduit 56. Simultaneously, the heads of screws 70 acting upon the shoulders 75 pull block 48b out of contact with valve body 44a, leaving an open space 62a through which the opening 62 of chamber 58 is vented to the ambient atmosphere. The conduit 12 is thereby connected to the atmosphere making it possible for the patient either to exhale or inhale without any material obstruction or interference.

From the above description, it is apparent that the work of respiration is done by the energy of compressed air or other suitable compressed gas controlled entirely by the successive positioning in repetitive sequence of push rod 40 to each of the positions shown in FIGS. 2, 3 and 4. It is through the medium of this push rod that the control, manual or automatic, is applied for the operation of the respirator.

A preferred embodiment of an electrical control system for the respirator is shown in FIG. 6. Electric power is supplied by a source P. Line 88 from power source P is connected through switch 90 to the solenoids 92a, 94a and 96a and the switches 92b, 94b and 96b of the corresponding, normally-open, slow-closing, adjustable time delay relays 92, 94 and 96. The opposite terminals of the time delay relay switches 92b, 94b and 96b are connected through conductor 98 to terminal 99 of the solenoid 100a of a stepping switch assembly 100. The other terminal 99a of the solenoid is connected through main power switch 101 to the power source P. The main power switch 101 is a pressure switch of a well known type arranged to close its contacts only when pressurized through communication with the gas delivery conduit 11 above a lower limiting value, in this case that pressure below which the respirator will not function satisfactorily. Failure of the gas supply pressure will cut off power to the control circuit and allow the respirator to "fail safe," as later described. The stepping switch assembly 100 is of the type commonly adapted to shift its switching elements to close one or more new circuits and open all others each time a pulse of current is applied to its actuating solenoid and removed. In this particular embodiment the actuating solenoid, through suitable ratchet means 102 rotates disc switches 104 and 106 simultaneously through three successive positions (one of which is shown) so that contact is established successively between the contact 104a and one of contacts 104b, 104c and 104d, and simultaneously between the contacts 106a and one of contacts 106b, 106c and 106d.

The solenoids 92a, 94a and 96a of time delay relays 92, 94 and 96 are connected respectively to contacts 106d, 106b and 106c of the stepping switch 100, and the common contact 106a of this switch is connected by conductor 108, through main power switch 101, to the power source P.

Closing switches 90 and 101 will permit current to flow through solenoid 92a of time delay relay 92 with the stepping switch in the position shown in FIG. 6. After the interval of delay, the switch 92b will close, permitting current to flow through the solenoid 100a of the stepping switch 100. The operation of this solenoid will cause the switch to break the connection between contacts 106a and 106d and establish it between contacts 106a and 106b. The breaking of contact between 106a and 106d will cut off the current through solenoid 92a of time delay relay 92 and permit the switch 92b to open, cutting off current to solenoid 100a of the stepping switch.

The establishment of the connection between contacts 106a and 106b will permit current to flow through the solenoid of time delay relay 94, the switch 94b of which will close after a suitable interval, again applying current to solenoid 100a of the stepping switch 100. Another movement of the switching elements will occur, interrupting the current supply to the solenoid 94a of time delay

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relay 94, permitting the switch 94b to open and cutting off current to solenoid 100a of the stepping switch. Simultaneously the circuit to the solenoid of time delay relay 96 will be closed, and after a suitable interval the switch 96b will close, providing current again for the operation of solenoid 100a of the stepping switch 100 to bring it back into the position from which it started. This cycle will repeat indefinitely.

It is apparent that the adjustment of the delay time of each time delay relay can be accomplished without affecting the delay time of either of the other two.

Selecting time delay of relay 92 controls the duration of the inhalation phase of the respiratory cycle; that of time delay relay 94 controls the exhalation phase; and that of time delay relay 96 controls the rest phase, since the phases occur in that order. To apply this timed sequence control to the respirator valve assembly, push rod 40 of control valve 10, seen schematically in this figure, is biased away from the valve body by the tension spring 41. Rocker arm Y is pivotally mounted at its center to the push rod 40 and at its extremities to the armatures or plungers, 42' and 43', of solenoids 42 and 43. They are shown in their extended positions with no current flowing through them (their "fail safe" positions) and the respirator valve in the position shown in FIG. 4, so that the patient connected to an extension of conduit 12 is free to breathe at atmospheric pressure.

