

Aug. 9, 1966

H. L. GAGE, JR

3,265,061

RESPIRATION APPARATUS

Filed Nov. 7, 1960

4 Sheets-Sheet 1

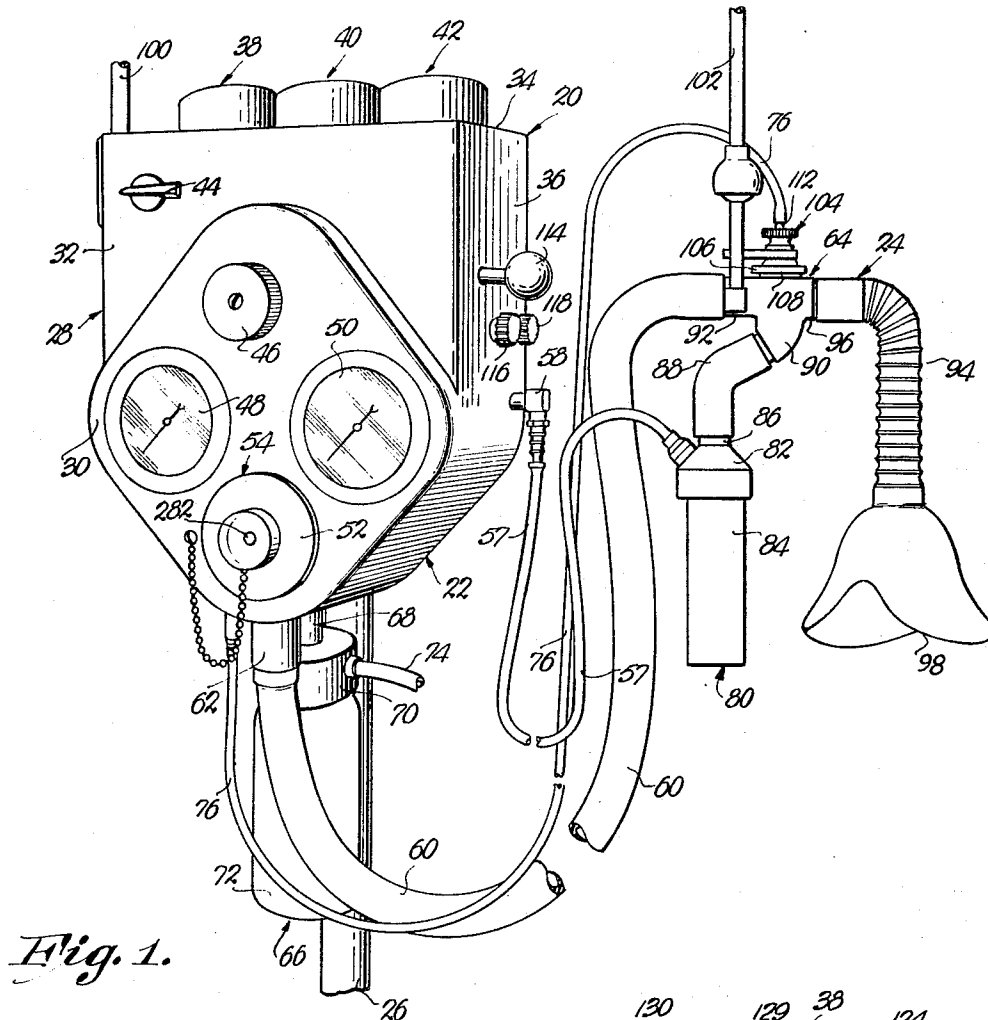


Fig. 1.

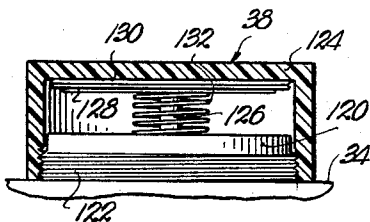


Fig. 2.

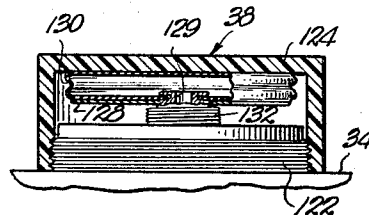


Fig. 3.

INVENTOR.
Herbert Lincoln Gage, Jr.

BY

Stoney, Schmidt, Johnson & Stoney
ATTORNEYS

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H. L. GAGE, JR

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4 Sheets-Sheet 2

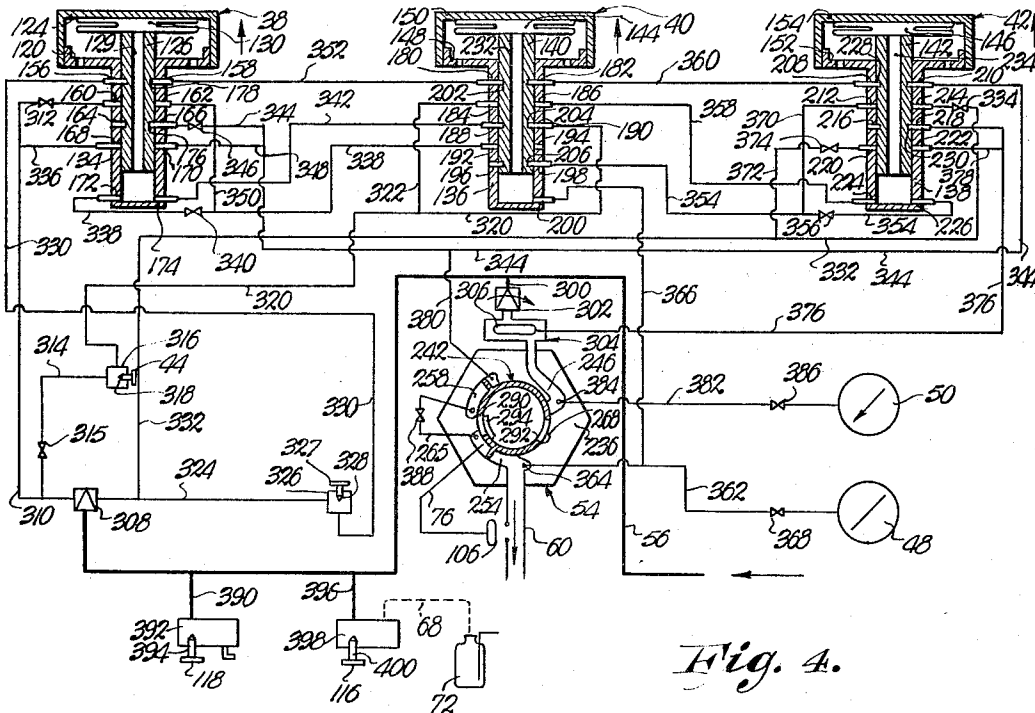


Fig. 4.

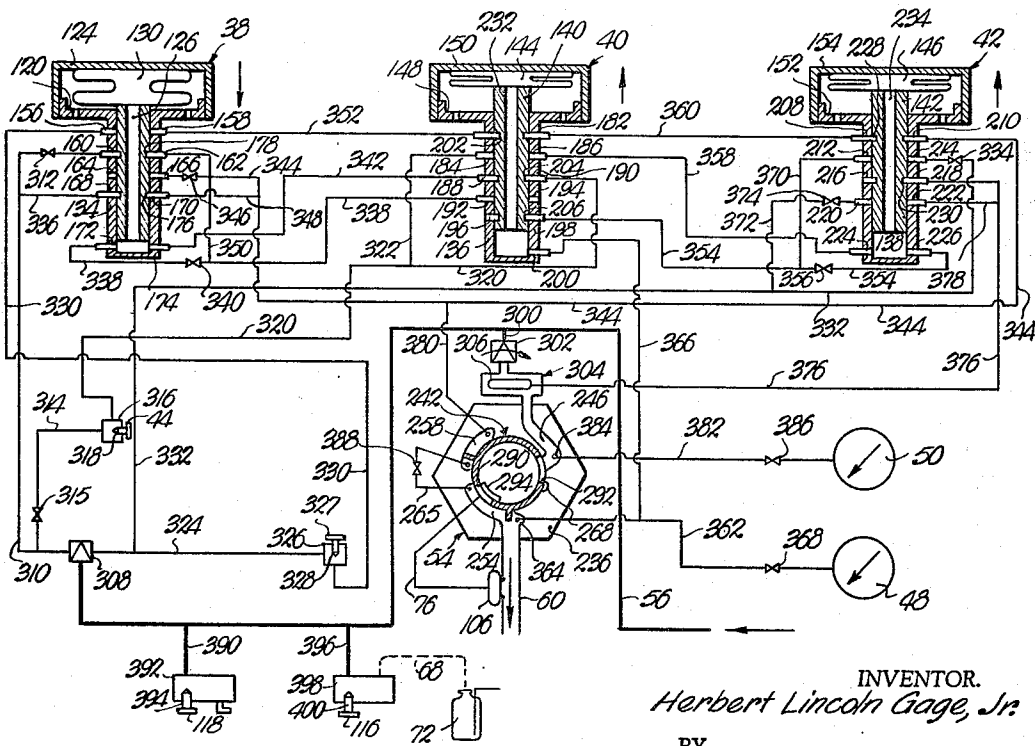


Fig. 5.

