

[54] **MEDICAL RESPIRATORS**

[75] Inventor: **Barry John Kipling**, Cambridge, England

[73] Assignee: **Pye Limited**

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[51] Int. Cl.....**A61m 15/00**

[58] Field of Search...128/145.8, 145.6, 142.2, 142.3

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Primary Examiner—Richard A. Gaudet

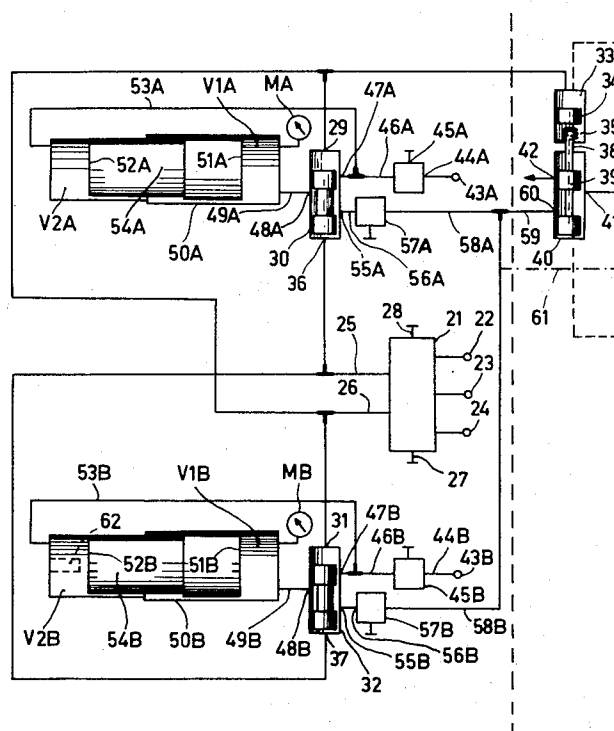
Assistant Examiner—G. F. Dunne

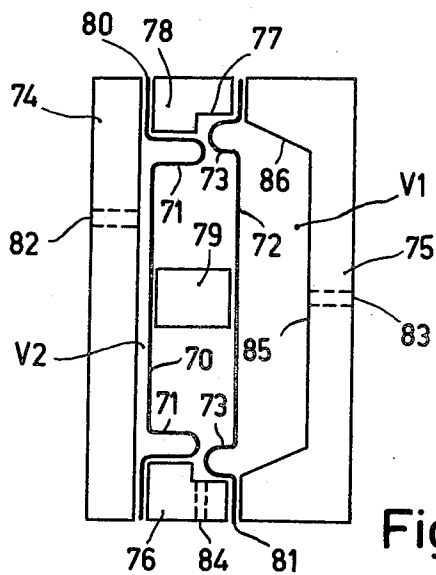
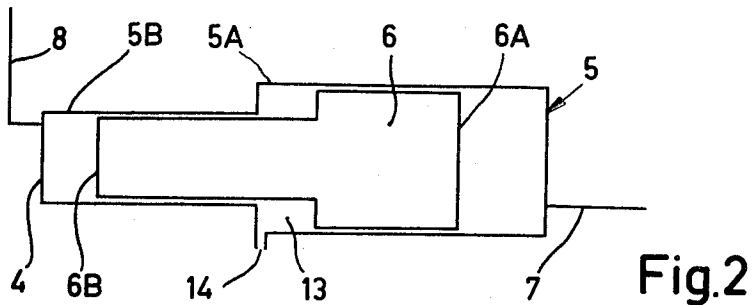
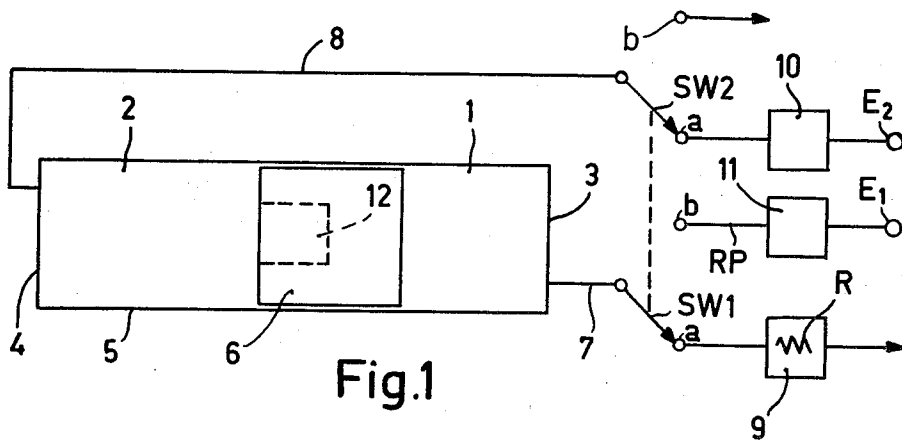
Attorney—Frank R. Trifari