One terminal of each of the coils of solenoids 42 and 43 is connected through line 110 and line 111 to the power source P. The other terminal of the coil of solenoid 43 is connected to contact 106d of the stepping switch 100 and the other terminal of the coil of solenoid 42 is connected to contacts 104b and 104d of the stepping switch. If switches 90 and 101 are closed, it will be observed that solenoids 42 and 43 are simultaneously energized during the delay period of time delay relay 92. The armatures 42' and 43' will both be retracted and rod 40 will be moved inwardly to the full extent of its stroke so that the respirator valve assembly is in the inhalation position as shown in FIG. 2. At the end of the delay period, the switching operation which follows will cut off the current to solenoid 43 but will retain current through solenoid 42 because of the latter's connection to contact 104b. This permits the right-hand end of rocker arm Y to rise through its full stroke and the center to rise through half its stroke, leaving the respirator valve assembly in the position shown in FIG. 3 corresponding to the exhalation phase.

The switching operation following the period of the exhalation phase will advance the stepping switch once more and cut off current from solenoid 42, permitting the left end of rocker arm Y to rise to its full stroke and the center to rise the second half of its full stroke, bringing the respirator valve assembly to the position shown in FIG. 4, corresponding to the rest phase. At the end of the period of rest, the switching operation which follows will return the circuit to the position from which it started. This cycle will repeat indefinitely.

To make the device responsive to the demands of the patient, there is connected to conduit 12 a pressure actuated device 112, having a chamber 112', one wall of which is a thin, pressure-responsive diaphragm 114. Mounted centrally on but electrically insulated from the diaphragm is a screw 115 upon which are threaded two contacts 116 and 117. Interposed between these two contacts is a third contact 118 fixed with respect to device 112 and insulated therefrom, and connected through a manual switch 119 and conductor 98 to terminal 99 of solenoid 100a of stepping switch assembly 100. The contacts 116 and 117 are individually and independently adjustable toward or away from contact 118 by means of their threaded engagement with screw 115 which is electrically connected through line 110 and line 111 with power source P. It will be observed that when the respirator is operating on the automatic time cycle as above

described, the closure of switch 119 will result in the delivery of a pulse of current through solenoid 100a of stepping switch 100 at any time the pressure in chamber 112' increases to the point where contact 116 touches contact 118, or when the pressure in chamber 112' falls low enough so that contact 117 touches contact 118. The pressures at which these events will occur depend entirely upon the adjustment of contacts 116 and 117 with respect to screw 115.

Take, for example, a case in which the respirator is operating in its normal automatic time cycle as before described and the time intervals and rates of gas flow are so adjusted that the shift from inhalation to exhalation phase occurs normally before the pressure in the conduit 12 and chamber 112' has risen to 10 mm. of mercury positive pressure and that the shift from exhalation phase to rest phase occurs before the pressure in conduit therein has fallen to 10 mm. of mercury negative pressure. With the adjustments of contacts 116 and 117 such that slightly more than 10 mm. of mercury positive pressure (or 10 mm. negative pressure) in chamber 112' is required to force these contacts to touch stationary contact 118, the patient will be normally respired at the adjusted automatic rate determined by the setting of the time delay unless the patient makes some respiratory effort which opposes the operation of the respirator. If the patient attempts to exhale when the respirator is engaged in inflating his lungs, pressure will rise quickly and the resulting closure of contact 116 with contact 118 will send a pulse of current through solenoid 100a of stepping switch assembly 100, causing the stepping switch to advance one step and throwing the respirator immediately into the exhalation phase, thus reinforcing the patient's own efforts. If the patient attempts to inhale while the respirator is attempting to evacuate his lungs, the resulting negative pressure will pull contact 117 against stationary contact 118, sending a pulse of current through solenoid 100a of stepping switch 100, advancing the switch one step and throwing the respirator immediately into the rest phase, eliminating all opposition to the patient's efforts. If the patient makes any respirator efforts during the rest phase, they will be unimpeded and no operation of the mechanism will result until the adjusted time of the rest phase has elapsed.