INVENTOR.
Herbert Lincoln Gage, Jr.

BY

Harvey Schmidt, Johnson & Sonny
ATTORNEYS.

Aug. 9, 1966

H. L. GAGE, JR

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4 Sheets-Sheet 3

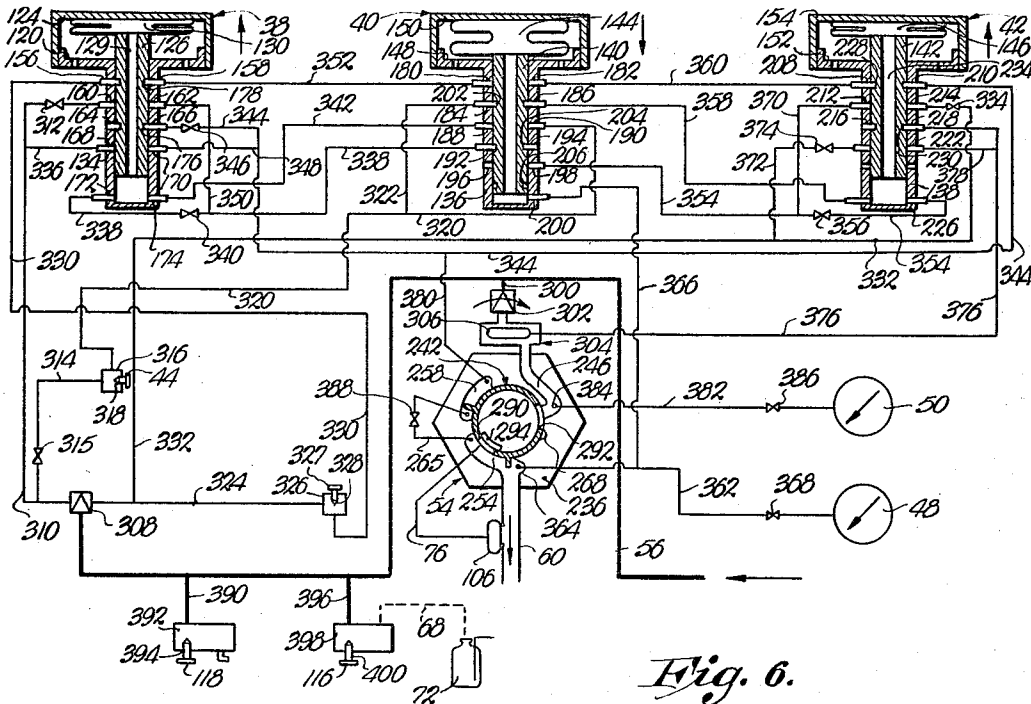


Fig. 6.

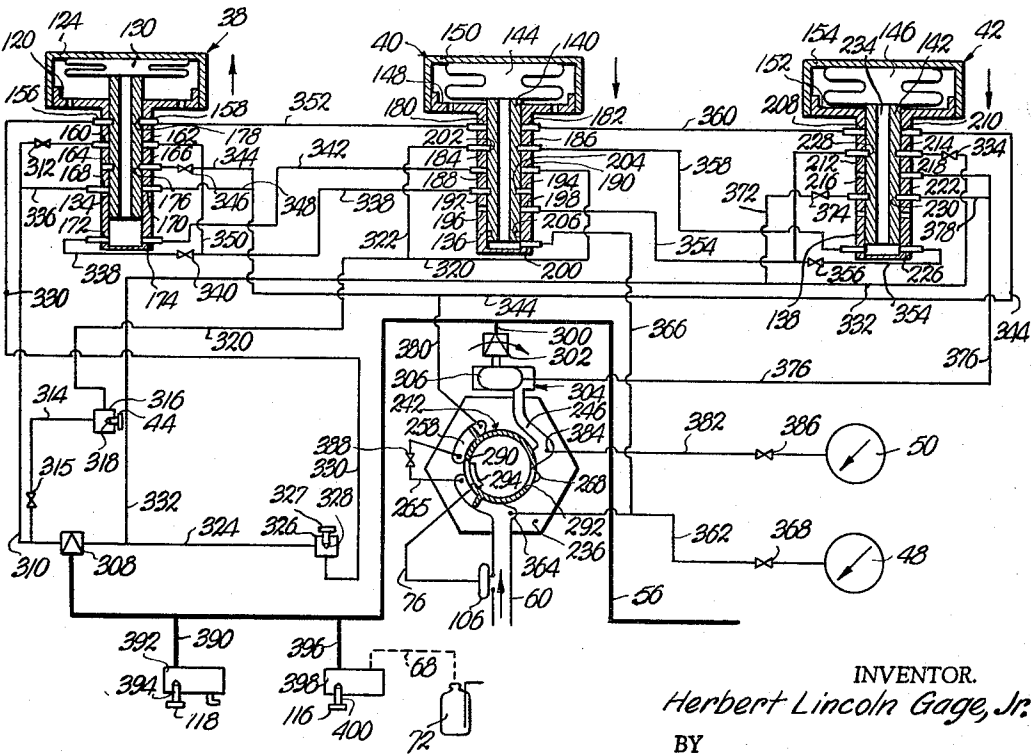


Fig. 7.

INVENTOR.

Herbert Lincoln Gage, Jr.

BY

Honey, Schmidt, Johnson & Honey
ATTORNEYS.

Aug. 9, 1966

H. L. GAGE, JR
RESPIRATION APPARATUS

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4 Sheets-Sheet 4

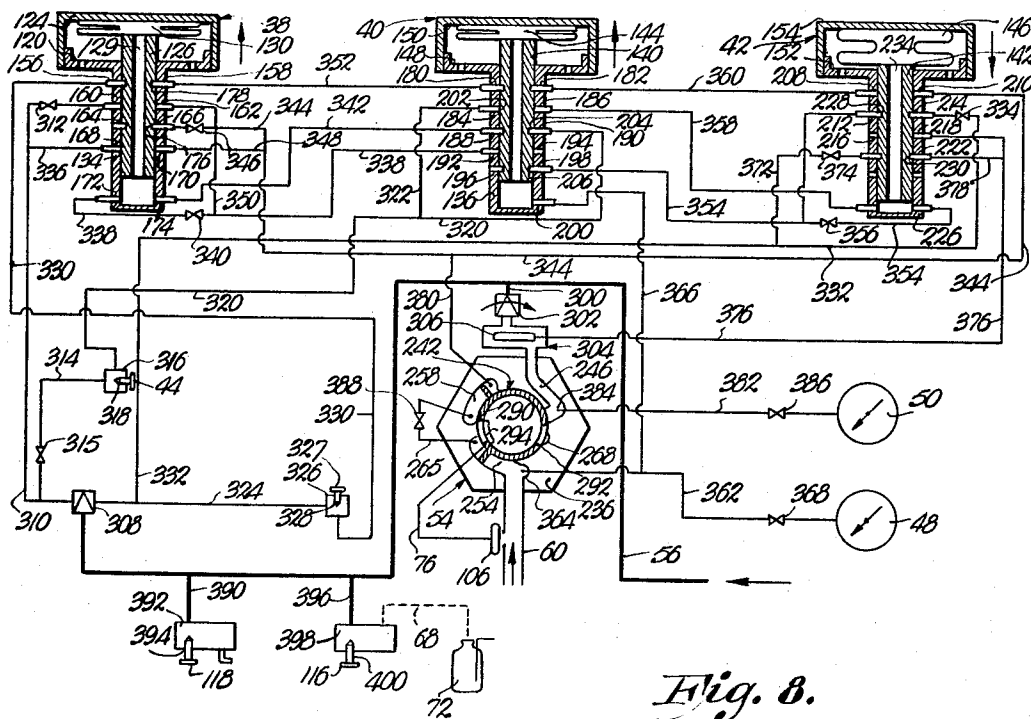


Fig. 8.

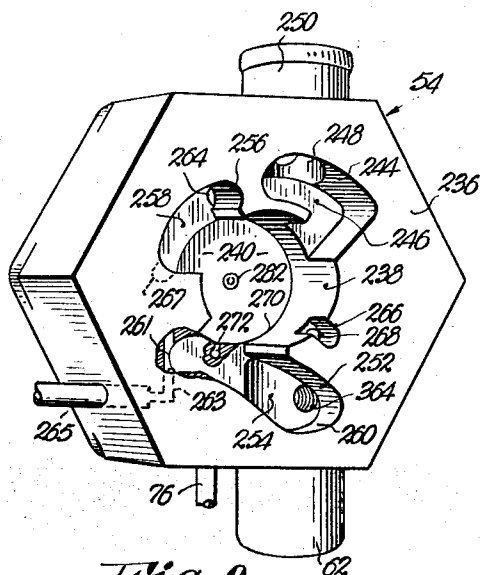


Fig. 9.

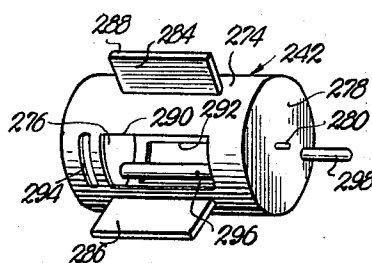


Fig. 10.

INVENTOR.
Herbert Lincoln Gage, Jr.

BY

Honey, Schmidt, Johnson & Honey
ATTORNEYS

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3,265,061

RESPIRATION APPARATUS

Herbert L. Gage, Jr., Pacific Palisades, Calif., assignor to
Bennett Respiration Products, Inc., Los Angeles, Calif.,
a corporation of California

Filed Nov. 7, 1960, Ser. No. 67,589

13 Claims. (Cl. 128-29)

This invention relates generally to respiration apparatus, and has for its primary object to provide an improved unit which may function as an intermittent positive pressure breathing therapy device, as a respiratory assistor or guarantor, or as a respiratory controller, with only adjustment of readily accessible, easily understood controls on the machine being required to place the unit in condition for the various operations specified.

Most resuscitators operate on a pressure-sensitive principle which presents many disadvantages, one of the most significant being the tendency of the equipment to cycle rapidly in the event there is any appreciable restriction or block of the patient's respiratory passage. In this prior equipment, the cycling pressure of the pressure-sensitive resuscitation apparatus is reached in the mask almost immediately if there is any substantial restriction to flow of gas into the patient's lungs. In order to overcome this defect, the pressure-sensitive resuscitators have been provided with a manually operated needle valve control of gas flow which may be individually adjusted to a fixed flow low enough to pass a flow of gas through the restriction, but it can be appreciated that the amount of gas delivered to the patient is seriously restricted and constant readjustment of the needle valve must be made in order to prevent chattering of the cycling structure on resuscitators of this type. Such needle valve type of control also requires readjustment for different patients, and readjustment for the individual patient as changes in resistance and compliance occurs.

It is, therefore, another important object to provide a respiration unit that operates on a flow-sensitive principle, rather than being pressure-sensitive as with prior units, thereby permitting inclusion of automatic cycling mechanism that is not in any way hampered or interfered with because of a restriction in the patient's respiratory passages and orifices. Moreover, it is an important advantage of the apparatus of this invention that, by virtue of its automatic cycling mechanism, it can function even when there is a leak in the system. It should be noted that leaks are oftentimes unavoidable in practice or desirable for physiological reasons.

It is another very significant object of the invention to provide a flow-sensitive respiration unit having the characteristics described wherein cycling of the cycling unit is effected by pneumatically operated structure, thereby avoiding many of the problems encountered in prior units with respect to rapid cycling of the resuscitator, or malfunction of certain of the components of the equipment, it being recognized that pneumatically controlled structure is much more positive in its action, and subject to finer control than with other types of units. In this respect, it may be noted that an important advantage of the utilization of a flow-sensitive, pneumatically operated respiration unit, is the fact that the motive power for the same is furnished from the source of gas which is being supplied to the patient so that as long as gas is available for the patient, the respiration apparatus of the present invention will continue to function in a normal manner.

A further important object of the invention is to provide respiratory apparatus which is not only completely automatic in operation, but may be utilized as an assistor, guarantor, or controller. As an assistor, the unit responds to a very slight inspiration effort on the part of the patient

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and provides positive pressure for inspiration. As a guarantor, with the rate control set slightly slower than the patient's normal breathing rate, the unit will cycle automatically into inspiration and expiration if the patient stops breathing or breathes erratically. As a controller, with the patient not breathing on his own, the unit cycles automatically into inspiration and expiration, but allows the patient to take over the cycling rate if he begins breathing on his own.

It can be recognized that it is desirable in respiration apparatus that the physician supervising operation of the same in administering therapeutic gases to patients having various kinds of respiratory difficulties, be able to utilize the apparatus selectively or progressively with a given patient in any one of the ways outlined above. Thus, in many instances, it is necessary that operation of the apparatus be completely automatic with time-controlled inspiration and expiration. At other times, the unit should be able to respond to an attempt on the part of the patient to inspire with automatic time-controlled expiration. Another requirement is that the unit be capable of assisting the patient in inspiring, by providing positive pressure during such inspiration, and also capable of permitting complete expiration of gases before beginning another inspiration cycle. It is also necessary that the apparatus provide for overriding any automatic time-control exercised by the apparatus over breathing functions in response to even a very small patient effort to initiate the corresponding breathing function. Another important requirement of the apparatus is that the same provide the attending physician with means for independently varying the total respiration time cycle without substantial alteration of the preferred ratio of inspiration time to expiration time pre-established in the apparatus.

It is, therefore, an important aim of the invention to provide simple, reliable, and relatively inexpensive equipment capable of performing all of the functions listed above and without costly maintenance being required at frequent intervals.

An additional important object of this invention is to provide mechanism for causing the respiration unit to cycle into the exhalation phase thereof, either in response to expiration of a time period determined by the automatic cycling mechanism, or by filling of the patient's lungs to a preselected pressure, whichever condition first occurs.

It is still further an aim of the invention to provide a pneumatically operated respiration unit wherein novel inspiration start, recycling and expiration start valves, are arranged in unique relationship to provide positive automatic cycling at a preselected rate when the patient is not breathing, or is breathing at an abnormal rate, and yet which is capable of being controlled by the patient when the latter begins to breathe, and without adjustment by the attending physician being required. An equally important object is to provide equipment as referred to, wherein a flow-sensitive valve is utilized in conjunction with the pneumatically operated valves described, to provide for overriding of the automatic respiration control structure, as well as to assure positive direction of gas to the patient and proper expiration by the patient.

A still further object of the invention is to provide a multi-purpose respiration unit wherein the rate of automatic cycling of the equipment may be readily changed, the ratio of oxygen to air may be varied as required, the amount of oxygen or air delivered to the patient changed at will, and the ratio of the inspiration period to the expiration period varied to suit the individual requirements. The latter variation of ratio of inspiration to expiration periods is accomplished by establishment of the patient pressure cut-off level at a value such that in-

spiration will be completed at a time different than contemplated by the automatic timing cycle.

It is another object of the invention to provide a respiration unit which can automatically adjust its operation to the needs of a patient throughout a uniquely wide range of flow rates, so as to accommodate the needs of all classes of patients from infants to adults and regardless of physiological condition. The unit is further adapted to commence and continue its operation even when the non-elastic resistance of the patient or the breathing circuit is extremely great.

Other important objects and details of construction of the present apparatus will become obvious or be described in greater detail as the following specification progresses.

In the drawings:

FIGURE 1 is a fragmentary, perspective view of a respiration unit embodying the concepts of the present invention and illustrating the control unit, as well as a mask assembly for delivering the gas to a patient;

FIG. 2 is a fragmentary, enlarged, vertical, cross-sectional view through the uppermost part of one of the pneumatically operated control valves and illustrating the same in the normal, uppermost position thereof;

FIG. 3 is an enlarged, fragmentary, vertical, cross-sectional view similar to FIG. 2, except that the valve is in the lower position thereof as the bellows on the same is in an expanded condition;

FIG. 4 is a schematic representation of the present respiration unit and illustrating the three pneumatically operated control valves, the flow-sensitive valve, and the structure associated therewith with all of the pistons of the control valves being illustrated in their upper positions;

FIG. 5 is a schematic representation similar to FIG. 4 and illustrating the disposition of the piston of the inspiration start valve in its lower position, as well as the disposition of the flow-sensitive valve, when the apparatus is at one point in the normal cycle of operation thereof;

FIG. 6 is a schematic view illustrating the disposition of the components when the piston of the recycling valve is at the lower end of its path of travel;

FIG. 7 is a schematic view showing the pistons of the recycling valve and the expiration start valves at their lower ends of their paths of travel and the flow-sensitive valve in the initial disposition thereof;

FIG. 8 is another schematic view showing only the piston of the expiration start valve at the lower end of its path of travel;

FIG. 9 is an enlarged, fragmentary, perspective view of the housing of the flow-sensitive valve forming a part of the present structure, certain parts thereof being broken away and in section to reveal details of construction of the same; and

FIG. 10 is a perspective view of the flow-sensitive valve member adapted to be mounted in the housing illustrated in FIG. 9.

Respiration apparatus embodying the preferred concepts of the present invention is designated broadly by the numeral 20, and includes as basic components, a respiration control unit 22 and a gas delivery assembly 24 operably coupled to unit 22. An upright standard 26 may conveniently serve as means for supporting the housing 28 of unit 22, and which has a primary front wall 30, a front wall 32, a top wall 34, side walls 36, and a removable back wall (not shown).

Housing 28 mounts inspiration start valve 38, recycling valve 40 and expiration start valve 42 which are carried by top wall 34 and extend downwardly into the interior of housing 28. A cycling rate control valve 44 is rotatably mounted on wall 32 of housing 28, while primary wall 30 mounts a pressure control valve within housing 28 having a rotatable member 46 connected to the control valve externally of housing 28. Also mounted on wall 30 is a mask pressure gauge 48, a control pressure gauge 50, and the external plate 52 of a flow-sensitive con-

trol valve broadly designated 54. Gas is caused to flow into housing 28 from a suitable source of supply, through a conduit 56 connected to a suitable coupling (not shown) on the back of housing 28, while a relatively large conduit 60 couples the outlet tube 62 of flow-sensitive control valve 54, to a T-coupling 64 forming a part of assembly 24. An aspirator 66, depending from housing 28, has a gas inlet tube 68 extending upwardly into the interior of housing 28 from cap 70, removably threaded on jar 72 of aspirator 66, while liquid secretion removal tube 74 is coupled to cap 70 and communicates with the interior of jar 72.

Another tube 57 is coupled to a tubular fitting 58 on the side wall 36 of housing 28 and leads to a nebulizer unit broadly designated 80. Tube 57 is coupled to the head 82 of nebulizer 80, while a jar 84 is threaded onto head 82 with the outlet 86 thereof receiving the lower extremity of an L-shaped connector tube 88 which in turn is telescoped over the lower tubular leg 90 of coupling 64. It will be noted that conduit 60 is fitted over the tubular leg 92 of coupling 64, while a flexible gas delivery hose 94 is removably connected to the outer leg 96 of coupling 64. A face mask 98 is releasably connected to hose 94, although it is to be understood that other gas delivery devices may be employed in lieu of mask 98 and hose 94, as for example, tracheotomy tubes or the like. The assembly 24 is carried by housing 28, through bracket arms 100 and 102 which are swingably interconnected through intermediate links not shown in FIG. 1.

The T-coupling 64 also carries an exhalation valve broadly designated 104 and including an inflatable member 106 disposed to close the outlet orifice of tubular boss 108 connected to coupling 64, while a gas delivery conduit 76 is connected to the outer coupling 112 of valve 104 for delivering gas thereto to effect inflation of member 106 in a sequence to be described hereinafter.

A manually operated control handle 114, extending through side wall 36, is connected to oxygen dilution components within the interior of housing 28 to permit selective control over dilution of the gas delivered to the patient, while manually operable needle valve control knobs 116 and 118 are mounted on side wall 36 immediately below handle 114. Knob 116 controls the needle valve associated with aspirator 66, while knob 118 controls the needle valve forming a part of the structure for delivering gas to nebulizer 80.

In order to more clearly understand inspiration start valve 38, recycling valve 40 and expiration start valve 42, shown schematically in FIGS. 4 to 8 inclusive, the upper part of valve 38 is shown in FIGS. 2 and 3 in vertical cross section. An upwardly extending boss 120 on top wall 34 of housing 28, is externally threaded at 122 and complementally receives the internally threaded portion of a cup-shaped cap 124 removably threaded over boss 120. Each of the valves 38, 40 and 42 has a cylinder which reciprocally receives a piston such as 126, which is of tubular configuration and mounting an annular plate 128 on the uppermost end thereof. An inflatable bellows 130 is carried by plate 128 in communication with the passage 129 through piston 126 so that upon inflation of bellows 130 in a manner as indicated in FIG. 3, piston 126 is forced downwardly as the upper part of bellows 130 engages the undersurface of the top of cap 124. A coil spring 132 surrounding piston 126 and engaging the bottom of plate 128 and the top of boss 120 respectively, normally biases piston 126 to the uppermost end of its path of travel as shown in FIG. 2.

Referring to the schematic representations of apparatus 20, as shown in FIGS. 4 to 8 inclusive, it can be seen that valves 38, 40 and 42 include cylinders 134, 136 and 138 respectively, receiving corresponding tubular pistons 126, 140 and 142. It is to be noted that bellows 130 is carried by piston 126 as shown in FIGS. 2 and 3, while similar bellows 144 and 146 are mounted in operable relationship on pistons 140 and 142 respectively. Cap 124

is removably mounted on the boss 120 in surrounding relationship to piston 126, while boss 148 of valve 40 carries a removable cap 150 and boss 152 surrounding piston 142 has a cap 154 thereover. It should be pointed out that the valve 38 including cylinder 134, piston 126, cap 124 and bellows 130, is constructed in a manner to cause the piston 126 to travel through a longer path of travel than piston 142, so that a greater charge of gas is required to move it. This desired function can be accomplished in a number of ways, but most expeditiously by providing for the inner circular surface of cap 124 to be in greater spaced relationship to the boss 120 of valve 38 than is the case in valves 40 and 42. Referring to FIGURES 2 and 3, it may be seen that it is simply necessary to rotate internally threaded cap 124 on threaded boss 120 to vary such spacing. This, of course, changes the initial position of piston 126 with respect to its cylinder 134. However, within the range of adjustment contemplated, the cylinder-ports and associated piston-grooves, to be described in detail immediately below, still line up sufficiently to afford the required flow passages.

All of the cylinders 134, 136 and 138 are closed at the bottoms thereof, and cylinder 134 is provided with a pair of opposed upper ports 156 and 158, a pair of opposed second tier ports 160 and 162, a pair of third tier ports 164 and 166, a pair of fourth tier ports 168 and 170, and a pair of sixth tier ports 172 and 174. Piston 126 is in turn provided with a pair of annular grooves 176 and 178 which are in alignment with ports 156-158 and 164-166 respectively when piston 126 is at the upper end of its path of travel as shown in FIG. 4.

Cylinder 136 is likewise provided with a pair of opposed first tier ports 180 and 182, a pair of opposed second tier ports 184 and 186, a pair of aligned third tier ports 188 and 190, a pair of fourth tier ports 192 and 194, a pair of fifth tier ports 196 and 198, and one sixth tier port 200. Piston 140 has three annular grooves 202, 204 and 206 therein extending circumferentially of the piston in longitudinally spaced relationship, and in alignment with ports 180-182, ports 188-190, and ports 196-198, respectively, when piston 140 is in the normal or upper disposition thereof as illustrated in FIG. 4.

Cylinder 138 also has a series of ports therein which are identified as opposed first tier ports 208 and 210, aligned second tier ports 212 and 214, opposed third tier ports 216 and 218, fourth tier ports 220 and 222, and aligned sixth tier ports 224 and 226. Piston 142 has a pair of longitudinally spaced, annular grooves 228 and 230 therein which are in direct alignment with ports 208-210 and ports 216-218 respectively when piston 142 is at the upper end of its path of travel.

It should be noted at this juncture, as illustrated in FIGS. 5, 6 and 7, that ports 172 and 174 in cylinder 134, port 200 in cylinder 136, and ports 224 and 226 in cylinder 138, are disposed at a point below the lowermost extremity of corresponding pistons 126, 140 and 142 when the latter are at the lower ends of their paths of travel. Additionally, it can be seen that pistons 140 and 142 have longitudinally extending passages 232 and 234 respectively, which communicate the interior of cylinders 136 and 138 with bellows 144 and 146 respectively, in the same manner that passage 129 communicates bellows 130 with the interior of cylinder 134.

The flow-sensitive control valve illustrated in FIGS. 9 and 10, and broadly designated 54, includes a transversely polygonal housing 236 having a central, generally cylindrical inner wall 238 defining a chamber 240, adapted to receive a rotatable valve member broadly denominated 242. An inner, curvilinear wall 244 of housing 236, presents an upstream chamber 246 communicating with a passage 248 leading to upper tubular boss 250 integral with housing 236. Another curvilinear wall 252 of housing 236 defines a recycling chamber 254 in direct opposition to chamber 246. A third curvilinear wall 256 of housing 236 presents an inspiration control chamber 258

which is above and to the left of chamber 254, as best shown in FIG. 9.

A passage 260 in the lower part of housing 236, communicates chamber 254 and thereby central chamber 240, with outlet tube 62 integral with housing 236. An orifice 261 in side wall 252 communicates with a passage 263 through housing 236, with a tube 265 extending into passage 263 being coupled to another passage (not shown) in housing 236 which terminates in an orifice 267 communicating with chamber 258 at the normally lowermost end thereof. Housing 236 is also provided with a passage (not shown) terminating in an orifice 264 which is disposed adjacent the uppermost extremity of curved chamber 258 for purposes to be hereinafter explained.

A notch 266 in wall 238 of housing 236, is in alignment with an orifice 268 which communicates with a passage (not shown) extending through housing 236 to the atmosphere. The rear cylindrical wall 270 of housing 236 and concentric with chamber 240, has a passage 272 therein which leads to the rear of housing 236 and is connected directly to line 76.

Valve member 242 is provided with a cylindrical side wall 274 closed by circular end walls 276 and 278, each mounting an elongated, outwardly extending pin 280 adapted to be received within corresponding bearing means forming a part of control valve 54. As indicated in FIG. 9, one of the bearings 282 is carried by the rear wall of housing 236, while the other bearing is mounted on removable plate 52.

A pair of outwardly projecting, rectangular vanes 284 and 286 are mounted on the outer surface of cylindrical side wall 274 and are disposed radially with respect thereto. Vane 284 is positioned to be received in chamber 258 with the outer edge 288 thereof in relatively close relationship to wall 256, while vane 286 is disposed to be received in chamber 254. Side wall 274 is also provided with a generally rectangular, first primary window 290 located in the relatively short, arcuate portion of wall 274 between vanes 284 and 286, as well as second primary window 292 in substantially direct opposition to window 290. A relatively narrow, secondary window 294 is provided in cylindrical wall 274 in alignment with primary window 290 and positioned to overlie the orifice of passage 272 leading into chamber 240 through wall 270. Valve member 242 has an elongated weight element 296 mounted within cylindrical side wall 274, extending between and carried by end walls 276 and 278, it being noted that weight 296 normally biases valve member 242 in a clockwise direction about the axes of pins 280.

The normal disposition of valve member 242 within housing 236 is shown in FIG. 4, wherein it can be seen that vane member 284 is adjacent orifice 264, while vane member 286 is intermediate the ends of chamber 254. Primary window 292 is thereby out of alignment with the opening of chamber 246 into chamber 240, while primary window 290 is in communication with the upper corner of chamber 254, and not with chamber 258. The counterweight 296 biases valve member 242 into the position illustrated in FIG. 4, and the same will remain in such position until rotated in a counterclockwise direction in a manner to be described.

In order to permit movement of valve member 242 manually when desired, plate 52 is provided with an arcuate slot therein, clearing an elongated pin 298 mounted on the outer face of end wall 278 and extending through the arcuate slot (not shown).

In the schematic diagram illustrated in FIGS. 4 to 8 inclusive, the gas supply conduit 56 is shown in relatively heavy line and is adapted to be coupled to an oxygen supply tank or a similar source of such gas. Line 300, coupling conduit 56 to boss 250, has combination pressure-control and diluter regulator valve 302 therein, under the control of member 46 and handle 114 respectively. A closure valve broadly designated 304, includes an inflatable valve 306 disposed in line 300 in a position to pre-

vent gas from flowing through line 300 into chamber 246 when valve 306 is inflated.

Conduit 56 leads to a fixed regulator 308 which is preferably set for a pressure of 60 centimeters of water. In this respect, it should be pointed out that the source pressure is preferably at 50 pounds per square inch gauge.

A line 310 leads from fixed regulator 308 to port 160 in cylinder 134, while a fixed orifice 312 of predetermined size is provided in line 310. Another line 314, having a fixed orifice 315 therein, leads from fixed regulator 308 or line 310 as shown, to the cycling control valve 316 having a needle valve 318 therein under the control of valve-operating knob 44. Line 320 couples the outlet of control valve 316 to port 190 of cylinder 136 and by-pass line 322 joins line 320 to port 184 of cylinder 136.

A second line 324 leading from fixed regulator 308, is connected to manually operated, sensitivity-control valve 326, having a needle valve 328 which is moved in and out by rotatable member 327 on housing 28 and not shown in FIG. 1. The outlet of control valve 326 is joined to port 156 of cylinder 134 by a line 330.

By-pass line 332 coupled to line 324, between fixed regulator 308 and control valve 326, is connected to port 214 of cylinder 138, and has a fixed orifice 334 therein adjacent expiration start valve 42. Another by-pass line 336 couples line 310 upstream from orifice 312 to port 168 of cylinder 134. The sixth tier port 172 of cylinder 134 is joined to port 192 of cylinder 136 by a line 338 having a fixed orifice 340 therein. The opposed port 174 of cylinder 134, is in communication with port 188 in cylinder 136 through a line 342.

Line 344 serves to join port 166 of cylinder 134 to port 210 of cylinder 138, with a fixed orifice 346 being provided adjacent port 166. By-pass line 348 couples line 344 upstream from orifice 346 to port 170 of cylinder 134. The second tier port 162 of cylinder 134 is joined to line 338, downstream from orifice 340 by a line 350, while line 352 intercommunicates ports 158 and 180 of cylinders 134 and 136 respectively.

It is to be noted that port 196 in cylinder 136 is open to the atmosphere, while the opposed port 198 is connected to port 226 of cylinder 138 by a line 354 having a fixed orifice 356 therein adjacent port 226. The port 194 of cylinder 136 aligned with port 192, is open to the atmosphere, and line 358 couples port 186 of cylinder 136 to port 224 of cylinder 138. Port 182, opposed to port 180, is in communication with port 208 of cylinder 138 through a line 360. The sixth tier port 200 of cylinder 136, is joined to a line 362 interconnecting gauge 48 and orifice 364 in housing 236, by a line 366, with line 362 having a fixed orifice 368 therein between line 366 and gauge 48. It should be noted that orifice 364 communicates with chamber 254 in housing 236.

A by-pass line 370 joins line 354 to port 212 of cylinder 138, and another by-pass line 372 having a fixed orifice 374 therein, interconnects line 332 and port 220 in cylinder 138.

The port 218 of cylinder 138 is coupled to inflatable valve 306 by line 376, and a by-pass line 378 intercommunicates port 222 of cylinder 138 and line 376.

Line 380 connects orifice 264 in housing 236 with line 344, and a line 382 is joined to gauge 50 and to an orifice 384 in housing 236 and communicating with chamber 246. A fixed orifice 386 is provided in line 382 adjacent gauge 50.

As previously noted, tube 265 intercommunicates orifices 261 and 267, and a fixed orifice 388 is provided in tube 265. Also, it is to be noted that line 76 communicates passage 272 in housing 236 with inflatable member 106 of valve 104.

Line 390 connects conduit 56 with the nebulizer control valve 392, having a needle valve 394 therein operated by knob 118. Another line 396 also connects conduit 56 to aspirator control valve 398 having a needle valve 400 movable in response to rotation of control knob 116. It is to

be noted that line 68 leads from control valve 398 to the inlet of aspirator jar 72.

OPERATION

Assuming that it is initially desired to operate apparatus 20 as an intermittent positive-pressure breathing unit with automatic inspiration and expiration when the patient is not breathing or breathing at an abnormal rate, the mask 98 is first fitted over the patient's face in a well-known manner, and the knob 44 moved to a position to effect cycling of the unit at a desired rate and with the ratio of inspiration to expiration being pre-established at 1 to 1½. This ratio is established by the charge of gas required to move piston 142 as compared to the charge required to move piston 126 and, therefore, in this case where the bellows associated with these pistons are the same diameter, by the length of the path of travel of piston 142 of valve 38 as compared with the distance which piston 126 must travel. Since piston 126 must pass through a longer path of travel than piston 142, such that a greater charge of gas is required, the inspiration cycle is of shorter duration than the expiration cycle. Exact dimensions must be determined for each unit with respect to the relative relationship between the length of the path of travel of piston 126 as compared with piston 142 because of the different pressures obtained from springs of equal length and other manufacturing tolerances. The handle 114 is shifted to disposition providing for either 100% oxygen, for a relatively high percentage of oxygen such as 70% of the total gas delivered, or with a lower oxygen content of about 40%.

The pressure-control operating member 46 is rotated to a disposition to cause the needle of pressure-control gauge 50 to register at a preselected pressure upon opening of the valve controlling flow of oxygen from the source tank through conduit 56 into control unit 22. It can be seen that the pressure of the gas in chamber 246 of control valve 54 is registered by gauge 50 by virtue of the fact that line 382 receives the gas from conduit 56 via line 300, pressure-control valve 302, shut-off valve 304, tube 62, chamber 246, orifice 384 and thence through the defined line 382 connected to gauge 50.

Automatic cycling of control unit 22 begins immediately with oxygen from conduit 56 initially passing through fixed regulator 308, whereupon such gas then flows through line 310, line 314, and through the fixed orifice 315 and into control valve 316. Needle valve 318 permits the gas to flow through valve 316 at a predetermined rate, whereupon the gas is conveyed via line 320 into port 190 of cylinder 136. Since all of the pistons 126, 140 and 142 are initially at the uppermost ends of their paths of travel, it can be seen that the gas from line 320 passes across groove 204 in piston 140 and is directed into line 342 through port 188. From line 342, the gas passes into the lowermost end of cylinder 134 through port 174. It can be seen that the gas flows upwardly through passage 129 in piston 126 to effect inflation of bellows 130, inasmuch as escape of gas from cylinder 134 is prevented by virtue of the fact that conduit 338, leading from port 178 in cylinder 134 to port 192 in cylinder 136, is blocked by virtue of the outer surface of piston 140 closing port 192.

Gas from fixed regulator 308 does not flow through line 310 by virtue of the fact that piston 126 blocks port 160 when piston 126 is at the upper end of its path of travel. Passage of gas through by-pass line 336 is also prevented, because annular groove 176 of piston 126 is out of alignment with port 168.

Simultaneously with passage of gas through cycling control valve 316, gas also passes through line 324, sensitivity-control valve 326, line 330, port 156 of cylinder 134, annular groove 178 in piston 126, port 158, line 352, port 180 in cylinder 136, annular groove 202 in piston 140, port 182, line 360, port 208 in cylinder 138, annular groove 228 in piston 142, port 210, line 344, through

fixed orifice 346, into port 166 in cylinder 134, across annular groove 176 in piston 126, and thence outwardly through port 164 communicating with the atmosphere.

Inasmuch as line 380 is connected to line 344, some gas also passes into chamber 258 via orifice 264, but member 242 is not rotated counterclockwise against the action of counterbalance 296, because of the escape of gas into the atmosphere through open port 164. It is to be recognized that the disposition of needle valve 328 controls the amount of gas passing into line 330 from line 324, and by adjusting needle valve 328, the amount of gas flowing into line 330 can be varied so that the rate of escape thereof through open port 164 is substantially equal to that permitted to pass by needle valve 328 in control valve 326. Passage of gas through line 332 from line 324 is prevented by virtue of the fact that port 214 in cylinder 138 is closed by the outer wall of piston 142.

It should also be pointed out that the interior of cylindrical member 242 is at atmospheric pressure inasmuch as window 292 is in alignment with orifice 268 which exhausts to the atmosphere. Furthermore, passage of gas from the inlet boss 250 of control valve 54, and into discharge tube 62, is precluded by virtue of the fact that window 292 is out of alignment with chamber 246, thereby blocking passage of air across chamber 240. Inflatable member 106 is in a deflated condition because gas cannot flow to the same through line 76 while member 242 is in the disposition thereof shown in FIG. 4.

The pressure in the patient's mask is measured by gauge 48 inasmuch as line 362 communicates chamber 254 with gauge 48, thereby registering the pressure in conduit 60.

Accumulation of gas in bellows 130 causes the same to expand as shown in FIG. 3, whereby piston 126 is shifted downwardly to bring the annular grooves 176 and 178 into alignment with ports 168-174 inclusive and 160-162 respectively, as shown in FIG. 5. Shifting of annular groove 178 into alignment with ports 160-162, permits gas from conduit 56 to pass through line 310, including fixed orifice 312, across ports 160 and 162, as well as groove 178, thence downwardly via line 350 into line 338 and finally, into the lower end of cylinder 134, it being noted that such gas must also pass through fixed orifice 340. This arrangement by-passing cycling control valve 316, causes positive shifting movement of piston 126 to the lower end of the path of travel thereof, and produces a quick valving action which is necessary to precise timing of the valves. The fixed orifices 312 and 340 serve to prevent a sudden blast of gas directed into the lower end of cylinder 134, but on the other hand, provide a positive pressure to effect inflation of bellows 130 in a minimum of time. The fixed orifice 340 serves to slow the upward return of piston 126, thus insuring positive valving.

Closing of port 164 prevents discharge of gas from line 344 and therefore, gas from conduit 56 passes through line 310 into by-pass line 336, across port 168, annular groove 176, and port 170 into by-pass line 348, thence through line 344 into line 380. It can be appreciated that annular groove 178 of piston 126 is now out of alignment with ports 156 and 158, thereby blocking the passage of gas from line 330 into chamber 258 according to the flow path described above. Inasmuch as the gas from regulator 308 is now directed into control valve 54 without any restriction whatsoever, it can be seen that such gas flows at full velocity through line 380 into chamber 258 via orifice 264. The gas entering control valve 54 is directed against the upper surface of vane 284, thereby positively causing valve member 242 to be rotated about the axes of pins 280 and against the weight of counterbalance 296.

Valve member 242 is rotated counterclockwise until the vane 284 is adjacent the lower part of chamber 258. In this manner, window 292 is shifted into disposition

aligned with the outlet of chamber 246 into chamber 240, whereby gas at a predetermined pressure is permitted to flow from conduit 56 through diluter regulator 302, thence through shut-off valve 304, into chamber 246 via boss 250 and passage 248, through window 292 into the interior of valve member 242, thence through window 290 into chamber 254, next through outlet tube 62, thence through conduit 60, coupling 64, hose 94, and finally, through mask 98 to the patient. The gas under positive pressure is forced into the patient's lungs, thereby causing inspiration, even though the patient is not breathing of his own effort, or is breathing at an abnormal rate.

Simultaneously with opening of valve member 242, as described, gas is permitted to pass into the lower end of cylinder 136 via orifice 364, line 362, line 366, and port 280. Inasmuch as the lowermost extremity of cylinder 136 is sealed, the gas must pass upwardly through passage 232 in piston 140 to thereby cause bellows 144 to be inflated. Downward movement of piston 140 in response to inflation of bellows 144, immediately closes ports 180 and 182 to thereby discontinue passage of gas across lines 352 and 360 and thus stop the flow of gas into chamber 258 via line 380. The disposition of pistons 126 and 140 at this instant is illustrated in FIG. 6, wherein it can be seen that piston 126 has returned to the uppermost end of its path of travel while piston 140 is held at the lower end of the normal reciprocable path thereof. Piston 126 is permitted to return to its initial upper position under the influence of spring 132, by virtue of the fact that shifting of piston 140 to the lower part of cylinder 136, causes annular groove 204 to be shifted into alignment with ports 192 and 194, whereby gas may pass from the lower end of cylinder 134 via port 172, line 338, port 192 and port 194 communicating with the atmosphere. It is to be recognized that fixed orifice 340 controls the rate at which the gas is exhausted from cylinder 134 and thereby, the time required for piston 126 to return to the uppermost end of the path of travel thereof.

Movement of piston 140 downwardly, also discontinues flow of gas into the lower extremity of piston 134 via lines 314 and 320, inasmuch as piston 140 is now disposed in blocking relationship to port 190 in cylinder 136.

Gas from conduit 56 passes through fixed regulator 308, line 310, line 314, including fixed orifice 315, adjustable control valve 316, line 320, line 322, port 184 in cylinder 136, annular groove 202 in piston 140, port 186, line 358, port 224, and into the interior of cylinder 138. The gas is not permitted to escape from cylinder 138 by virtue of the fact that line 354, coupled to port 226, is connected to port 198 of cylinder 136 which is blocked by the outer surface of piston 140 when the latter is in the disposition illustrated in FIG. 6. The gas accumulating in cylinder 138 moves upwardly in passage 234 to thereby effect inflation of bellows 146 to cause piston 142 to be shifted downwardly as shown in FIG. 7.

Movement of piston 142 downwardly, shifts the grooves 228 and 230 therein into alignment with ports 212-214, and 220-222 respectively, as shown in FIG. 7. Upon movement of annular groove 228 into communication with ports 212 and 214 in cylinder 138, gas from conduit 56 is permitted to pass through line 324, line 332, and including fixed orifice 334, across ports 212 and 214, as well as groove 228, thence downwardly through line 370 across line 354 having fixed orifice 356 therein, and thence into the interior of cylinder 138 through port 226. This action causes positive inflation of bellows 146 and produces a quick valving action which is necessary to precise timing of the valves as previously indicated. Thus, positive movement of both pistons 126 and 142 to the lower ends of their paths of travel, is provided by the pneumatic arrangement described in by-passing relationship to cycling control valve 316.

It can be seen that when groove 230 in piston 142, moves into alignment with ports 220 and 222, gas may pass from fixed regulator 308 through line 324, line 332,

line 372 including fixed orifice 374, across ports 220 and 222, as well as annular groove 230 in piston 142, thence through line 378, and finally, through line 376 into inflatable valve 306 which closes the passage communicating with chamber 246.

Since flow of gas into chamber 258, through line 380, ceases upon movement of piston 142 to the lower end of its path of travel, the counterbalance 296 within cylindrical member 242, rotates the latter clockwise, thereby moving window 292 out of alignment with chamber 246 and interrupting flow of gas from conduit 56 through control valve 54.

It should also be noted that during the period that valve 54 is open, with window 292 aligned with chamber 246 and window 290 communicating with chamber 254, the gas passing through member 242 flows over the upper surface of vane 286 and thereby tends to maintain such valve in the open position thereof. However, upon closing of such valve through counterweight 296, passage of gas into member 242 through window 292, is precluded and the interior of member 242 is brought to atmospheric pressure inasmuch as orifice 268 is in communication with the interior of member 242 through window 292.

With reference to exhalation valve 104, it is to be noted in FIGS. 5 and 6 that inflatable member 106 is in an inflated condition throughout the conditions illustrated in these figures, by virtue of gas passing from the interior of member 242, through window 294, thence through passage 272 to delivery conduit 76 communicating with member 106. Inflation of the member 106 closes the outlet orifice in tube 60 and prevents gas from escaping therefrom. However, upon return of member 242 to the closed disposition thereof, as shown in FIG. 7, inflatable member 106 is exhausted through delivery conduit 76, passage 272, the secondary window 294 which is always in communication with passage 272 regardless of the disposition of member 242, and thence to the atmosphere through orifice 268 communicating with the atmosphere.

Line 265 having orifice 388 therein and interconnecting orifices 261 and 267, equalizes the pressure in chambers 254 and 258 and aids in proper shifting movement of cylindrical member 242 between the open and closed positions thereof, variable orifice 388 serving to restrict the flow of gas, but not interfering with continuous passage thereof. Gas flowing into chamber 258 from chamber 254 and via line 265, impinges against the lower surface of vane 284 and assures that the member 242 is shifted into the closed disposition thereof. The function of line 265 and orifice 388 is to linearize the flow cut-off point of valve 54 by building pressure against opening 267 at high control pressures. It is to be understood that chamber 258 has a fixed bleed, bleeding a portion of the flow from chamber 254 via opening 263, thus preventing premature closing of valve 54 by pressure building to an excessive value. This feature is especially important since it can be recognized that gas leaks around the circumference of drum 242 and into chambers 258 and 254, with line 265 having orifice 388 therein counterbalancing this leakage around the drum. Thus, the shunt line 265 maintains the closure pressure of valve 54 linear, regardless of the control pressure of regulator valve 302.

In FIG. 8, piston 140 has returned to the uppermost disposition thereof, while piston 142 continues to be depressed, by virtue of the interior of cylinder 136 being exhausted to the atmosphere via port 200, line 366, line 362, orifice 364, tube 60, and the outlet opening therein normally closed by inflatable member 106.

The next cycle in the operation, involves return of piston 142 to the upper end of its path of travel under the action of the associated coil spring 132 with the interior of cylinder 138 exhausting to the atmosphere, through port 226, line 354, port 198 in cylinder 136 annular groove 206 in piston 140 aligned with port 198 and thence through port 196 open to the atmosphere. Return of the piston 142 to the upper end of its path of travel, com-

pletes the cycle of operation and the machine goes through another complete cycle identical with that described above, so long as the apparatus is on automatic operation.

It can be seen that the rate of cyclic inspiration and expiration can be changed by adjusting the disposition of needle valve 318. In this manner, delivery of gas to the various piston and cylinder assemblies 38, 40 and 42, can be changed to comply with particular requirements.

Additionally, the sensitivity of valve 54 may be varied by adjusting needle valve 328 so that more or less gas pressure is provided on the upper surface of vane 284 to cause the same to be rotated against the action of counterbalance 296.

This sensitizing of the valve 54 for response to even weak inspiration efforts on the part of the patient, overcomes an important problem in this type of apparatus. It will be apparent that since the valve 54 has responded to an inspiration effort on the part of the patient, the sensitizing pressure to the chamber 258, is no longer required and is cut off by the successive downward movements of pistons 126, 140 and 142. Therefore, since the flow of gas to sensitize valve 54, passes successively across valves 38, 40 and 42, the flow of gas to chamber 258 is cut off by downward movement of piston 126 to preserve the automation respiration ratio of 1:1½, and such flow remains shut off when piston 140 shifts downwardly so that the gas will not flow into chamber 258 to interfere with normal rotation of member 242, and finally, such flow is still cut off when piston 142 moves downwardly to prevent surging and bouncing of the member 242 in valve 54 during movement thereof. It is to be recognized that the pressure of gas across valves 38, 40 and 42 and in lines 352, 360 and 344, is reduced during downward and upward movement of pistons 126, 140 and 142, thereby preventing a surge of gas into chamber 258.

Because of the utilization of a flow-sensitive valve such as valve 54, it can be seen that even though the machine is on automatic operation, breathing of the patient on his own will override the automatic apparatus and the machine will breathe at the same rate as the patient, although gas is delivered under positive pressure to the patient's lungs. Furthermore, inspiration by the patient will cause a negative pressure in chamber 254, thereby causing valve member 242 to be rotated in a counter-clockwise direction, and with the amount of negative pressure required to effect opening of valve 54 being primarily dependent upon the positive pressure of gas in chamber 254 and against the upper surface of vane 284 by virtue of such gas being directed thereinto through orifice 264 from line 380.

In those instances wherein it is desired to use aspirator 66 or nebulizer 80, this may readily be accomplished by simply opening needle valves 394 and 400. Actuation of either nebulizer 80 or aspirator 66, does not in any way interfere with normal operation of the automatic control unit 22, and the gas delivered to the patient may be humidified or treated with a medicament as required and either under automatic operation or patient-controlled response as desired for each particular therapeutic use.

It can now be seen that the present apparatus is designed to operate as a patient-controlled, nonautomatic cycling unit for all types of respiratory assistance, breathing therapy, or resuscitation, as a cycling and pressure assistance unit wherein the cycling rate may be set slightly slower than the normal breathing rate, to assure respiration if the patient does not breathe voluntarily, and to assist respiration by positive pressure during inspiration, and finally as an automatically cycled unit for resuscitation purposes wherein the patient is not breathing of his own accord.

Having thus described the invention, what is claimed as new and desired to be secured by Letters Patent is:

1. In respiration apparatus, the combination of a source of pressurized gas to be administered to the patient; gas

delivery means adapted to be applied to the patient; a main valve having an inlet connected to said source and an outlet connected to said delivery means and operable between an open position, wherein flow of gas takes place from said source to said delivery means, and a closed position, wherein such flow is blocked, said main valve being responsive to a predetermined negative pressure in said delivery means when in its closed position to shift to its open position and to a predetermined minimum flow through said delivery means when in its open position to shift to its closed position; an inspiration start timer coupled to said main valve and operable after a predetermined time period independent of the pressure in said delivery means when said main valve is in its closed position to shift said main valve to its open position; and an expiration start timer coupled to said main valve and operable after a predetermined time period independent of the flow through said delivery means to shift said main valve to its closed position.