[57] **ABSTRACT**

A medical respirator in which gas is stored and passed to a patient in an adjustable predetermined time having switch means to control the flow of gas from a pressure source into a variable volume during the expiration period of the respirator and from the variable volume to the patient through restrictive means during inspiration period. The gas container is divided into two volumes separated by a movable member. Gas for the patient is expelled from the first volume, which is variable, by decrease of the first volume caused by movement of the movable member as a result of patient gas pressure in the second volume.

11 Claims, 4 Drawing Figures





INVENTOR.

BARRY JOHN KIPLING

BY

Frank R. Sullivan

AGENT

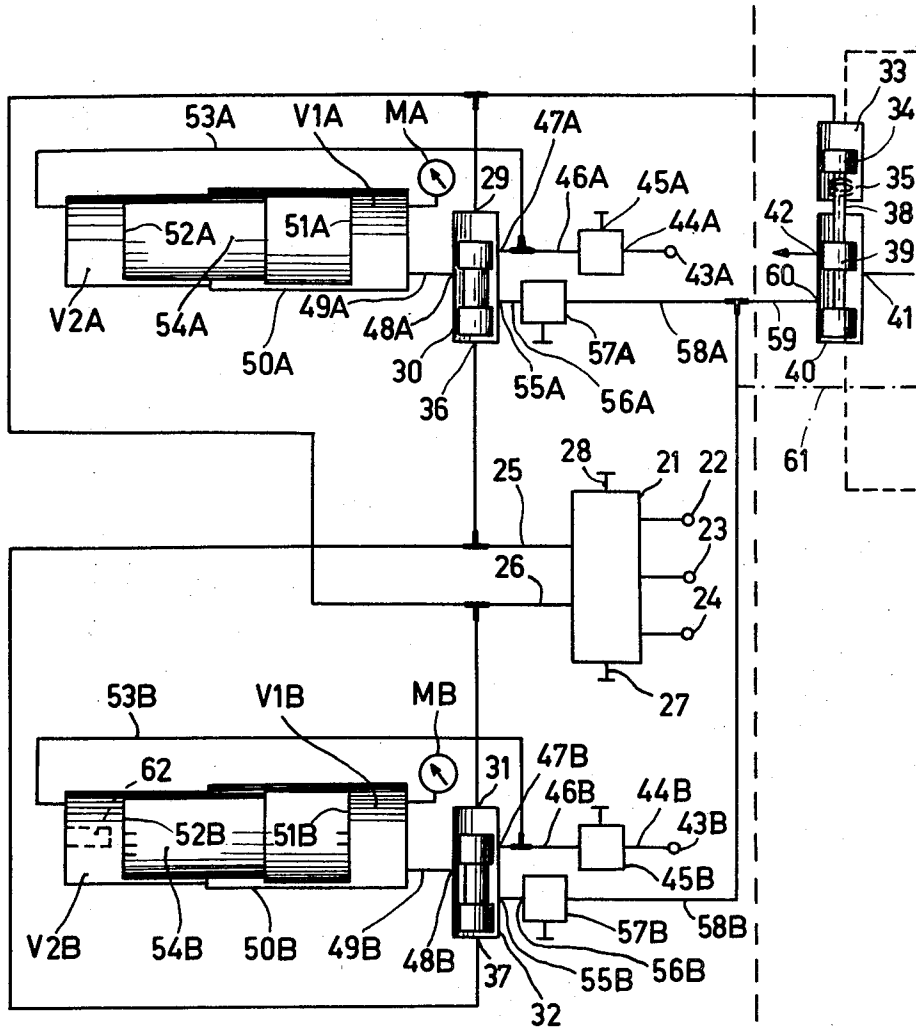


Fig.3

INVENTOR.