Since in the case of a patient making frequent or continued respiratory efforts of his own, it may be desirable to eliminate the rest phase and thus allow the respirator to assist the patient both to inhale and exhale at all times, the substantial elimination of the delay in the operation of time delay relay 92 may be desired. This may be accomplished by the manual readjustment of the relay, but can more conveniently be achieved by the addition of another relay 120. The coil 120a and normally-open switch 120b of this relay are connected through a switch 122 with line 111 and power source P. The other terminal of the coil 120a is connected to contact 106c of stepping switch 100, and the other terminal of relay switch 120b is connected to terminal 99 of solenoid 100a of stepping switch 100. Since relay 120 has substantially no time delay, it will be appreciated that with switch 122 closed the coil 120a of relay 120 is energized at the same time as coil 96a of time delay relay 96 and a pulse of current will be immediately delivered through switch 120b to solenoid 100a, making the stepping switch 100 operate immediately to return the respirator to the inhalation phase. In this manner the rest phase is substantially eliminated and two-phase operation of the respirator results.

The timing of the two-phase respiratory cycle also can be made entirely dependent upon either the respiratory efforts of the patient if any are made, or upon the capacity of his lungs in the event he makes no such efforts. To do this, the switch 90 is left open, cutting off current to the time delay relays 92, 94 and 96. Switch 122 is closed, and compressed air is admitted to conduit

11, closing pressure switch 101. Switch 119 is closed. Starting from the position shown in FIG. 6, armatures 42' and 43' of solenoids 42 and 43 will retract, putting the respirator valve assembly in the condition shown in FIG. 2. Inflation of the lungs will follow until the pressure rises to the value necessary for closure of contact 116 with contact 118 when the resulting pulse of current through solenoid 100a will shift the respirator to exhalation phase. The lungs will then be evacuated until the pressure falls to the value necessary for closure of contact 117 with contact 118. The pulse of current following this event will shift the respirator to rest phase and the immediate closure of switch 120b of relay 120 will again provide a pulse of current to shift back to the inhalation phase without loss of time. The required pressures may be produced solely or partly by the efforts of the patient, or entirely by the respirator. The time intervals of each phase in the latter event may be controlled by the adjustment of needle valves 54b and 56b, and contacts 116 and 117. As may be seen, for example, increasing the rates of flow by needle valves 54b and 56b will decrease the intervals, while increasing the spacing between the contacts 116, 117 and 118 will increase them.

Should it be desired to operate the respirator manually, either as a supplement to automatic operation or as a substitute for it, normally-open switch 124 is inserted between line 111 and solenoid 100a of stepping switch 100. At any time, switch 124 is closed momentarily by whatever means a pulse of current operates the stepping switch 100 to shift the respirator to the next phase of its cycle, without regard to whatever other switching facilities are in use.

It will be seen that when provided with a source of power P and a supply of gas under suitable pressure in conduit 11, the respirator hereinabove described may be operated:

(a) To provide an automatically repeating cycle including a positive pressure inhalation phase, a negative pressure exhalation phase, and an atmospheric pressure rest phase, the duration of each of which is individually adjustable, or

(b) To provide an automatically repeating cycle including a positive pressure inhalation phase and a negative pressure exhalation phase, the duration of each of which is individually adjustable, or

(c) To provide an automatically repeating cycle as described in (a) above in combination with sensitivity to respiratory efforts on the part of the patient which will eliminate obstruction to, and in some cases reinforce, the respiratory efforts of the patient, or

(d) To provide an automatically repeating cycle as described in (b) above in combination with sensitivity to respiratory efforts on the part of the patient which will not only eliminate obstruction but will reinforce the patient's efforts and reduce the work of respiration to a minimum, or

(e) To provide an automatically repeating respiratory cycle including a positive pressure inhalation phase and a negative pressure exhalation phase, the duration of each phase being limited to the period required to achieve an adjustable degree of pressure or vacuum in the breathing circuit during the inhalation and exhalation phases respectively, or

(f) To provide manual control of the entire respiratory cycle of three phases as described in (a) above, or of two phases as described in (b) above, or

(g) To provide manual overriding control in combination with any of the automatic respiratory cycles as described in (a), (b), (c), (d) and (e) above, and

(h) To provide, when operated in any of the manners above described, an unobstructed breathing connection from the patient to atmospheric pressure in the event of failure of the supply of compressed air and/or electric power.