2. In respiration apparatus, the combination of a source of pressurized gas to be administered to a patient; gas delivery means adapted to be applied to the patient; valve means having an inlet connected to said source and an outlet connected to said delivery means, said valve means being operable between an open position wherein flow takes place from said source to said delivery means, and a closed position wherein such flow is blocked; valve operating means associated with said valve means for shifting the latter between its open and closed positions; inspiration start means coupled to said source and operatively connected to said valve operating means, said inspiration start means being responsive to a flow of a predetermined charge of gas from said source at a predetermined rate for causing said valve operating means after a corresponding time delay to shift said valve means to its open position; expiration start means coupled to said source and operatively connected to said valve operating means, said expiration start means being responsive to flow of a predetermined charge of gas from said source at said predetermined rate for causing said valve operating means after corresponding time delay to shift said valve means to its closed position; and phase control means coupled to said inspiration and expiration start means and operable when said valve means is in its open position to render said inspiration start means inoperative and when said valve means is in its closed position to render said expiration start means inoperative.

3. Respiration apparatus as set forth in claim 2, wherein is provided means for adjustably establishing said predetermined rates of flow to said inspiration and expiration start means.

4. In respiration apparatus, the combination of a source of pressurized gas to be administered to a patient; gas delivery means adapted to be applied to the patient; valve means having an inlet connected to said source and an outlet connected to said delivery means, said valve means being operable between an open position wherein flow takes place from said source to said delivery means, and a closed position wherein such flow is blocked; valve operating means associated with said valve means for shifting the latter between its open and closed positions; phase control means coupled to said delivery means and movable between inspiration and expiration operating positions responsive to opening and closing, respectively, of said valve means; inspiration start means coupled to said source through said phase control means and operatively connected to said valve operating means, said inspiration start means being responsive to flow of a predetermined charge of gas from said source when said phase control means is in its expiration position for causing said valve operating means after a corresponding time delay to shift said valve means to its open position; and expiration start means coupled to said source through said phase control means and operatively connected to said valve operating means, said expiration start means being responsive to flow of a pre-

determined charge of gas from said source when said phase control means is in its inspiration position for causing said valve operating means after a corresponding time delay to shift said valve means to its closed position.

5. Respiration apparatus as set forth in claim 4, wherein said valve means and valve operating means include mutually cooperable parts responsive to a negative pressure in said delivery means when said valve means is in its closed position for shifting said valve means from its closed to its open position independently of and in overriding relationship to inspiration and expiration start means.

6. Respiration apparatus as set forth in claim 4, wherein said valve means and valve operating means include mutually cooperable parts responsive to a predetermined terminal flow through said delivery means when said valve means is in its open position for shifting said valve means from its open to its closed position independently of and in overriding relationship to said inspiration and expiration start means.

7. In respiration apparatus, the combination of a source of gas to be administered to a patient; gas delivery means adapted to be applied to the patient; a valve housing provided with an inner chamber, an outlet and an inlet, each communicating with the chamber, and a valve member within the housing and movable from an open position permitting flow of gas therethrough to a closed position preventing flow of gas from the inlet to said outlet; first and second conduit means coupling said inlet of the housing to said source of gas and said outlet of the housing to said gas delivery means, respectively, said housing having a compartment therein communicating with said chamber and said valve member being provided with vane means thereon extending into said compartment; means on said valve member biasing the latter toward said closed position thereof; and pneumatically operated means connected to said first conduit and to the housing in communication with said compartment therein for intermittently directing pressurized gas from said source against said vane means in a direction to shift said valve member from said closed position to the open position of same and venting such pressurized gas to permit said valve member to shift to the closed position thereof under the influence of said biasing means, said pneumatically operated means including pneumatic timing means for sequentially causing the pressurized gas at predetermined intervals independent of the patient's respiration effort to be so directed and vented at a predetermined timed cyclic rate.

8. In respiration apparatus, the combination of a source of gas to be administered to a patient; gas delivery means adapted to be applied to the patient; a valve housing provided with an inner chamber, an outlet and an inlet each communicating with the chamber, and a valve member within the housing and movable from an open position permitting flow of gas therethrough to a closed position preventing flow of gas from the inlet to said outlet; first and second conduit means coupling said inlet of the housing to the source of gas and said outlet of the housing to said gas delivery means respectively, said housing having a compartment therein communicating with said chamber and said valve member being provided with vane means thereon extending into said compartment; means on said valve member biasing the latter toward said closed position thereof; a third bias conduit connected to said housing and communicating with said compartment at a point to effect direction of gas against said vane means when the valve member is in said closed position thereof and thereby move the valve member to said open position of the same; and pneumatically operated means including a plurality of piston and cylinder assemblies, each of said cylinders having a number of ports therein and respective pistons movable in the same being provided with circumferentially extending grooves selectively alignable with corresponding ports in the cylinders, and pneumatically actuated

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means connected to each of the pistons for shifting the latter from positions with the grooves therein aligned with the ports of respective cylinders, to another position with said grooves aligned with other ports in the cylinders, said third conduit being connected to one port of one of the cylinders out of alignment with a groove in the corresponding piston when the latter is in one of said positions thereof, a fourth conduit being connected to a second port in said one cylinder in alignment with said one port therein, and to said first conduit for conveying gas from said source into the compartment when said piston in said one cylinder is in the other position thereof, said other piston and cylinder assemblies being operably coupled to said first conduit and to said pneumatically actuated means for effecting shifting movement of the piston in said one cylinder from one position to the other position at a predetermined cyclic rate whereby the valve member in said housing is opened and closed in phase with shifting movement of the piston in said one cylinder.

9. Respiration apparatus as set forth in claim 8, wherein each of said pistons is provided with a passage extending longitudinally therethrough and said pneumatically actuated means include a bellows connected to one end of each of the pistons and communicating with a respective passage therethrough, closure means secured to each of the cylinders in surrounding relationship to each of the bellows and of dimensions to cause the piston to be shifted from one position to the other position thereof upon inflation of a corresponding bellows, and means engaging each of the pistons and a corresponding cylinder for biasing respective pistons toward said one position thereof.

10. Respiration apparatus as set forth in claim 9, wherein is provided a fourth conduit connected to said first conduit and a port in said one cylinder at a point to cause gas to be directed into said passage through the piston therein, another of said cylinders being connected in said fourth conduit with the respective ports in said other cylinder being in alignment with a groove in the piston therein to permit gas to pass into said one cylinder for effecting inflation of the bellows on the piston in said one cylinder when the piston in said other cylinder is in one position, and for preventing direction of gas into said one cylinder when the piston in said other cylinder is in the other position thereof, and conduit means coupled to ports in said one and said other cylinders for exhausting the gas from said bellows connected to the piston in said one cylinder, when the piston in said other cylinder is in the other position thereof.

11. Respiration apparatus as set forth in claim 10, wherein is provided a fifth conduit connected to said first conduit and a port in said other cylinder at a point to cause gas to be directed into said passage through the piston therein, a third cylinder being connected in said fifth conduit with the respective ports in said third cyl-

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inder being in alignment with a groove in the piston therein to permit gas to pass into said other cylinder for effecting inflation of the bellows on the piston in said other cylinder, when the piston in said third cylinder is in one position, and for preventing direction of gas into said other cylinder when the piston in said third cylinder is in the other position thereof, and conduit means coupled to ports in said other and said third cylinders for exhausting the gas from said bellows connected to the piston in said other cylinder, when the piston in said third cylinder is in the other position thereof.

12. Respiration apparatus as set forth in claim 11, wherein is provided a sixth conduit connected to said first conduit and a port in said third cylinder at a point to cause gas to be directed into said passage through the piston therein, said other cylinder being connected in said sixth conduit with the respective ports in said other cylinder being in alignment with a groove in the piston therein when the latter is in said other position thereof to permit gas to pass into said third cylinder for effecting inflation of the bellows on the piston in said third cylinder, and for preventing direction of gas into said third cylinder when the piston in said other cylinder is in said one position thereof, and conduit means coupled to ports in said third and said other cylinders for exhausting the gas from said bellows connected to the piston in said third cylinder, when the piston in said other cylinder is in said one position thereof.

13. Respiration apparatus as set forth in claim 12, wherein is provided an inflatable valve unit in said first conduit adjacent said inlet of the housing for preventing flow of gas into said inlet upon inflation of said valve unit, and seventh conduit means connected to said valve unit and to ports in said third cylinder aligned with a groove in the piston therein when the latter is in said other position thereof to direct gas into said valve unit to effect inflation thereof, and for preventing direction of gas into said unit when the piston in said third cylinder is in said one position thereof, there being conduit means connected to said seventh conduit and to ports in said third cylinder aligned with a groove therein when the piston in the same is in said one position thereof for exhausting the gas in said valve unit to the atmosphere.

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RICHARD A. GAUDET, *Primary Examiner*.

R. E. MORGAN, *Examiner*.