BARRY JOHN KIPLING

BY

Frank R. Lufkin
AGENT

MEDICAL RESPIRATORS

This invention relates to medical respirators in the use of lung ventilators, generally referred to as respirators in medical applications, any harmful cardiovascular effects are basically the result of the abnormally high positive pressure within the lungs which eliminates in part or wholly the sub-atmospheric pressure normally present within the thorax. The lower the mean intrapulmonary pressure during the respiratory cycle the less marked these cardiovascular effects will be, where mean is defined as the area bounded by the curve of instantaneous pressures in the lungs and the zero pressure line.

It is therefore desirable to limit the time during which the lungs are at maximum pressure during the inspiratory period, i.e. positive pressure should not be maintained for longer than is necessary to effect the desired volume exchange, the inspiration period should be shorter than the expiration period, the lungs should be inflated by a rapid flow of gas and expiratory resistance should be low. A common ratio for inspiration/expiration periods is of the order of 1:1.5, while the faster the flow of gas to the lungs the shorter may be the inspiration period though a limit is set to this by the danger of alveolar rupture in circumstances of uneven ventilation.

Negative pressure provided by a ventilator during the expiratory period will assist in providing a mean intrapulmonary pressure of low value but where the ventilator has no such provision a substantially constant flow of gas to the patient or a flow that increases during the inspiratory period is beneficial provided that the desired volume exchange is completed at substantially the same time as the inspiration period is terminated.

For pediatric use the volume of gas supplied to the patient, commonly referred to as the Tidal Volume, must be carefully controlled to avoid inflation of the lungs and the limitation regarding flow of gas becomes more stringent.

A known type of Tidal Volume respirator uses a fixed volume container to store gas at pressure, the quantity stored being a product of volume and pressure, during an expiratory period and allows the stored quantity to discharge to the patient, at substantially atmospheric pressure, during an inspiratory period. Such a discharge tends to be of exponential character with early inflation of the patient during the inspiration period and therefore not desirable as earlier mentioned, and to overcome this, flow from the container is held more constant by controlled adjustment of a variable flow control during the inspiratory period.

It is an object of the invention to provide a Tidal Volume respirator, i.e. one in which an adjustable predetermined quantity of gas is first stored and subsequently passed to a patient in an adjustable predetermined time, in which gas pressure prior to a preset flow control in the gas path to the patient is controlled to determine the flow, of the previously stored quantity of gas, to the patient and provide required instantaneous pressures in the lungs of the patient. The flow to the patient may be substantially constant.

From another aspect the invention provides a medical respirator as aforesaid in which the flow of gas to the patient during the said inspiratory part of the period from the first volume is determined by patient gas at pressure passing through means controlling the flow, or pressure applied, to the second volume.

Preferably gas in the second volume used for reducing the capacity of the first volume during an inspiration period is subsequently transferred to the first volume for expulsion to the patient.

The invention also provides a medical respirator in which a mixture of patient gases in controllable proportions is passed to the patient during each inspiration period comprising a variable volume for each individual gas of the mixture.

The various features and advantages of the present invention will be apparent from the following description of exemplary embodiments thereof, taken in conjunction with the accompanying drawings, in which:

FIGS. 1 and 2 are explanatory diagrams of the principle used in the invention;

FIG. 3 is a diagram of a Tidal Volume Respirator embodying the invention in which a predetermined adjustable mixture of two gases is passed to a patient in each inspiratory period; and

FIG. 4 shows an alternative construction for the cylinders shown in FIGS. 2 and 3.

In FIG. 1, first and second volumes 1 and 2 are provided by the respective end caps 3 and 4 of a cylinder 5 and a free piston 6 within the bore thereof. Switches SW1 and SW2, ganged to operate together as indicated by a broken line, are connected to volumes 1 and 2 respectively by pipe lines 7 and 8. With the switch arms in the *a* position shown, volume 1 is connected to substantially atmospheric pressure, as indicated by an arrow head, through a restriction 9 acting as a flow control and volume 2 receives gas from a pressure source E2 through control means 10. Such gas will move piston 6 towards the right of the Figure to expel gas from volume 1 accordingly as that volume is reduced towards zero capacity by the piston movement. In position *b* of the switch arms volume 2 discharges to substantially atmosphere pressure, as indicated by an arrow head and volume 1 receives a fixed pressure of gas RP as determined by a pressure regulator 11 supplied from a pressure source E1. Such pressure RP will move piston 6 towards the left of the figure, thereby increasing volume 1 towards a maximum and decreasing volume 2 towards a minimum or zero to expel gas therefrom.