In certain instances, it is deemed highly advantageous

to produce adequate ventilation of the patient during the positive and negative phases, wherein these phases are existent over a minimum duration so that a rest phase, wherein the patient's lungs are subjected substantially to atmospheric pressure, exists during the remainder of each cycle. It will be seen that the method and apparatus of the present invention are eminently effective to apply such a mode of respiration. It will further be noted, that it is sometimes desired to impose one or more of the respective phases for a predetermined time interval. The present apparatus wherein the duration of the respective phases may be regulated independently of each other and of the rate of gas flow, etc., facilitate such a method of administration.

The above-described control circuit may be readily modified as shown in FIG. 7 to adapt the respirator for two-phase operation wherein a phase other than the rest phase is eliminated from the cycle. For example, to select the three-phase (inhalation, exhaust, rest) automatic operation or to eliminate any one of the three phases for two-phase operation, the coil 120a of phase cut-out relay 120 may be connected as shown in FIG. 7 to the common terminal of a four position selector switch S. Three of the selector switch contacts S₁, S₂ and S₃ then are connected respectively to contacts 106d, 106b and 106c of stepping switch 100. This permits relay 120 to be put on parallel with anyone or none of the three, time delay relays 92, 94 and 96, effectively eliminating their delays from the timing of the circuit.

The circuit may be further modified, as shown in FIG. 7, to permit any desired sequence for the occurrence of the respective phases of the respiration cycle. This sequence selection is accomplished by connecting the solenoid 42 to the center terminal r₁ of a single throw double pole switch R and connecting terminals 104b and 104c to the other switch terminals r₂ and r₃ respectively. It will be seen that with the switch R closed on the side corresponding to terminal 104c, the solenoid 42 will be energized first, followed by both solenoids 42 and 43 being energized, followed by both solenoids being de-energized, whereas with the switch closed on the side corresponding to terminal 104b, both solenoids 42 and 43 will be energized first, then solenoid 43 will be de-energized, and finally both will be de-energized.

Occasionally it is desirable to prolong a single phase of one or more successive cycles. This may be readily accomplished by the insertion of a normally closed switch between terminal 99 of stepping switch 100 and the conductor 98. Opening this switch will prolong the phase then in effect, and will initiate the next succeeding phase immediately when closed, since no current impulse can energize the solenoid 100a while the switch is open, but will be immediately available as a result of closure during the interval of the switch of the relay corresponding to the prolonged phase.

In a further improved, modified embodiment of the respirator herein shown and described, the respirator may be made to operate cyclically through the selected phases wherein each of the phases is independently time controlled, while the operation thereof is carried out between prescribed limits of positive and negative pressures. This may be done by inserting an adjustable vacuum relief valve and an adjustable pressure relief valve in the conduit 12, the vacuum relief valve permitting the ingress of air in the event the negative pressure drops below a desired level and the positive pressure relief valve functioning to vent gas from the conduit when the pressure exceeds its set operating pressure. When these relief valves are employed the pressure switch 112 may be disconnected so that the respective phases persist for their entire prescribed intervals, excessive positive and negative pressure merely being vented for the duration of the phase if exceeded. The switch 112 also may be retained in the circuit. However, in this event, it is preferable to set the operating limits of this switch, respectively, slightly above and below, the positive and negative oper-

ating pressures of the relief valves. In this manner, the switch 112 will function to advance the control valve only if the pressure exceeds the pressure limits of the relief valves.

The respirator apparatus hereinabove described has been shown and related in operative association with a closed anesthetic circuit, for the respiration of a patient breathing through an anesthetic mask. It will be understood, however, that such respiration may be applied directly to a patient and need not be done through an anesthetic circuit wherein the outlet of the respirator is applied to a confined chamber surrounding a breathing bag. For direct respiration, the delivery conduit 12 may be connected directly to a face mask covering both the mouth and nose of the patient which, in effect, constitutes the equivalent of the confined chamber 34, so that the gas delivered to and from the conduit 12 directly enters into or discharges from the patient's respiratory tract. In this case, of course, the gas delivered through conduit 11 must contain a sufficient amount of oxygen to be breathed by the patient.

