

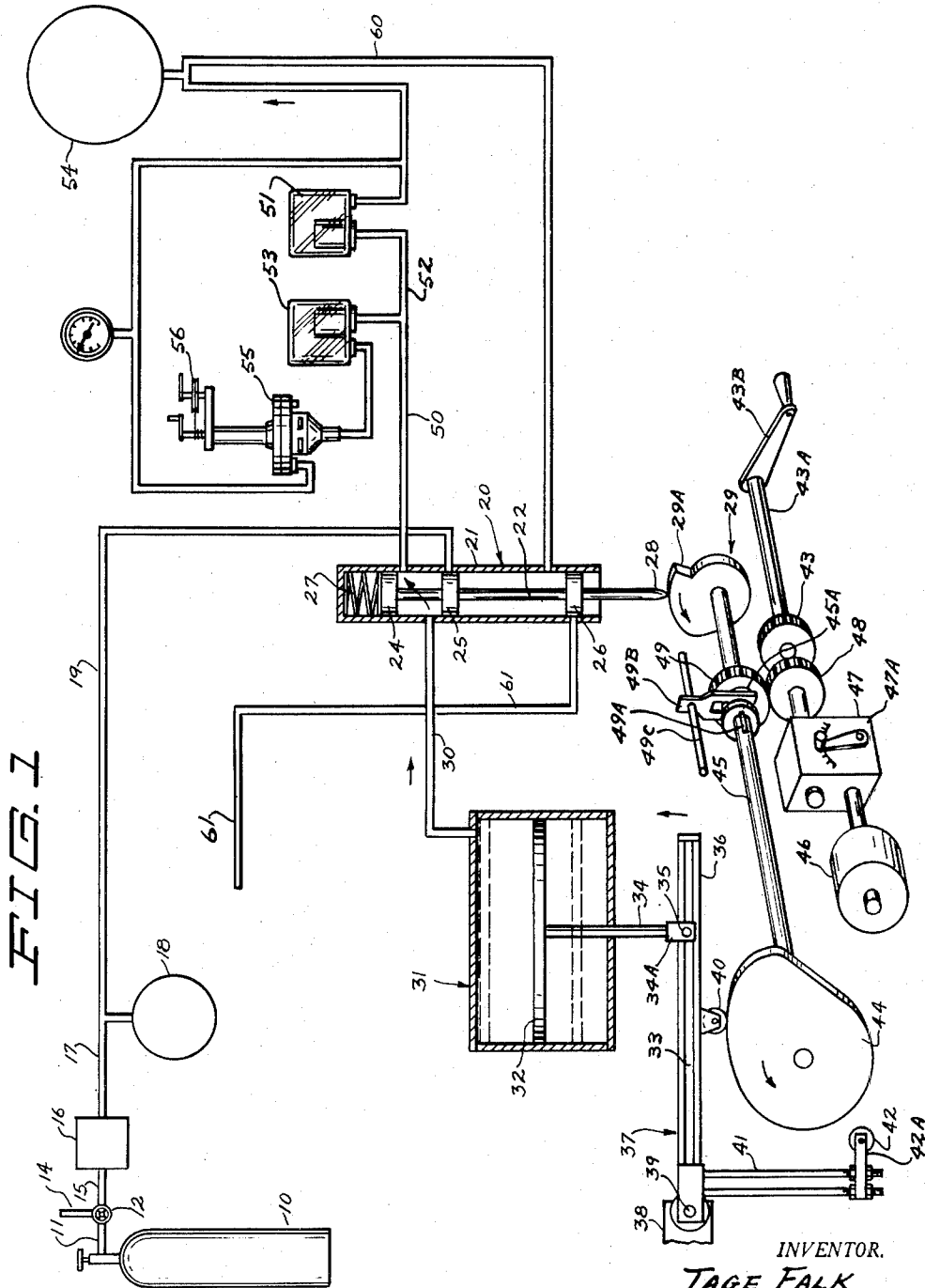
Nov. 13, 1956

T. FALK
RESPIRATOR SYSTEM

2,770,232

Filed May 26, 1954

6 Sheets-Sheet 1



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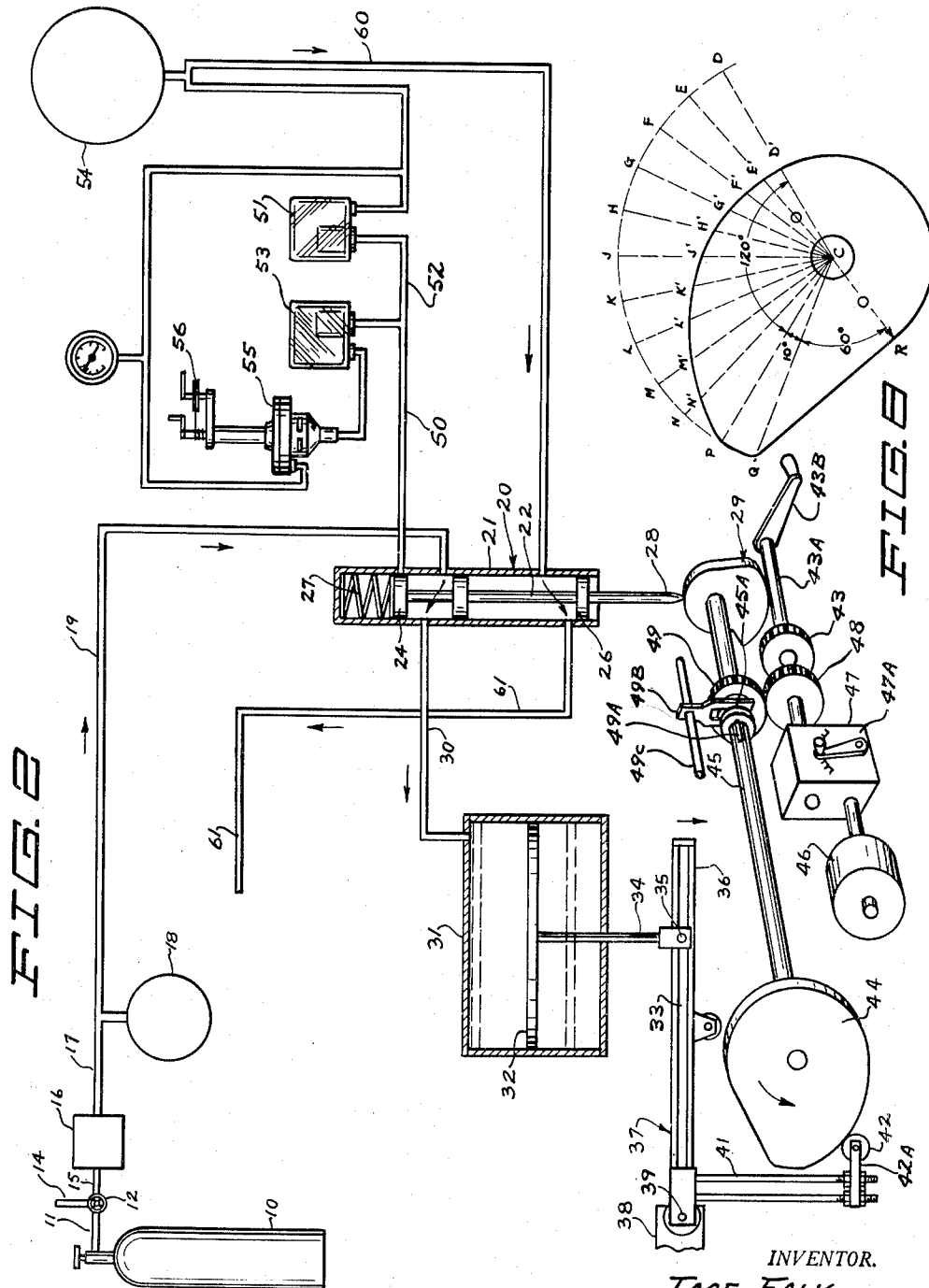
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T. FALK
RESPIRATOR SYSTEM