If, in position *b* of the switches, volume 2 discharges to a pressure level RP, i.e. the pressure set by pressure regulator 11, instead of to atmosphere, no movement to the left by piston 6 will occur. The movement may be restored, as shown in FIG. 2, by providing cylinder 5 with two unequal bores 5A and 5B and piston 6 with corresponding unequal diameters, 6A and 6B, the force on one side of the piston then being greater than on the other with equal pressures in the two volumes. Alternatively a spring may be connected between piston 6 and, for example, end cap 4 such that, with equal pressures on both sides of piston 6 of FIG. 2, the piston is drawn to the left to reduce volume 2 to a minimum. Such a spring requires to have little tension and is preferably of the type providing a constant force throughout its extension and may be housed within a recess 12, indicated by broken lines, in the piston 6, e.g. a spiral retractile extension spring having one end attached to end cap 4 and its other end to a spool rotatably mounted within the recess 12. This alternative also provides piston movement to the left when pressure RP is substantially atmospheric.

Control means 10 may be either a pressure control or a flow control. Where it is a pressure control providing a pressure P_2 equal to or greater than RP , flow through restriction 9 will be constant at a rate proportional to P_2/R where R is the resistance of restriction 9. Where a pressure of P_2' , of lesser magnitude than RP , is provided by the control, flow through restriction 9 will, on operation of the switches to the a position, decrease exponentially from RP/R until pressure within volume 1 has dropped to P_2' and will thereafter be constant at P_2'/R until piston 6 has decreased volume 1 to zero.

Where the control means 10 is a flow control, i.e. a restriction or resistance to flow R_2 , the normal exponential discharge of a volume through a restriction is modified. The flow through restriction 9 may then take any one of several forms depending on the relative pressures of E_1 and E_2 and values of resistances R and R_2 e.g. of exponential form when resistance R_2 is infinite, substantially constant when $(E_2 - RP/R_2)$ equals RP/R , or rise from RP/R to a higher value during movement of piston 6 from one extreme position to the other. Where volume 2 is never reduced to zero, a delay in modifying the normal exponential discharge is introduced.

Operation of the switches SW_1 and SW_2 to position b will thus increase volume 1 to a maximum with gas therein at a pressure RP , the quantity of gas stored being the product of the maximum volume and the pressure, and subsequent change of the switches to position a will be accompanied by a discharge of the above quantity in a time determined by the flow through restriction 9, this quantity being discharged to the patient.

The above described charge and discharge of a variable volume employs two switches and three controls 9, 10 and 11 which are somewhat inter-dependent, and such multiplicity and such inter-dependence is not desirable in a medical respirator especially when used by an operator who is not highly skilled or who is working under conditions of stress. In the respirator shown in FIG. 3 the number of controls has been reduced by using a common pressure source and a common pressure regulator for supplying gas at pressure to the two volumes; the number of switches being reduced to one.

In FIG. 3 the timing means employed are pneumatic, and represented by rectangle 21 receiving air at pressure from ports 22, 23 and 24. Air pipe lines 25 and 26 connected thereto are respectively alternately pressurized and vented to atmosphere, the duration of the pressurized condition of each line being determined by the setting of controls 27 and 28 which respectively control the duration of inspiration and expiration periods. Pressure in line 26 is applied to a control port 29 of a changeover switch 30, to a control port 31 of a similar switch 32, and to a cylinder 33 on the face mask of the respirator. Such pressure moves the spools of the switches to the inspiration position shown and also a piston 34 within cylinder 33 against the pressure of a bias spring 35. Such movement of the spools is possible since, when line 26 is at pressure, line 25 is vented to atmosphere. This line is connected to second control ports 36 and 37 of switches 30 and 32. Piston 34 is connected by a rod 38 to the spool 39 of an expiration switch 40 which in the shown inspiration position, with line 26 pressurized, prevents egress of gas from the face

mask via port 42 which vents to atmosphere as indicated by an arrowhead issuing therefrom.