Having understood the preceding description, it will be seen that a respirator device in accordance with the present invention affords a wide degree of flexibility of control and operation as a result of which the conditions or mode of respiration deemed to be optimum in a given case may be achieved.

It will be understood that the present invention is not limited to the specific embodiment herein illustrated and described, but may be used in other ways without departure from its spirit as defined in the following claims.

I claim:

1. A resuscitator comprising a confined chamber subjected to periodically varying pressures for resuscitating a patient, means including a control valve for controllably delivering or discharging gas to or from said chamber, said valve having three operative positions in which said chamber is subjected, respectively, to positive pressure, negative pressure and atmospheric pressure and which apply to the patient's corresponding respiratory phases, respectively, of inhalation, exhalation and rest, and an electrical control circuit for actuating said valve, operable, automatically, to regulate the duration of each of said respiratory phases individually.

2. A resuscitator according to claim 1 wherein said circuit includes separately adjustable timing means corresponding to each of the respective operating positions of said control valve and said valve is operated cyclically through said operating positions and retained in each successive position for a time interval dependent upon said respective timing means.

3. A resuscitator according to claim 2 wherein said electrical circuit includes pressure responsive means, adjustable, to override said timing means and permit said valve means to be placed in its next operative position when the pressure in said chamber exceeds a predetermined limit.

4. A resuscitator according to claim 2 wherein said valve is automatically disposed in rest position when said circuit is de-energized, means are provided for supplying said valve with a gas of at least a predetermined minimum positive pressure, and said control circuit includes pressure responsive means preventing energization of said circuit when said delivery gas is below said predetermined pressure.

5. A resuscitator according to claim 2 wherein said electrical circuit includes means for selectively eliminating one of said phases.

6. A resuscitator according to claim 2 wherein said electrical circuit includes means for selecting the sequence of the respective phases of the respiratory cycle.

7. A respirator comprising a confined respiratory chamber, a source of respiring gas under pressure, control valve means connected to said gas source and having an

outlet connected to said chamber, said valve means being operable in normal rest position to connect said outlet with the atmosphere and in a first operative position to connect said outlet directly with said gas inlet and in a second operative position to connect said outlet with the aspirator of a venturi passage through which said gas is conducted to produce a suction in said outlet, actuating means for displacing said valve from rest position to each of said operative positions and means energizing said actuating means including adjustable timing means effective to selectively control the length of time said valve means is placed in each of its respective operative positions.

8. A resuscitator according to claim 7 wherein said valve means includes a valve having a longitudinally movable plunger resiliently biased toward one end of its stroke corresponding to the rest position of said valve and solenoid means corresponding to each of said operative positions, operatively connected to displace said plunger and dispose said valve in said respective operative positions when energized, and electrical control circuit means for periodically energizing said solenoid means for adjustable time intervals.

9. A respirator according to claim 8 wherein said circuit includes an adjustable time delay relay corresponding to each of said rest and two operative valve positions, and switch means actuated by the closing of the contacts of each of said relays to de-energize the coil of the corresponding relay and energize one of the other of said relays in a continuous cyclic sequence, and said solenoid means being so connected, respectively, in said circuit as to be energized simultaneously with the coils of said relays corresponding to the operative positions of said valve means and to be de-energized during the period the coil of said relay corresponding to the rest position is energized.

10. A respirator according to claim 9 wherein said circuit includes switching means for reversing the sequence of operation of said solenoid means.

11. A control valve device for controlling a bi-directional gas flow in a delivery conduit comprising a valve block having a delivery passage for connection to a delivery conduit and a valve chamber therein connecting with said passage, a venturi nozzle disposed to discharge into said chamber, a port disposed in confronting relation to the discharge end of said nozzle, opening from said chamber into an external substantial flat seating surface of said valve block, a first movable plate arranged in opposition to said seating surface adapted to be seated against said seating surface and having a venturi passage aligned with said venturi nozzle, which registers with said port at its entrance end and terminates in a flat seating surface in its discharge end, a second plate movable with respect to said valve block and said first plate effective alternatively to seat against said first plate to occlude the discharge end of said venturi passage or to be positioned away therefrom, means for delivering a pressurized gas to said valve chamber, and selector means including said pressurized gas delivery means for delivering said gas through said venturi nozzle and operably connected with said first and second plates to position said plates and thus control the direction of fluid flow in said delivery passage.

12. A control valve device according to claim 11 wherein said selector means includes a separate delivery passage for conducting said pressurized fluid to said chamber, a movable valve stem for alternatively delivering said pressurized fluid to said chamber in corresponding operative positions, through either said venturi nozzle or said separate delivery passage, and means operatively connecting said stem with said first and second plates for correspondingly positioning said plates.

13. In a resuscitator, a confined respiratory zone, inhalation phase control means for producing in said zone an inhalation phase during which the pressure is greater

than atmospheric, exhalation phase control means for producing in said zone an exhalation phase during which the pressure is less than atmospheric, rest phase control means for producing in said zone a rest phase during which said zone is open to the atmosphere, and sequence control means operable to actuate said phase control means repeatedly and sequentially to produce first an inhalation phase, then an exhalation phase and then a rest phase, said sequence control means including three timing means, one for each of said phase control means, said three timing means being individually setttable to predetermine the duration of each phase independently of the other phases.

14. In a resuscitator, a confined respiratory zone, inhalation phase control means for producing in said zone an inhalation phase during which the pressure is greater than atmospheric, exhalation phase control means for producing in said zone an exhalation phase during which the pressure is less than atmospheric, sequence control means operable to actuate said phase control means repeatedly and sequentially, said sequence control means including two timing means, one for each of said phase control means, said two timing means being individually setttable to predetermine the duration of each phase independently of the other phase, means responsive to the pressure in said zone operable at times to override either of said timing means and terminate either of said phases, and selectively operable control means movable between a first position in which the duration of the phases is determined only by said timing control means and said pressure responsive means is ineffective, and a second position in which the pressure responsive means is effective to terminate either of said phases.

15. Respirator apparatus, comprising a confined respiratory zone, gas supply and withdrawal means connected to the respiratory zone for the supply to the patient of gas for inhalation and the withdrawal from the patient of exhaled gas, gas flow control means operatively connected to the gas supply and withdrawal means, said gas flow control means being operable selectively to establish any of at least three respiratory phases, each characterized by a distinctive condition of gas flow between the gas supply and withdrawal means and the respiratory zone, a plurality of phase relays corresponding in number to said phases, means controlled by said phase relays for operating said gas flow control means, said last-named means being effective when each relay is energized to establish a particular respiratory phase, and means for energizing the relays one at a time in a predetermined sequence.

16. Respirator apparatus as defined in claim 15, including selectively operable means for energizing the relays one at a time in any of a plurality of different sequences.

17. Respirator apparatus as defined in claim 15, including manually operable means for modifying the sequence by removing one of the phase relays therefrom.

18. A respirator having a confined respiring chamber, means for supply to a first region gas under a predetermined pressure, means for establishing in a second region a second gas pressure substantially lower than said predetermined pressure, valve means controlling the flow of gas from said first region to said chamber and from said chamber to said second region and movable selectively to: (1) a first position in which the chamber is connected to the first region and an inhalation phase is established; (2) a second position in which the chamber is connected to the second region and an exhalation phase is established; and (3) a third position in which the chamber is connected to the atmosphere and a rest phase is established; selectively energizable electrical means for operating the valve means to its first and second positions, timing means operable to control the energization of said electrical means for predetermined intervals during said inhalation and exhalation phases, and biasing means acting

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on said valve means in a direction to move the valve means toward said third position, said biasing means being effective in the absence of electrical energy for energization of said electrically energizable means to connect said respirating chamber with the atmosphere.

19. A respirator according to claim 18, wherein said timing means includes three timers, one for each phase, each timer being individually settable to control the duration of each phase independently of the other phases.

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20. A respirator according to claim 19, including means for selectively reducing the duration of one of said phases substantially to zero.

References Cited in the file of this patent**UNITED STATES PATENTS**

2,547,458	Goodner	Apr. 3, 1951
2,830,580	Saklad et al.	Apr. 15, 1958
2,972,345	Spigel	Feb. 21, 1961