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6 Sheets-Sheet 2



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6 Sheets-Sheet 3

FIG. 3

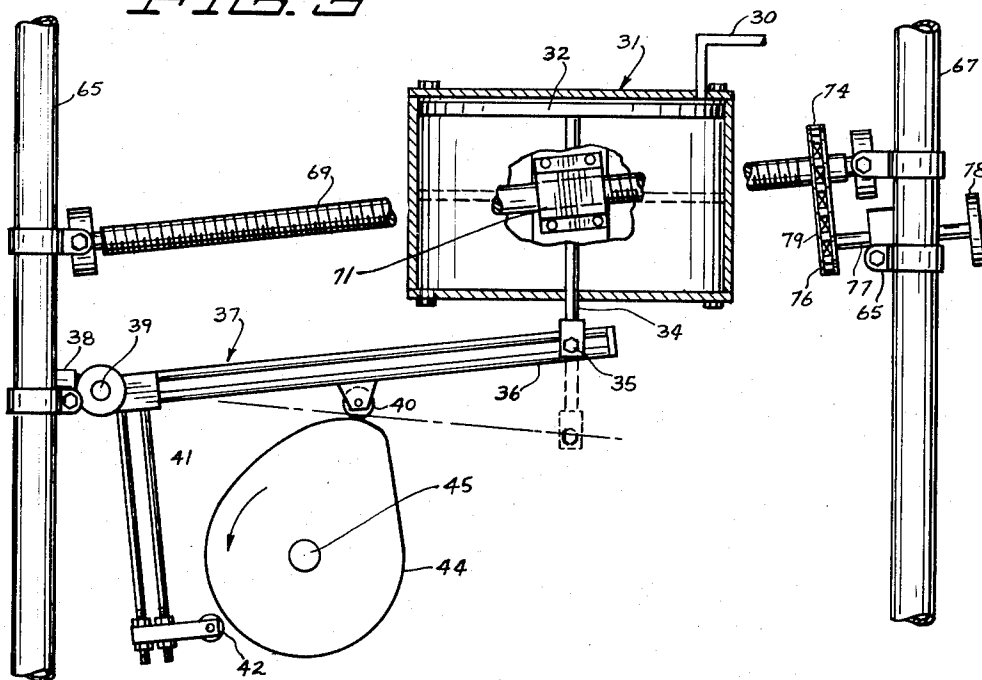
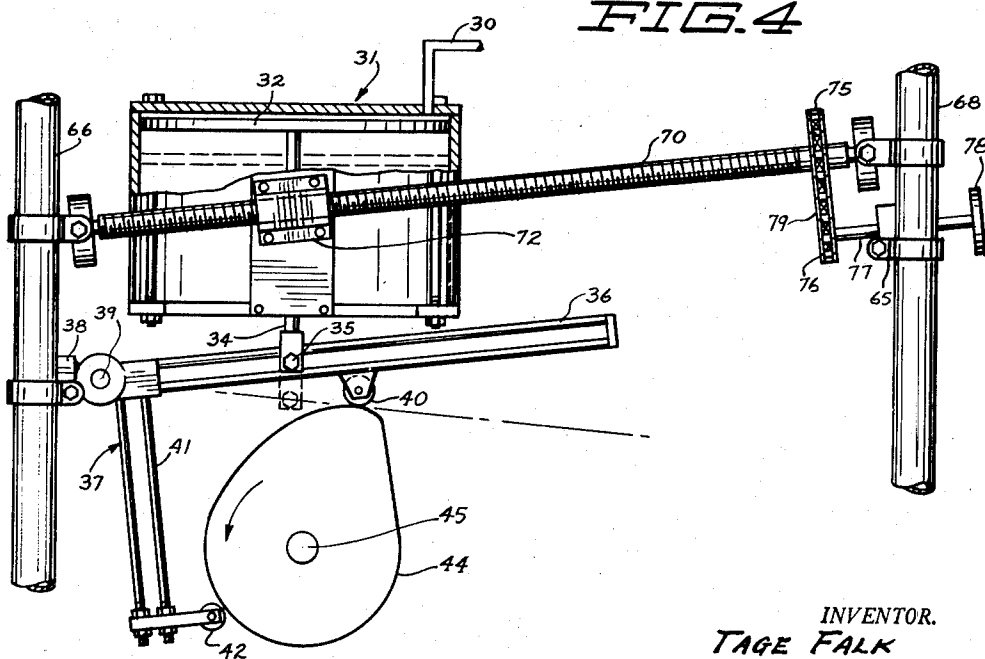


FIG. 4



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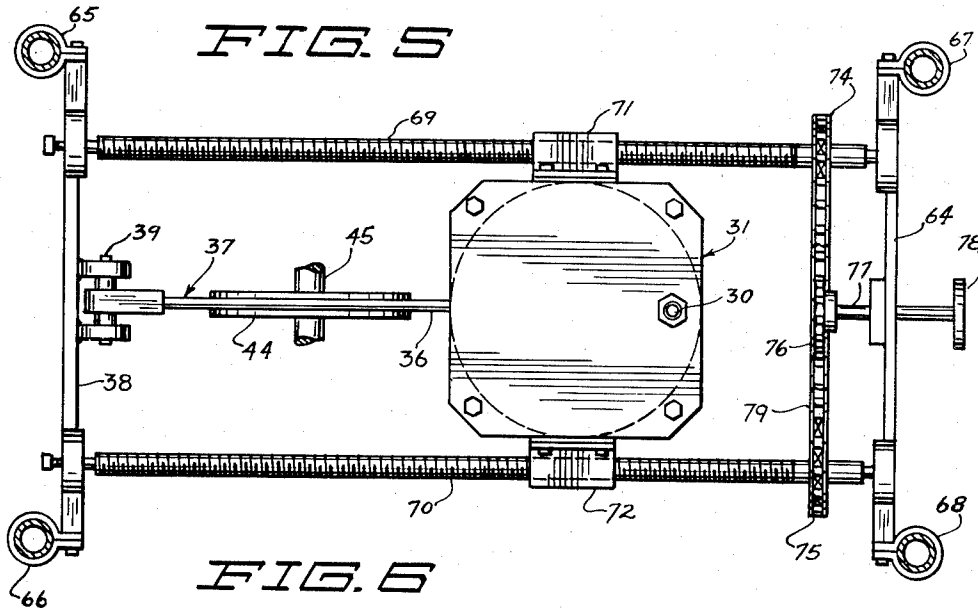


FIG. 6

COMPRESSION STROKE CHARACTERISTIC
CONSTANT BACKPRESSURE

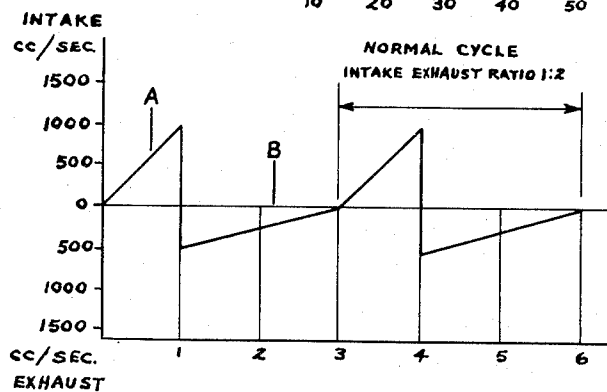
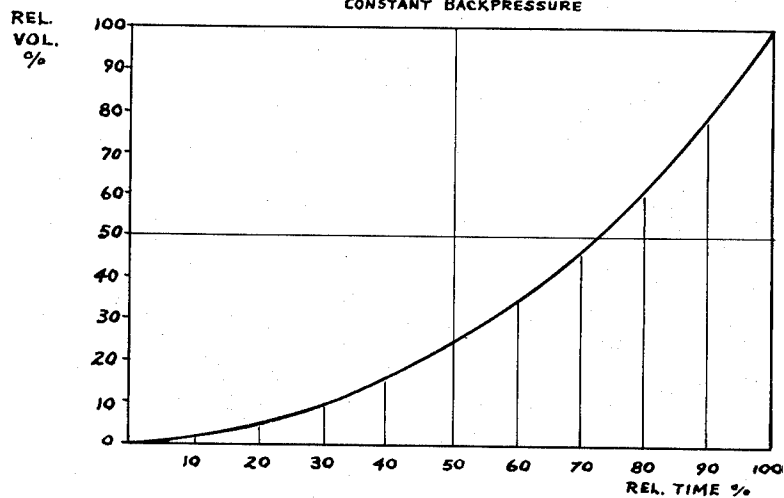


FIG. 7

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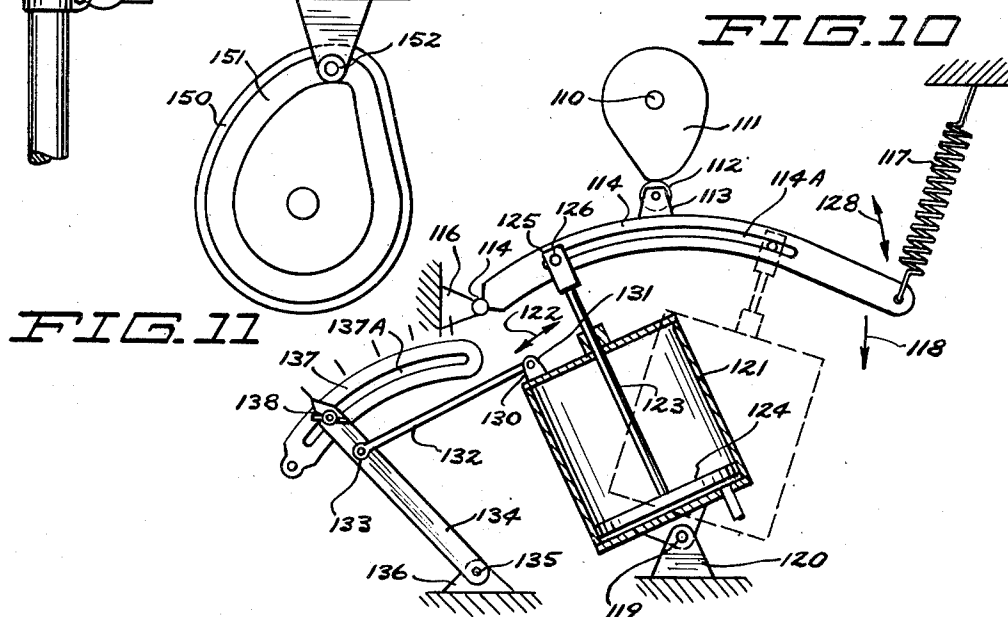
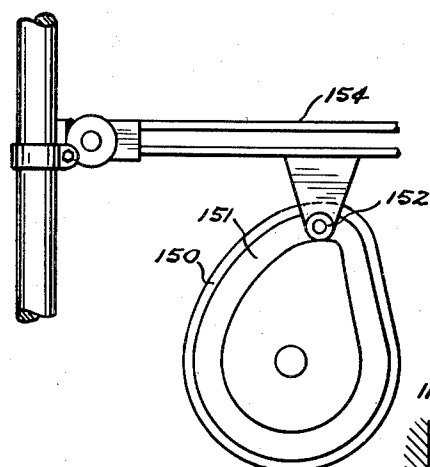
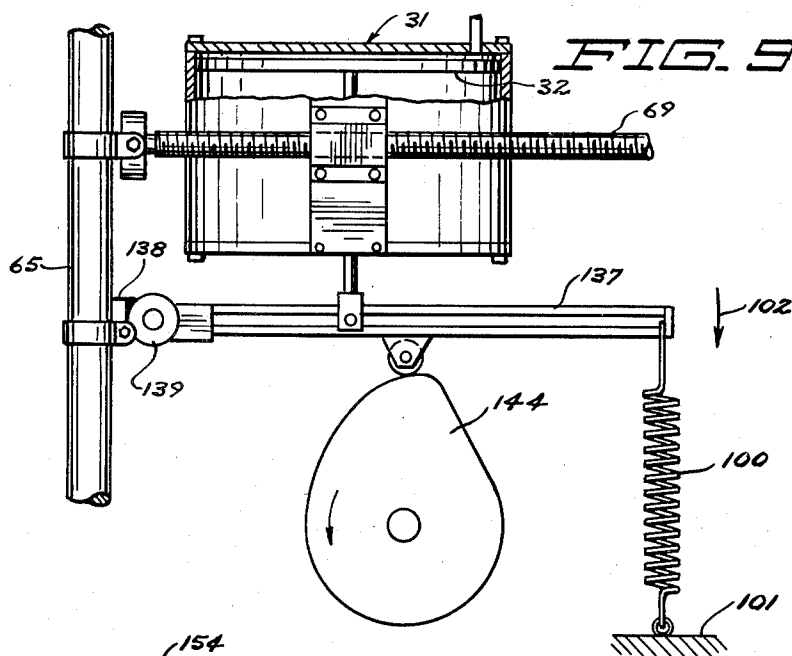
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6 Sheets-Sheet 5



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RESPIRATOR SYSTEM

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FIG. 12

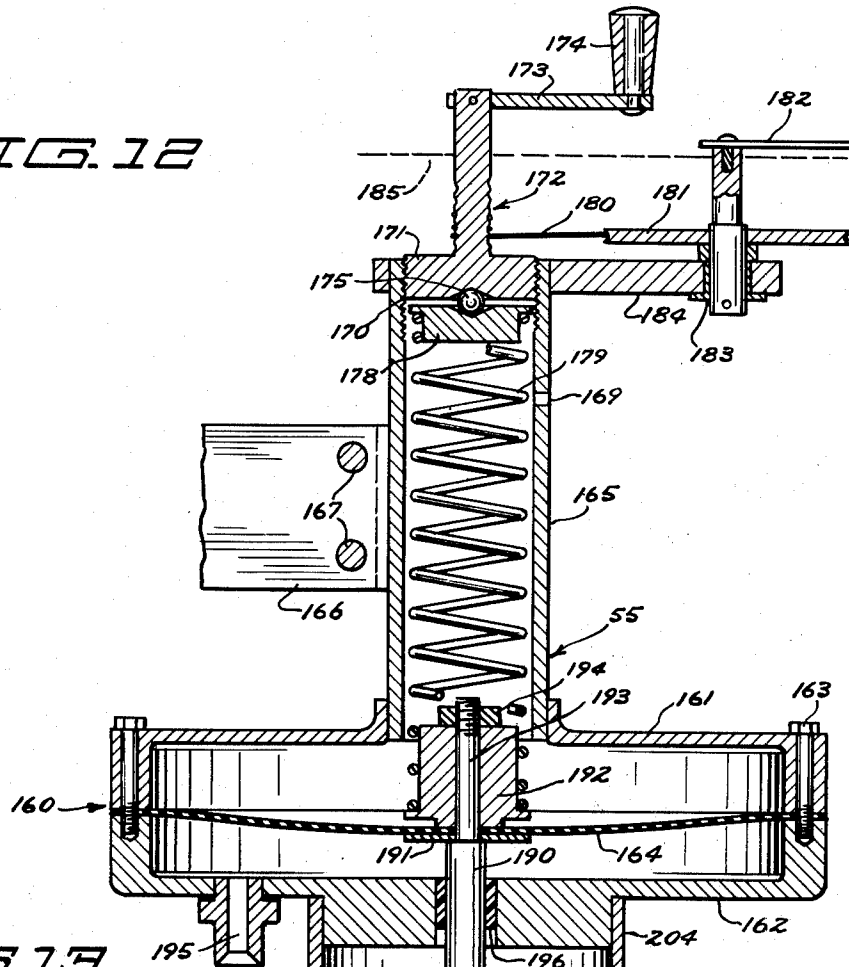
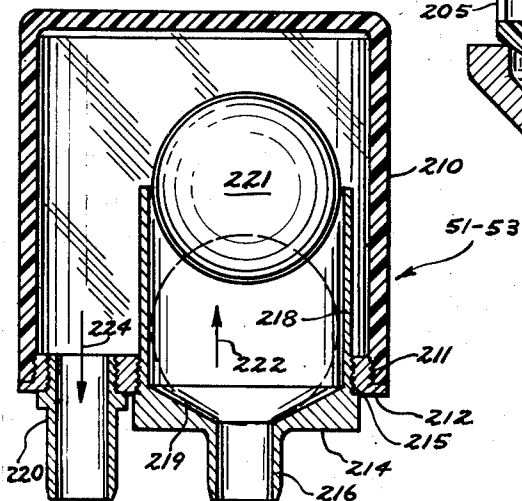


FIG. 13



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2,770,232

RESPIRATOR SYSTEM

Tage Falk, St. Paul, Minn., assignor to Smith Welding Equipment Corporation, Minneapolis, Minn., a corporation of Minnesota

Application May 26, 1954, Serial No. 432,532

25 Claims. (Cl. 128—29)

This invention relates to improvements in apparatus for the control of respiration, resuscitation and anaesthesia. More particularly, this invention relates to apparatus capable of automatically controlling the respiration of a patient in rhythm with, and at the same rate as the normal respiration of the patient and means for varying the volume and rate of gas introduced into the lungs of the patient. For resuscitation and maintenance of respiration, the gas is normally simply fresh air or oxygen enriched air may be employed. For anesthesia, the anesthetic agent may be vaporized and diluted with air or other gases, such as inert gases. The selection of the particular gas or mixture being used is the province of the physician's determination. For the purposes of this specification and in the claims, the term "gas" will therefore be understood to mean any gaseous fluid such as is prescribed by the physician.

The respirator system, which is the subject of this invention, is of the "positive-pressure" type. That is, the gas is forcibly introduced under appropriately slight but positive pressure through a face mask, tracheotomy tube or the like into the patient's respiratory system to expand the lungs in simulation of the normal inhalation portion of the respiratory cycle. For expiration of the gas, reliance is placed upon the normal elasticity of the lungs and lung cavity of the patient for expelling the gas from the lungs. In this manner, the possibly dangerous effects of the imposition of an artificial breathing cycle upon the patient are avoided. It is within the province of the invention to utilize slight negative pressure during at least the last part of the expiratory portion of the respiratory cycle.

One disadvantage of prior respirators is that they use mechanical components which are themselves somewhat elastic and which cannot be accurately set as to pressure, volume and cycling, and furthermore, such elastic components may develop leaks, and the like. In the so-called "iron lung" type of respirator, the patient is locked in the lung chamber except for his head, which passes through an elastic wall which encircles the patient's neck. This elastic wall is essentially a gland through which the patient's neck passes and it should fit snugly, but this is uncomfortable to the patient. If this elastic wall or gland is made tight enough to be leak-proof or reasonably so, then the patient is uncomfortable; if loose enough for the patient's comfort, it will leak. In either event, it is elastic, and accurate volume control to the patient is precluded. Furthermore, since the patient is encased, the patient is deprived of easy movement, mild exercise, the advantages of an erect position, his position cannot be easily changed and nursing care is difficult to administer.

It is the principal object of this invention to provide a respirator system adapted to reproduce as nearly as possible the natural breathing cycle of the patient, and in such a manner as to allow the patient at least limited freedom of movement and an erect position if desired by the patient.

Another object of this invention is to provide means for easily varying the volume and rate of gas introduced

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into the patient's respiratory system during the breathing cycle.

Still another object of this invention is to provide improved means for varying the rate of respiration.

A further object of this invention is to provide a respiratory system having regulatory components which do not appreciably change volume under the pressures used, whereby variations and inaccuracies due to the use of flexible components are avoided and mechanical control and accuracy are achieved.

Other objects of the invention will become apparent as the description proceeds.

To the accomplishment of the foregoing and related ends, this invention then comprises the features herein-after fully described and particularly pointed out in the claims, the following description setting forth in detail certain illustrative embodiments of the invention, these being indicative, however, of but a few of the various ways in which the principles of the invention may be employed.

The invention is illustrated by means of the following drawings, in which the same numerals refer to corresponding parts and in which:

Figure 1 is a diagrammatic and schematic representation of one form of the respirator system of this invention showing the relative positioning of the elements during the intake stroke (inhalation portion) of the normal respiratory cycle;

Figure 2 is a similar representation of the system during the exhaust or expiratory portion stroke of the respiratory cycle;

Figure 3 is an elevation, partly in section and partly broken away, showing the gas delivery and volume varying means, that embodiment of the invention shown in Figures 1 and 2, showing the same in a position for delivering a large volume of gas to the patient as for an adult;

Figure 4 is an elevation similar to Figure 3 showing the gas delivery and volume adjusting means in a position for introducing a smaller volume of gas to the patient, as for a child;

Figure 5 is a fragmentary top plan view of the gas delivery and volume adjusting means shown of Figures 3 and 4, the same being in the position of Figure 3. Figure 5 is taken along the line and in the direction of arrows 5—5 of Figure 3.

Figure 6 is a chart showing the compression stroke characteristics of the apparatus of this invention;

Figure 7 is a chart showing the normal cycle of respiration using the system of this invention;

Figure 8 shows a pattern for a cam capable of producing the desired respiratory cycle;

Figure 9 is a schematic and fragmentary side elevational view of a slightly modified form of the invention, illustrating slight modifications in the components;

Figure 10 is a schematic fragmentary side elevational view of another slightly modified form of the invention;

Figure 11 is a side elevational view of a slightly modified form of cam and lever actuator;

Figure 12 is an enlarged vertical sectional view of a variable pressure release valve; and

Figure 13 is an enlarged vertical sectional view of the flow indicator.

Referring now to the drawings and particularly to Figures 1 and 2, there is here shown the respirator system of this invention in simplified diagrammatic and schematic form during the intake stroke and exhaust stroke respectively. The system as shown comprises an intake line 15, which may be connected to atmosphere through three-way valve 12, or to a source of gas 10 which may be oxygen, an anesthetic gas or the like. The gas from this source, namely bottle 10, is introduced into a duct or line 11 to valve 12 which in one position shuts off

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line 14 and connects to line 15. Or valve 12 may be set in another position to shut off gas from the cylinder 10 and leave a clear opening to atmosphere through line 14, or in a third position to permit mixtures of air and gas. It will be obvious that instead of using a single gas cylinder, a plurality of bottles 10, each equipped with appropriate regulators and valves, may be used. Thus, for example, oxygen and nitrogen or oxygen and helium and the like may be employed, permitting introduction into the respirator system of a gas having a desired composition.

Line 15 leads to a saturator 16 wherein the gas to be introduced to the patient may be humidified to the desired degree. From the saturator line 17 leads to a reservoir 18, which is preferably an expandable pouch or bag. Reservoir 18 should have a capacity equal to or exceeding the volume of the gas dispensing cylinder means of the present invention (to be described) so that when the said cylinder is being recharged during the exhaust stroke, there will always be sufficient gas available in the system to meet these demands where the inlet flow through valve 12 may not be sufficient. Gas from the reservoir 18 is introduced through line 19 to a valve indicated generally at 20.

Valve 20 can be a cylinder, slide, piston or multiple poppet valve arrangement, which is selected for simplicity and reliability. It is here illustrated as a piston (or slide) valve, and comprises a cylinder 21 into which is fitted a valve stem or rod 22 carrying three spaced-apart pistons 24, 25 and 26 dividing the cylinder into three valve chambers, at least two of which are gas tight. In the uppermost of the chambers (which need not be gastight) is a coil spring 27 which urges rod 22 downward so that cam follower 28 is constantly held against the working edge of cam 29. The chamber between pistons 24 and 25 is gas tight and forms an inlet chamber. The chamber between pistons 25 and 26 is also gastight and forms an exhaust chamber.

The valve structure 20 is essentially a combined one-way (open or closed) valve and a two-way (two direction, or directive) valve, operated by a common valve actuating element 22 and in a common valve casing 21. It is not essential to the full realization of the advantages of the present invention that these valves be combined in a single casing, or that they be operated by a single valve actuating element, but for mechanical assembly, it is sometimes convenient to so construct the valve 20.

The one-way (open or closed) valve element is comprised by the valve piston 26 operating in conjunction with the ports in casing 21 to which lines 60 and 61 are connected. When the plug or piston 26 is in the inspiration respiratory position shown in Figure 1, the free flow of gas from line 60 to 61 is interrupted, whereas when it is in the expiration respiratory position shown in Figure 2, communication between lines 60 and 61 may freely occur.

The valve pistons 24 and 25, operating in conjunction with the ports in casing 21 to which lines 19, 30 and 50 are connected, constitute the two-way (to direction, or directive) section of the combined valve structure. When in the inspiration respiratory position shown in Figure 1, communication is established from the cylinder line 30 through the space between pistons 24 and 25 to the patient supply line 50 and the respirator gas supply line 19 is closed off, whereas when the valve elements are in expiration respiratory position shown in Figure 2, the patient supply line 50 is closed off and communication is established between the respirator gas supply line 19 and the cylinder line 30.

Any combination of reliable valves operated by a cam or cam means cyclically with the operation of piston 32 in cylinder 30 for accomplishing the valving of lines 19, 30, 50, 60 and 61 in the manner described may be utilized.

A gas line 30 connects the inlet chamber of valve 20

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and the single port of the gas measuring and dispensing cylinder 31. A piston 32 supported on piston rod 34 is mounted for movement in the cylinder 31, the lower end of rod 34 carrying a pin 35 which rides in the slot 33 of one arm 36 of a slotted bell crank 37. The arm 36 of bell crank lever 37 may be made conveniently of two rods held parallel in spaced relation so as to provide a slot 33 between them. The lower end of piston rod 34 carries a clevis 34A which straddles the upper rod and reaches down so as to locate pin 35 at the slot 33. The bell crank is mounted on machine frame 38 and is pivoted at 39 for oscillation. The lower rod of long arm 36 of the bell crank 37 carries a cam follower 40 and the short arm 41 of bell crank 37 of the crank carries a cam follower 42. Cam follower 42 is held by a bracket that is adjustably mounted between nuts on the lower threaded ends of the two rods comprising arm 41 of the bell crank 37. Both of the cam followers 40 and 42 are adapted to ride on the rim of cam 44. Cam follower 40 rides upon the rim of cam 44 and urges the long arm 36 of the bell crank and piston 32 to its fully actuated position, or upwardly in Figure 1. At the point of highest movement of the crank arm corresponding to minimum cylinder-piston volume, both cam followers touch the rim of the cam, and thereafter follower 42 riding the rim of the cam and positively returns the crank arm in the opposite direction, or downwardly, as in Figure 2, and once again both followers touch the cam rim.

Both cams 29 and 44 are carried on shaft 45 driven by a suitable motor 46 through a variable drive 47 and drive wheels 48 and 49. Gear 49 is keyed at 49A on shaft 45 and is slidable thereon, so as to be capable of being shifted. A shifting fork 49B on frame bracket 49C on the machine frame permits the gear 49 to be moved to "Motor drive" position, in engagement with motor-driven gear 48 or moved to "Hand operation" position, in engagement with hand crank operated gear 43 which is mounted on shaft 43A journaled in the machine frame and provided with hand crank 43B. In the event of power failure, gear 49 is shifted out of mesh with gear 48 and into mesh with gear 43, and then by turning the crank 43B, the machine can be kept going by hand.

Speed reducer 47 is preferably an infinitely variable ratio speed reducer having a ratio selector handle 47A on the side. By changing the setting of arm 47A, the speed of gear 48 can be changed to any desired speed, using a constant speed motor 46. A variable speed motor with suitable control may also be used in place of motor 46 and variable speed reducer 47.

Also communicating with the inlet chamber of valve 20 is a gas line 50 leading to a flow indicator or meter 51. A further gas line 52 leads from the flow indicator to the patient indicated at 54. The means of introducing the gas to the patient is preferably a respiratory mask or a tracheotomy tube or the like by which a firm and leakless connection of minimum idle volume is made to the patient's respiratory system. Connected to line 50 is a maximum pressure valve 55 having means 56 for adjusting and varying a maximum gas pressure limit in the respirator system. A gas exhaust line 60 leads from the patient connection to the exhaust chamber of valve 20, and the exhaled gas passes thence through line 61 to atmospheric exhaust.

The construction of the maximum pressure valve 55 is illustrated in detail in Figure 12. The valve 55 comprises a chamber 160 having an upper half 161 and a lower half 162, each of which has a thickened edge flange. The edge flange is held together by cap screws 163 in a manner so as to clamp between them the peripheral edge of a flexible circular diaphragm 164. The upper half 161 of the chamber has an upwardly extending tubular section 165, which is adapted to be mounted on the machine frame by means of the bracket 166 and the bolts 167. The space above the diaphragm is vented to atmosphere by means of the port 169, and tube 165 is pro-

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vided with screw threads 170 on its upper inner surface to receive the corresponding threaded head 171 of the spring regulator 172. The spring regulator is provided with a crank 173 and handle 174, and when it is screwed down, the head 171 will be moved vertically within the tube 165. The head 170 has a central dimple which rotates on the ball bearing 175, the latter seating in a corresponding dimple in the cap 178 which rests upon the light spring 179. The rotation of the screw 171 is transmitted through a light belt 180 to a wheel 181 carrying the indicator 182. The wheel 181 being journaled in bearing 183 is carried in the side arm bracket 184. The shaft of wheel 181 extends through the top of the cabinet indicated by the dotted line 185 and the indicator hand 182 which rotates with wheel 181, operates adjacent a scale provided on the top of the cabinet. Accordingly, the operator knows the condition of compression of the spring 179 by the position of the needle 182, and hence the "pressure" at which the valve will open.

The diaphragm 164 has attached to it a valve spindle 190 which is held by the thin washer 191 and the spring centering slug 192 which are retained on the reduced end 193 of the valve spindle by means of the nut 194. Accordingly, as the diaphragm 164 moves up or down, the spindle 190 will likewise be moved up or down in the space in the lower half of the chamber 162 which is closed by the diaphragm 164. The lower half of chamber 162 is provided with a pressure coupling 195 which is connected to line 50, and accordingly the diaphragm 164 is sensitive to the pressure in line 50. The portion of lower casing half 162 through which the spindle operates is suitably bushed at 196. The lower end of the spindle 190 is reduced in diameter and upon it are mounted two thin and flexible metallic washers 198 which are held in place by the cap 199 and the nut 200. The washers carry a valve member 201 which is in the form of a ring having a valve seating surface 201A. The valve member 201 is preferably made of "Teflon" (trademark) which is used because of its ability to resist sticking to any surface, more particularly to the surface of the valve seat which is a part of the lower member 202. The member 202 has an upper cylindrical portion 204 which is attached to the lower portion 162 of the pressure casing. The cylindrical portion 204 is provided with a plurality of ports 205 to atmosphere and with a valve seat 205A. Thence, the member converges downwardly and is provided with a coupling 205B which is attached to line 50. Any slight tipping of the valve spindle 190, or irregularities on the valve seat 205 or variation of the valve member 201 from a strictly normal position relative to the spindle will be taken up by the flexibility of the thin metal washer 198.

The flow indicators 51 and 53 are illustrated in Figure 13 and comprise a transparent inverted cup 210 which can be of plastic or glass, which is fastened by a screw thread (or any other suitable mode of attachment) at 211 to a metal base 212. The metal base is provided with a coupling 214 which here is screw threaded to the base at 215, the coupling being provided with a connection nipple at 216 which is connected to line 50, as shown in Figures 1 and 2. The member 214 has a thin tubular portion 218 which extends up into the hollow interior of the transparent cup 210, and the interior bottom surface of the member 214 is made with a slight conical shape as at 219. Also, connected to the base 212 is an outlet nipple 220 which here is screw threaded to the base, and is connected in the apparatus to the line 52, as shown in Figures 1 and 2. Within the thin metal tube 218 there is positioned a very lightweight ball 221 which can very conveniently be of Celluloid or similar light plastic, for example, a Ping-pong ball. This light ball is slightly smaller in diameter than the diameter of the coupling 218, but enough clearance is provided so as to avoid sticking or any excessive requirement of pressure for lifting the ball 221. The height of the tube 218 is such

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that while the ball 221 can move upwardly to a position sufficient that its largest diameter fully clears the upper edge of the tube 218, still the ball cannot move high enough so as not to return to the tube 218 when flow ceases. Alternatively, a wire guard may be placed around the upper edge of 218. The flow through the indicator is in an upward position, as shown by arrow 222, and the light ball 221 quickly lifts at each pulsation of flow and then settles again into the tube 218 when flow ceases. Flow from the indicator is out through nipple 220, as shown by the arrow 224. It is preferred to use different colors of balls in indicators 51 and 53, thus in indicator 51, a white ball may be used, while in indicator 53, a red ball may be used, so as to avoid confusion. While in the foregoing explanation, reference is particularly made to connections of the flow indicator in the patient supply line with reference to indicator 51, it will be appreciated that indicator 53 is connected so that its connection nipple 216 is attached to the exhaust line, and its outlet nipple 220 then is the atmospheric exhaust port.

In the operation of the system, as shown in Figures 1 and 2, drive shaft 45 driven by motor 46 turns cams 29 and 44 in the direction of the arrows shown on these cams. As shown in Figure 1, which corresponds to the inspiration portion of the respiratory cycle, the action of the cam 29 against cam follower 28 has lifted valve stem 22 upwardly against spring 27 moving valve elements 24, 25 and 26 upwardly. In this inspiration position, or "up," as shown in Figure 1, valve element 25 closed the opening from gas supply line 19, valve element 24 has opened the gas feed line to the patient (allowing communication from line 30 to line 50) and valve element 26 closes the exhaust line 61 to the atmosphere. At the same time, cam 44 steadily raises cam follower 40, and arm 36 of the bell crank 37 pivoted at 39 is oscillated upwardly, as shown by the arrow, forcing piston 32 upwardly so as to expel the gas from cylinder 31 through gas line 30, through the valve 20, thence through line 50, the flow indicator 51 and line 52 to the patient at 54. Although exhaust line 60 and the exhaust chamber of valve 20 may have some of the gas from line 52 forced around into them, escape of that gas is cut off by valve element 26 and the small additional volume requirement is taken into account in calculating the patient's requirements.

Cam 44 is designed carefully so as to reproduce the natural action of the human lungs during the inspiratory portion of the respiratory cycle. Thus, during the inspiration portion of the respiratory cycle, cam 44 lifts arm 36 of bell crank 37 to its fully actuated position. As shown in the chart of Figure 6, the cam 44 is designed so that during such inspiratory portion of the cycle, the gas is forced into the lungs at a gradually increasing rate comparable to that of normal breathing.

The apparatus is designed to permit unimpeded expiration, due to the natural elasticity of the patient's lungs and lung cavity. Thus, the expiratory portion of the cycle shown in Figure 2, is accomplished as follows: As the cam 29 continues to turn with shaft 45, cam follower 28 is suddenly dropped under urging by spring 27 at step 29A from the higher portion of the rim of cam 29 to a relatively lower rim portion. As valve actuating rod 22 moves downwardly, it shifts the positions of valve elements 24, 25 and 26. Valve element 24 then closes the patient's gas feed line 50 from communication with the intake chamber of valve 20. Valve element 25 opens supply line 19, and valve element 26 opens exhaust line 61. The exhalation of gases from the patient's lungs (expiration) is then accomplished by the natural relaxation and elasticity of the patient's lungs and chest, which causes the gases within the lungs to be expelled naturally out through exhaust line 60, through the exhaust chamber of valve 20 and exhausts to the atmosphere through line 61.

During the expiratory portion of the cycle, the rim of cam 44 urging against cam follower 42 positively

lowers arm 36 of the bell crank 37, thus lowering piston 32 and drawing gas from reservoir 18, through supply line 19 to the intake chamber of valve 20 and thence through line 30 to the gas measuring and dispensing cylinder 31. Thereafter, the cycle is repeated.

As shown in Figure 7, the normal cycle comprises an intake stroke and an exhaust stroke. To correspond with the cycle of natural breathing, the exhaust stroke is approximately twice as long as the intake stroke. The positions of the elements as shown in Figure 1, are about as they would be at point A of the cycle, as shown in the chart of Figure 7, and the positions of the elements as shown in Figure 2, are about as they would be at point B of the cycle in the chart. The inspiratory portion of the respiratory cycle is shown from 0 to 1 and from 3 to 4 on the chart, Figure 7, and is shown as fifty percent as long as the expiratory portion of the cycle which is from 1 to 3 and from 4 to 6. These proportions (inspiration half as long as expiration) correspond approximately to the normal breathing cycle, but they may be varied, if desired, by re-shaping cam 44.

The means for varying the volume of gas introduced to the patient's respiratory system during each cycle is shown in detail in Figures 3, 4 and 5. The adjusting means is supported on two cross frame members 38 and 64 which in turn are mounted and supported between posts 65-66, and 67-68 respectively of the machine frame. The two cross frame members 38 and 64 support two inclined, parallel, screw threaded rods or shafts 69 and 70, which are mounted for rotation on the members. The cylinder 31 is supported in a horizontal position by means of two threaded supporting brackets 71 and 72 which are threaded onto shafts 69 and 70 respectively. The threaded openings through the supporting brackets must necessarily be inclined to the same degree and in the same direction as shafts 69 and 70 where the cylinder is held in a horizontal position.

Shaft 69 has keyed on it a chain sprocket 74 and shaft 70 similarly carries the aligned sprocket 75. Also journaled on cross frame 64 is shaft 77 carrying a third sprocket 76 which is aligned in the same plane as sprockets 74 and 75. A handwheel is provided for rotating shaft 77 and sprocket 76. Over the three sprockets 74, 75 and 76 is run a chain 79, and when wheel 78 is turned, the chain will be moved and sprockets 74 and 75 (and hence threaded shafts 69 and 70 respectively) will be rotated simultaneously and uniformly. Rotation of the shafts 69 and 70 causes simultaneous movement backward or forward of brackets 71 and 72 respectively and hence of cylinder 31. As the cylinder is moved one way or the other on shafts 69 and 70, the length of the stroke of piston 32 is lengthened or shortened. This causes a proportional increase or decrease in the volume of gas delivered from the cylinder and permits the volume to be accurately predetermined and varied according to needs.

Figure 3 shows cylinder 31 at relatively higher volume position so that the stroke of piston 32 is relatively large, as indicated by the area between the dotted position of the piston at the bottom of the stroke and the full position of the top of the stroke. Similarly, Figure 4 shows the cylinder at the lower volume position near the end of the shafts 69 and 70 so that the stroke of piston 32 is relatively small. In both of these views, the positions of cam 44, arm 36 of the bell crank 37 and piston 32 are shown at their highest position, and the dotted lines indicate the lowest positions of the piston and piston rod 34.

On its upward stroke piston 32 substantially completely dispels all the gas from cylinder 31, regardless of the position of the cylinder. This is the condition of minimum cylinder volume. From Figures 3 and 4, it will be observed that when the high point of cam 44 has raised the lever 37 to the fully actuated position (up in Figures 1-4), the lever 37 is parallel to the path of transla-

tory motion of cylinder 31, as determined by threaded shafts 69 and 70. Stated another way, when the cam 44 has moved the piston 32 to a position in which it expels to the greatest degree the air from cylinder 31, then lever 37 is parallel to the support rods 69 and 71. Accordingly, cylinder 31 can be shifted along its path at will, for varying the volume of stroke, and the piston 32 yet will always come to the same fully actuated position near the cylinder head of cylinder 31 for each stroke.

It may be noted that it is not necessary for the accomplishment of the foregoing ends, that lever 37 be in a slanted position as shown in Figures 3 and 4; the lever 37 could (when actuated to the fully actuated position corresponding to the high point of cam 44) just as well be horizontal, or in any other slanting position. The slanted position shown is merely for convenience of mechanical design.

Because of the design of the cam 44, as shown in Figure 8, the stroke of piston 32 is moved towards fully actuated position at a gradually increasing rate forcing the gas into the patient's respiratory system at a gradually increasing volumetric rate in simulation of normal inhalation. As an illustration of a cam adapted to reproduce such suitable action in the human lungs, that cited in Figure 8 is an example. It is to be understood, however, that variations in dimensions may be made as herein pointed out without materially altering the respiratory pattern.

In the cam shown in Figure 8, the cam has a periphery from R to D comprising the arc of a circle of $1\frac{1}{2}$ dimension units radius about center C. A reference line CD is then drawn, and another reference line CP is drawn, the angle DCP being 120 degrees. The arc DP is then divided in ten equal sectors of 12 degrees. The curve D'P is then plotted according to the following table:

Reference radius point:	Radius from C, units
D'-----	1.500
E'-----	1.516
F'-----	1.565
G'-----	1.646
H'-----	1.760
J'-----	1.906
K'-----	2.085
L'-----	2.296
M'-----	2.540
N'-----	2.818
P-----	2.125

Another reference line CQ is drawn, so that the angle PCQ encloses ten degrees and arc PQ is drawn with a radius equal to the distance PC or 3.125 units. Reference line CR is drawn so that angle QCR encloses 60 degrees. Points Q and R are connected by a straight line and the point Q is rounded off, as by a $\frac{1}{4}$ unit radius arc, in order to permit the cam followers 40 and 42 to smoothly pass over this point. The active cam arc is that portion between points D', E', F', etc. to P included in 120 degrees about center C, as it is the action of cam follower 40 upon this portion of cam 44 which expels the gas from cylinder 31 and forces it into the lungs of the patient.

The proportion of cycle devoted to the inspiration part of the respiratory cycle is here illustrated as being one-third of the complete cycle. Thus, the inspiration (portions 0 to 1 or 3 to 4 of Figure 7; also arc D'—C—P—N'—D' of Figure 8) is twice as long as the expiration portion (portions 1 to 3 or 4 to 6 of Figure 7, also arc P—C—D'—R—Q of Figure 8). These proportions may be varied according to the desiderata established by the medical profession and the cam 44 shaped accordingly.

The rate of respiration is varied by varying the number of cycles through which the apparatus is permitted to go in the course of one minute by means of variable drive

47. This is accomplished by varying the position of le-

ver 47A. Normally an adult will be given from about 12 to 18 respirations a minute, and a child will be given a somewhat higher rate up to about 22 to 24 respirations a minute.

In Figure 9 there is illustrated a slightly modified form of the invention, in which the lever 137 is pivoted at 139 on the frame bracket 138 on post 65. Here the lever 137, in its fully actuated position as determined by highest point on cam 144, is in a horizontal position as previously described, and the mounting screws 69 and 70, of which screw 69 is illustrated in Figure 9, which carry the cylinder 31, are parallel to the lever 137 in such fully actuated position. In this position, the cylinder 31 may be moved along the screws 69—70, as previously described, for varying the gas expelled in each cycle, and the piston 32 will, as previously mentioned, always be brought to its fully actuated position closely adjacent the cylinder head of cylinder 131 (i. e. to a condition of minimum cylinder volume), regardless of the position in which the cylinder is situated along rods 69—70.

In Figure 9, the second lever arm 37 of the bell crank has been eliminated and the lever 137 is returned downwardly (or more generally stated, in a retracted direction toward the cam 144), by the actuation of spring 100 which is anchored to the frame piece 101.

In Figure 10 there is illustrated a further modification of the invention. In this figure, the shaft 110 (which corresponds to shaft 45 of the earlier figures), carrying the actuating cam 111, operates against a roller cam follower 112 mounted on the bracket 113 of an arcuate lever 114. The arcuate lever 114 is pivoted at 115 upon a bracket 116 which is mounted on any suitable part of the machine frame. The lever 114 has an arcuate slot 114a in it. When the lever 114 is in the fully actuated position, as moved in the direction of arrow 118, corresponding to high point of the cam 111, the lever assumes a datum position from which is determined the location of the pivot point 119 of bracket 120. The bracket 120 is mounted on the machine frame and pivot 119. The cylinder 121 is mounted for oscillation back and forth in the direction of the double arrow 122 for adjusting volume of gas moved by the piston 124 in cylinder 121. The pivot point 119 is the center of the arcuate slot 114a of lever 114 when the lever 114 is in its fully actuated position, as determined by roller 112 being upon the high point of the cam 111 (i. e. the Figure 10 position). The cylinder 121 has a piston rod 123 carrying the piston 124 and the piston rod is equipped with a clevis 125 at its end through which extends a pin 126 that reaches through the slot 114a of lever 114. As the lever is oscillated back and forth in the direction of the double arrow 122, the piston rod will be moved in and out, and hence the piston will be actuated within the cylinder 121. By virtue of this construction, the entire cylinder 121, its piston rod 123, clevis 125 and pin 126 may be swung arcuately in the direction of the double arrow 122, so as to bring the position of the pin 126 to any desired position between the full line position for cylinder 121. In this way, the stroke of the piston can be varied, and yet the piston 124 will for each stroke always be brought to the fully actuated condition adjacent the head of the cylinder 121, thus always completely expelling from the cylinder the air that has been drawn into it.

For adjusting the position of the cylinder 121, there is provided a lug 130 on the end of the cylinder at a position removed from pivot 119, and to this lug there is pivotally attached at 131 a link 132 which is in turn pivotally attached at 133 to the adjusting lever 134. Lever 134 is pivoted at 135 on the bracket 136, which is a part of the machine frame. The end of lever 134 swings next to an arcuately slotted bracket 137 which is also attached to the machine frame and wing nut and bolt 138 reaches through the lever 134 and into the slot 137a of the bracket 137, thereby permitting the operator to adjust the position of lever 134 as desired, and also lock the adjust-

ment. In the selected position, link 132 thereafter steadies the cylinder 131, and it in turn positions the pin 126 in the arcuate slot 114a with the result that piston 124 is moved to a degree within the cylinder 121 determined by the position of the pin 126 in slot 124a. The roller 112 on lever 114 is held constantly against the edge of cam 111 by the spring 117, which accordingly serves to provide energy for the outward stroke of piston 124, the rod 123 and the associated mechanisms.

In Figure 11 there is illustrated a further modification of the invention, which is similar to those previously described, except that cam 150 is provided with cam slot 151 in one of its faces in which the actuating roller cam follower 152 is adapted to roll. The roller 152 is mounted on the actuating arm 154, which can be the long lever 36 of the bell crank or any of the corresponding levers of the other modifications described. In Figure 11, there is thus provided another form for positive actuation of the lever 154, and it therefore does not require a return spring such as spring 100 in Figure 9. If desired, the form of positive cam action illustrated in Figure 11 may be utilized in any of the modifications illustrated, such as that shown in Figure 10.

As many apparently widely different embodiments of this invention may be made without departing from the spirit and scope thereof, it is to be understood that I do not limit myself to the specific embodiments herein.

What I claim is:

1. A respiratory system comprising a respirator gas supply line, a cylinder having a port and a piston operable in said cylinder for drawing in and expelling respirator gas through said port, a patient supply line for conducting respirator gas to the patient and a patient exhaust line for exhausting gas from the patient; multi-chamber valve means including two-way and one-way valve sections, said two-way section having ports connected respectively to said cylinder port, said respirator supply line and said patient supply line, said one-way section being connected in said patient exhaust line for opening and closing said line, said multi-chamber valve means including valve mechanism connected to be actuated by cam means and movable to alternate first and second positions in which, in said first position as the cam means moves the piston to draw gas into said cylinder port, the respirator gas supply line is connected to the port of the cylinder and said patient exhaust line is opened to atmosphere and said patient supply line is closed and in said second position as said cam means moves the piston to expel gas from said cylinder port, said respirator gas supply line and patient exhaust line are both closed and said cylinder port is connected to said patient supply line; and cam drive means connected to the piston for actuating the piston in said cylinder and actuating said valve mechanism cooperatively to move said valve mechanism to the first position when the piston is actuated in the cylinder to draw gas into said cylinder and to said second position when the piston is actuated in said cylinder to expel gas from said cylinder.

2. The respiratory system of claim 1 further characterized in that said valve mechanism is actuated for quickly moving from the second to the first position as said piston begins to move in a direction to draw air into the port of the cylinder.

3. The respiratory system of claim 1 further characterized in that said cam means is proportioned so as to move the piston and actuate said valve mechanism in said first position for a time period substantially twice as long as for said second position.

4. The respiratory system of claim 1 further characterized in that said cam means is formed so as to move the piston in said cylinder at a variable speed which increases as the piston is moved in a direction to expel gas from said cylinder.

5. A respiratory system of claim 1 further characterized in that said cam means is shaped so as to move the piston

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in the cylinder at varying speeds during the cycle of motion of said piston in said cylinder, said variation in speed corresponding substantially to the pressure pattern of the inspiration portion of an inhaling-exhaling cycle of the human lung system.

6. A respiratory system of claim 1 further characterized in that the cam drive means connected to the piston in said cylinder includes a lever pivoted to be engaged by said cam for oscillating the lever between retracted and fully actuated positions and a link is provided for connecting said lever and said piston in said cylinder, said piston and cylinder being mounted for translations along a path of motion substantially parallel to the position of said lever when in the fully actuated position.

7. The apparatus of claim 6 further characterized in that said cam and lever are shaped for positive oscillation of the lever by the cam as the cam is moved.

8. The apparatus of claim 6 further characterized in that said lever is a bell crank and includes a first arm connected by the link to the piston and a second arm, both of said arms being positioned to be engaged by the cam means for positively oscillating said bell crank lever.

9. The apparatus of claim 6 further characterized in that said bell crank levers are set at an angle to each other and each includes a roller cam follower mounted thereon, positioned to be engaged by the cam for positively oscillating said bell crank.

10. The apparatus of claim 6 further characterized in that said lever includes a connection to a cam follower and said cam is grooved for receiving said cam follower for positively oscillating said lever.

11. The apparatus of claim 6 further characterized in that said link, piston and cylinder are proportioned so as to position the piston in the cylinder at the point of minimum cylinder volume when the lever is moved to the fully actuated position.

12. The apparatus of claim 6 further characterized in that said cam means is provided for actuating the lever in one direction and said lever is spring biased for movement in the other direction.

13. The apparatus of claim 6 further characterized in that said lever includes an arcuate surface, and said link is formed for pivoting motion about the center of said arcuate surface when the lever is in the fully actuated position for varying the stroke of the piston in said cylinder.

14. The gas volume regulating means for a respirator system comprising a frame including ways thereon, a cylinder mounted for translation along said ways, a lever mounted on said frame for oscillation from a position substantially parallel to said ways to a position at an angle to said ways, a piston in said cylinder and means connecting the piston and lever for operating said piston, said piston and means being translatable with said cylinder along said ways, said means being slidable along the lever as the cylinder and piston are translated and means on the frame connected to the lever for oscillating said lever.

15. The gas volume regulating means for a respirator system comprising a frame support means mounted on said frame, a cylinder mounted for translatable movement along said support means, a piston operable within said cylinder, a crank lever pivoted on the frame for oscillatory movement from a position substantially parallel to said support means to a position at an angle to said support means, a link connection between said lever and said piston for operating the piston as the lever is oscillated, said link being slidable with reference to the lever as said cylinder and piston therein are moved along said support means, said piston being at a position of minimum cylinder volume when it is moved to a position corresponding to that occurring when the lever is substantially parallel to said support means and means on the frame and connected to the lever for oscillating said lever.

16. A gas volume regulating means for a respirator

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system comprising a frame, inclined supporting means mounted on said frame, a cylinder mounted for translatable movement along said supporting means, a piston operable within said cylinder, a bell crank pivoted on said frame, one arm of said crank operatively connected to the rod of said piston to move said piston within the cylinder and driven cam means to actuate the movement of said arm.

17. A gas volume regulating means for a respirator system comprising a frame, a pair of parallel supporting means mounted on said frame, a cylinder mounted between supporting brackets carried by said supporting means for translatable movement along said support means, a piston and a rod operable within said cylinder, a bell crank pivoted on said frame, a link connecting one arm of said crank to the rod of said piston to move the piston within the cylinder, said link being movable along said arm of the bell crank with the movement of the cylinder, cam means for oscillating said bell crank and means for driving said cam, whereby as the piston is moved within the cylinder, respirator gas is pumped thereby.

18. A gas volume regulating means according to claim 17 further characterized in that said bell crank arm is slotted.

19. A gas volume regulating means according to claim 17 further characterized in that at least one of the cylinder supporting means mounted on the frame and the supporting bracket thereon are threaded and means are provided for rotating the supporting means, whereby upon rotation of the supporting means the cylinder is moved along said supporting means.

20. A gas volume regulating means according to claim 17 further characterized in that the cam has a contour controlling movement of the piston in the cylinder to reproduce in the respirator system the pressure pattern of an inhaling-exhaling cycle of the human lungs.

21. In a respirator system comprising a gas expelling cylinder and a piston mounted on a rod and operable within the cylinder for forcing gas out of the cylinder and into a patient's respiratory system, the improvement which resides in providing a gas volume regulating means comprising a frame, a pair of parallel supporting members mounted on said frame, supporting brackets on said cylinder and carried by said parallel supporting members for moving said cylinder along the supporting members, a lever pivoted on the frame for movement from a position substantially parallel to said lever to another position at an angle thereto, said lever being operatively connected to the rod of the cylinder to move the piston within the cylinder to and from a position of minimum cylinder volume, which occurs when the lever is parallel to said support members, the rod connecting means being movable along said lever with the movement of the cylinder along the supporting members, cam means for positively oscillating said lever and means for driving said cam, whereby the piston is forcibly moved back and forth within the cylinder.

22. A respirator system according to claim 21 further characterized in that said bell crank is slotted.

23. A respirator of the positive pressure type comprising a gas delivery line and an exhaust line and means for connecting each of them in substantially pressure-tight relation to and at the respiratory tract of the patient, a cyclically operative pump and cooperatively operating valving system for cyclically and alternately moving a quantity of respiratory gas into the gas delivery line while closing the exhaust line and then terminating the forcing of such gas while opening said exhaust line, an excess pressure release valve connected to the gas delivery line and a flow indicator connected in circuit with said gas delivery line, said indicator including a visual indicator element operated by the gas flow in said line.

24. The respiratory apparatus of claim 23 further characterized in that a second flow indicator is connected

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in the line between the gas delivery line and pressure relief valve.

25. In a respirator system comprising an assembly composed of a gas expelling cylinder having a piston and piston rod movable in cooperation with the cylinder for forcing gas out of the cylinder and into a patient's respiratory system, a crank and means for moving it arcu- 5 ately with reference to a center of rotation and a slidable pivot connection between the piston rod and crank for variably adjusting the distance between said slidable pivot 10 and said center of rotation of the crank, and means connected to the cylinder and piston assembly for adjustably positioning said assembly for holding said slid-

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able pivot connection at a prescribed position of adjustment.

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