At the start of an expiration period, line 26 is vented and line 25 is pressurized, so driving the spools of switches 30 and 32 to their second position, while spring 35 moves piston 34 and spool 39 to close port 60 and to link ports 41 and 42 to allow gas from a patient and the mask to escape to atmosphere. In the second position of switch 30, a first patient gas at pressure applied to a port 43A will flow through gas pipe 44A to pressure regulator 45A and thence, at a pressure determined by the regulator, through pipe 46A, ports 47A and 48A of switch 30 and pipe 49A to a volume V1A of a cylinder 50A. It will also flow at the determined pressure through a pipe 53A to a volume V2A of cylinder 50A. Volumes V1A and V2A are formed by the walls of cylinder 50A and the respective ends 51A and 52A of a free piston 54A, the bore and piston diameter of volume V2A being slightly less than those of volume V1A. Due to the unequal piston area the equal pressures in volumes V1A and V2A result in piston movement to the left of FIG. 3 and volume V2A will reduce to a minimum which may be substantially zero and volume V1A reach a maximum value. During movement of the piston 54A, gas within volume V2A will be transferred by pipes 53A, 46A and 49A through switch 30 to volume V1A. The quantity of gas then within volume V1A is thus the maximum cubic capacity of volume V1A multiplied by the pressure delivered from regulator 45A when such pressure is measured in atmospheres, and regulator 45A may be calibrated in terms of quantity of the first gas.

In a similar manner, a second patient gas at pressure applied to a port 43B is passed via a pipe 44B, regulator 45B, pipe 46B, ports 47B and 48B of switch 32, pipe 49B to volume V1B of a second cylinder 50B of similar construction to cylinder 50A, and to a volume V2B of cylinder 50B via a pipe 53B. As before, volumes V1B and V2B are not equal due to unequal bores and diameters of ends 51B and 52B of a piston 54B and the quantity of gas stored is the maximum volume of V1B multiplied by the pressure in atmospheres from regulator 45B, so that regulator 45B may also be calibrated in terms of quantity of the second gas.

After a time determined by the setting of time control 28 the expiration period will be terminated and lines 25 and 26 vented and pressurized respectively. Switches 30, 32 and 40 are then reoperated to the shown position. The first gas will then pass from volume V1A through pipe 49A, ports 48A and 55A of switch 30, pipe 56A, a variable restriction or flow control 57A, a pipe 58A, pipe 59 and ports 60 and 41 of switch 40 to the patient. The second gas will also pass from volume V1B through pipe 49B, ports 48B and 55B of switch 32, pipe 56B, pipe 59 and ports 60 and 41 of switch 40 to the patient. The patient thus receives a total quantity of gas or Tidal Volume which is the sum of the two quantities determined by the two regulator settings and by the volumes.

As switch 40 is primarily concerned with opening the path between ports 41 and 42 during expiration and closing it during inspiration, pipe 59 may alternatively lead directly to the face mask, as shown by a chain dot line 61, port 60 then being unused and sealed.

Were piston ends 51 and 52 of equal areas a constant pressure determined by a regulator 45 would be applied to piston 54 during discharge of gas to a patient, and, neglecting the small rise in pressure within the lungs, flow through a restriction 57 would be constant and equal to the regulated pressure divided by the resistance to flow. The time T to discharge would then be proportional to the resistance of the restriction and the piston would travel at a uniform rate along the cylinder. With piston ends 51 and 52 of slightly different diameter there will be no initial movement of the piston and flow will decrease from a maximum of regulated pressure divided by resistance to a lesser value at which it becomes constant with the piston moving to expel gas. The difference in diameters may be small and with, for example, a diameter ratio of 9/10, the time for discharge will be approximately 1.22T. Flow controls 57 may therefore be calibrated in terms of time and adjusted to coincide with or be slightly less than the time determined by the pneumatic drive circuit 21.

Preferably the sum of the maximum values of volumes V1A and V1B is small in relation to the minimum Tidal Volume to be delivered so that a pressure considerably above atmospheric is required to store the required amount of gas therein. Such relatively high pressure in relation to the small maximum pressure within a patient's lungs ensures that the flow of gas to a patient during inspiration is substantially constant. It also ensures that friction between piston and bore has little effect and that overall size of cylinders 50 is relatively small. Where the ratio of gases to be supplied is large, i.e. one gas is a small percentage of the quantity of the other, it is advantageous to have maximum volumes V1A and V1B of different capacity so that pressures considerably above atmospheric can be applied to both. To effect this cylinders 50A and 50B may differ in both diameter and/or length. Alternatively cylinders of equal size may be employed but the stroke of one piston be limited so that maximum volume V1 may differ for the two cylinders. This is illustrated in FIG. 3 in which broken lines outline the end of a screw 62 inserted through and sealed in the end wall of volume V2B. Such screws may be used in both volumes V2 to provide precise adjustment of the maximum value of volumes V1A and V1B.

Providing that volumes V1 reduce substantially to zero capacity and that the volume of gas at pressure within valves 30 and 32 and pipes 49 and 56 is small, flow of gas to the patient will cease rapidly when a piston 54 reaches the end of its stroke during expulsion of gas, and be accompanied by a rapid drop in pressure. Meters MA and MB, recording pressure in volume V1A and V1B respectively and which may also be calibrated in terms of gas stored, may thus serve as indicators of the end of the piston stroke. Indicating means, not shown, may be operated from the pneumatic timing circuit 21 so that comparison of the inspiration time, set by the timing circuit 21, and duration of gas flow to the patient, set by flow controls 57 and denoted by a drop in reading of meters M, may be compared.

It should be noted that in the arrangement shown in FIG. 3 alteration of Tidal Volume by alteration of pressure supplied from a regulator 45 also alters the flow through the associated flow control. The time of gas

flow is thus constant for a given setting of a flow control 57 and requires no corrective alteration due to alteration of Tidal Volume. To enable the flow controls 57A and 57B to be ganged and operated from a common shaft their resistance ratio RA/RB must be maintained constant and equal to the ratio V1B max/V1A max.

An alternative construction for the cylinder of FIGS. 2 and 3 is shown in FIG. 4, in which frictional losses due to piston sealing have been substantially reduced. In the figure two volumes V1 and V2 are formed between two rigid circular diaphragms 70 and 72 of unequal diameters, i.e. differing surface areas, having respective flexible portions 71 and 73 towards their peripheries, and respective end pieces 74 and 75. Separating the end pieces is a ring 76 having two internal diameters formed by surfaces 77 and 78, the ring being similar in length to a rod member 79 attached to adjacent faces of the diaphragms. Not shown are bolts passing through holes in the end pieces and ring whereby the assembly may be clamped together, such clamping securing the peripheries 80 and 81 of the diaphragms between the end pieces and ring to seal the two volumes. Entry ports 82 and 83 shown by broken lines, in respective end pieces 74 and 75 allow passage of gas to and from volumes V2 and V1 respectively, whilst a port 84, also indicated by broken lines, in ring 76 provides a facility enabling the space between the diaphragms to be at any desired pressure, e.g. atmospheric.

As drawn, volume V2 is reduced to substantially zero and volume V1 is at a maximum. Application of gas at pressure to port 82 will move both diaphragms to a position in which diaphragm 72 is in contact with a flat internal face 85 of end piece 75 and the flexible portion 73 is extended to its limit and in contact with a tapered wall 86 of the end piece so reducing volume V1 to substantially zero. As shown in FIG. 4 flexible portion 71 surrounding diaphragm 70 has a greater depth than flexible portion 73 surrounding diaphragm 72. Surround 71 is less flexible than surround 73 and retains diaphragm 70, rod 79 and diaphragm 72 central about the axis of ring 76 during travel of the diaphragms between their limit positions. Alternatively, support means, forming a bearing, may be provided to co-operate with a rod carried by diaphragm 70 and centrally locate the diaphragms, both surrounds 71 and 73 then being equally flexible. With such alternative construction a diaphragm and surround may comprise a rigid disc-attached to a "rolling" diaphragm, for example, of the type known as "Bellofram" manufactured by George Angus and Company Limited, of Coast Road, Wallsend-on-Tyne.

The cylinder and piston of FIG. 1 may also be of similar construction to that shown in FIG. 4, though with diaphragms and surrounds 70, 71 and 72, 73 of equal diameter and ring 76 of uniform internal diameter. The spring housing referenced 12 in piston 6 of FIG. 1 may in this case be situated in the rod member 79 of FIG. 4, the diaphragm 70 being suitably pierced and sealed to rod 79 to allow passage of a spring therethrough while preventing escape of gas.

An alternative form of construction to the cylinders of FIGS. 1, 2 and 3 and the diaphragm valve of FIG. 4 is a flexible bellows, the enclosed volume of which provides the volume V1, surrounded by a closed container;

the space between the bellows and the container constituting the volume V2.

In the unstressed condition, the bellows are in the fully expanded state and volume V2 is small compared with volume V1. Pressure in volume V2 collapses the bellows to provide the minimum volume of V1, which is made very small by suitable design of the end faces of the bellows.

What is claimed is:

1. A medical respirator comprising a patient gas container, a movable member within said container for dividing it into first and second volumes, said movable member being responsive to pressure acting thereon, said first volume arranged so as to be variable with the position of said movable member, first connection means connected to said first volume for passing patient gas therefrom to a patient during an inspiration period of the respirator, restrictive means within said first connection means for controlling the flow of gas to the patient, second connection means connected to said first volume and to a pressure source for providing patient gas to said first volume during an expiration period of said respirator, means within said second connection means for regulating the pressure of gas from said pressure source to said first volume, switching means arranged for connecting said first volume to the first or second connection means during inspiration or expiration periods of said respirator, automatic timing means connected to said switch means for causing switching operation thereof for cyclically changing the periods of the respirator between inspiratory and expiratory, third connection means connected with said switching means for connecting said pressure source to said second volume when said switching means is in one position during an inspiratory period, gas from the pressure source being supplied to said second volume during said inspiratory period so that said movable member will be displaced as a result of pressure of the gas in said second volume acting on said movable member so as to decrease said first volume, gas for the patient thereby being expelled from said first volume during at least part of the inspiration period as a result of the decrease of said first volume caused by movement of said movable member, the ratio of the first volume to the second volume varying with the position of said movable member, said switching means being arranged for transferring gas which acted on said movable member for decreasing the capacity of said first volume, from the second volume, to the first volume when said switching means is in another position during the expiration period of the respirator said transferred gas to be expelled therefrom to a patient.

2. The medical respirator according to claim 1 wherein said movable member comprises a piston

movably mounted within said gas container for movement in one of two opposing directions to thereby vary the ratio of said first volume to said second volume.

3. The medical respirator according to claim 2 wherein said piston has two end faces, one of which forms a boundary of said first volume, and the other of which forms a boundary for said second volume, the surface areas of the two end faces being unequal so that said piston will be caused to move in the direction of the face having the smaller area when the pressures acting on the opposite end faces of said piston are equal.

4. The medical respirator according to claim 2 further comprising spring means attached to said piston for causing said piston to be displaced within said gas container when the force of pressure acting on one of said end faces is equal and opposite to the force of pressure acting on the other end face.

5. The medical respirator according to claim 1 wherein said restrictive means within said first connection comprises a variable restrictor to gas flow which is capable of adjustment so that the minimum pressure of the gas in said first volume during an inspiratory period is higher than the maximum pressure in the patient's lungs.

6. The medical respirator according to claim 1 further comprising a pair of gas containers, each having a movable member therein defining first and second volumes, each of said first volumes being arranged to be variable, means for supplying patient gas to each of said variable volumes so that a mixture of patient gases is passed to the patient during each inspiration period, and means for controlling the proportions of said mixture.

7. The medical respirator according to claim 6 further comprising a pressure regulator connected to the first volume of each of said pair of gas containers for adjusting the respective proportions of the constituent gases in the mixture.

8. The medical respirator according to claim 7 further comprising means for adjusting the maximum volume of each gas in said variable volumes of each container, said maximum volume being dependent on the proportion of said gas in the mixture.

9. A medical respirator according to claim 1 wherein the movable member comprises at least one diaphragm.

10. A medical respirator according to claim 9 wherein the movable member comprises two parallel diaphragms arranged to move in unison at their centers and having different surface areas.

11. A medical respirator according to claim 10 wherein in which the diaphragms have flexible edges and rigid centers.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,714,941 Dated February 6, 1973

Inventor(s) Barry John Kipling

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the heading:

Priority date of "June 5, 1970" should read

-- January 2, 1970 --.

Signed and sealed this 16th day of July 1974.

(SEAL)

Attest:

McCOY M. GIBSON, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents