

Dec. 28, 1965

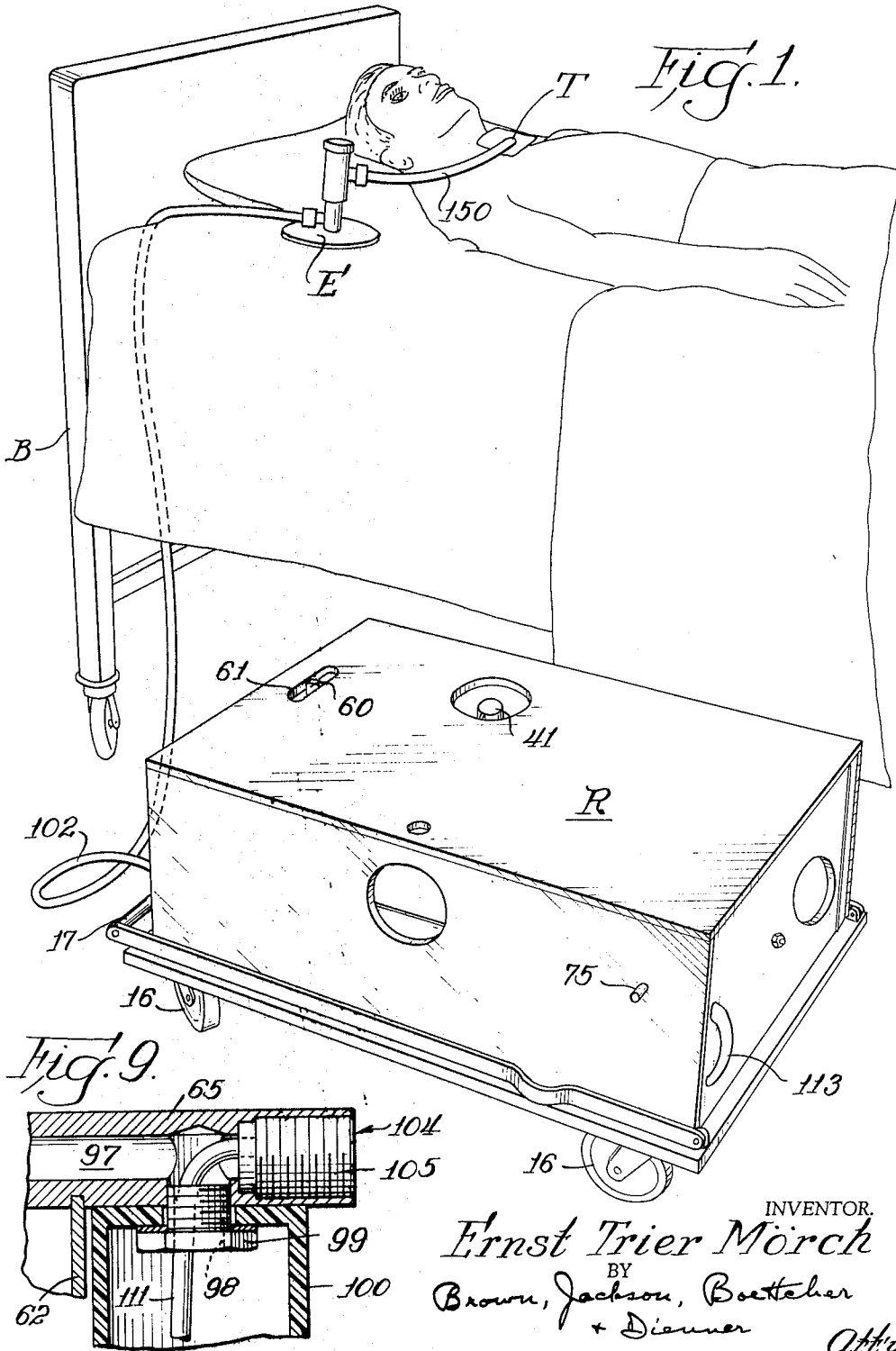
E. T. MÖRCH

3,225,758

PISTON TYPE RESPIRATOR

Filed Dec. 30, 1959

7 Sheets-Sheet 1



Dec. 28, 1965

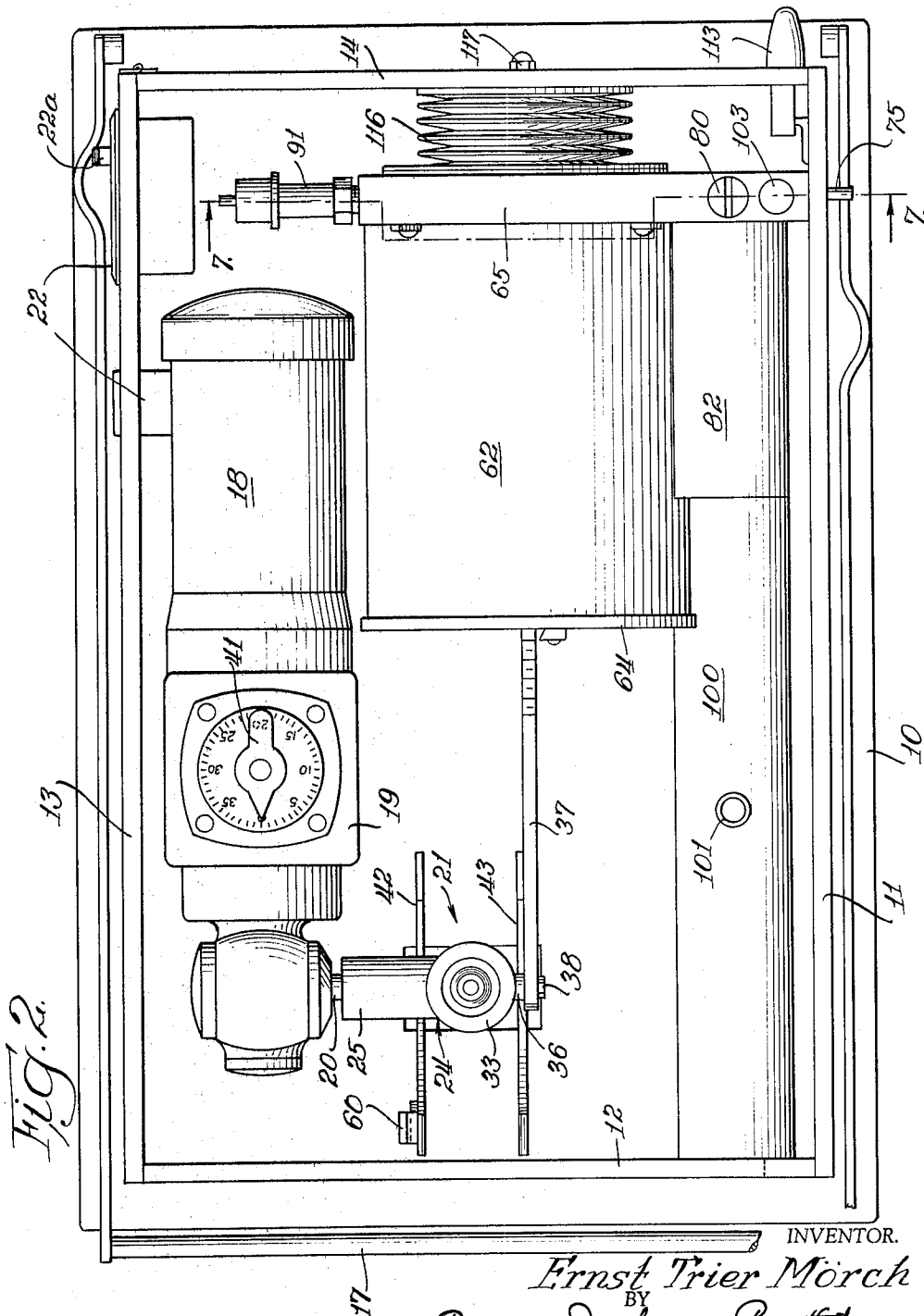
E. T. MÖRCH

3,225,758

PISTON TYPE RESPIRATOR

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7 Sheets-Sheet 2



INVENTOR.
Ernst Trier Mörck
BY
Brown, Jackson, Boettcher
+ Dienner
Att'ys.

Dec. 28, 1965

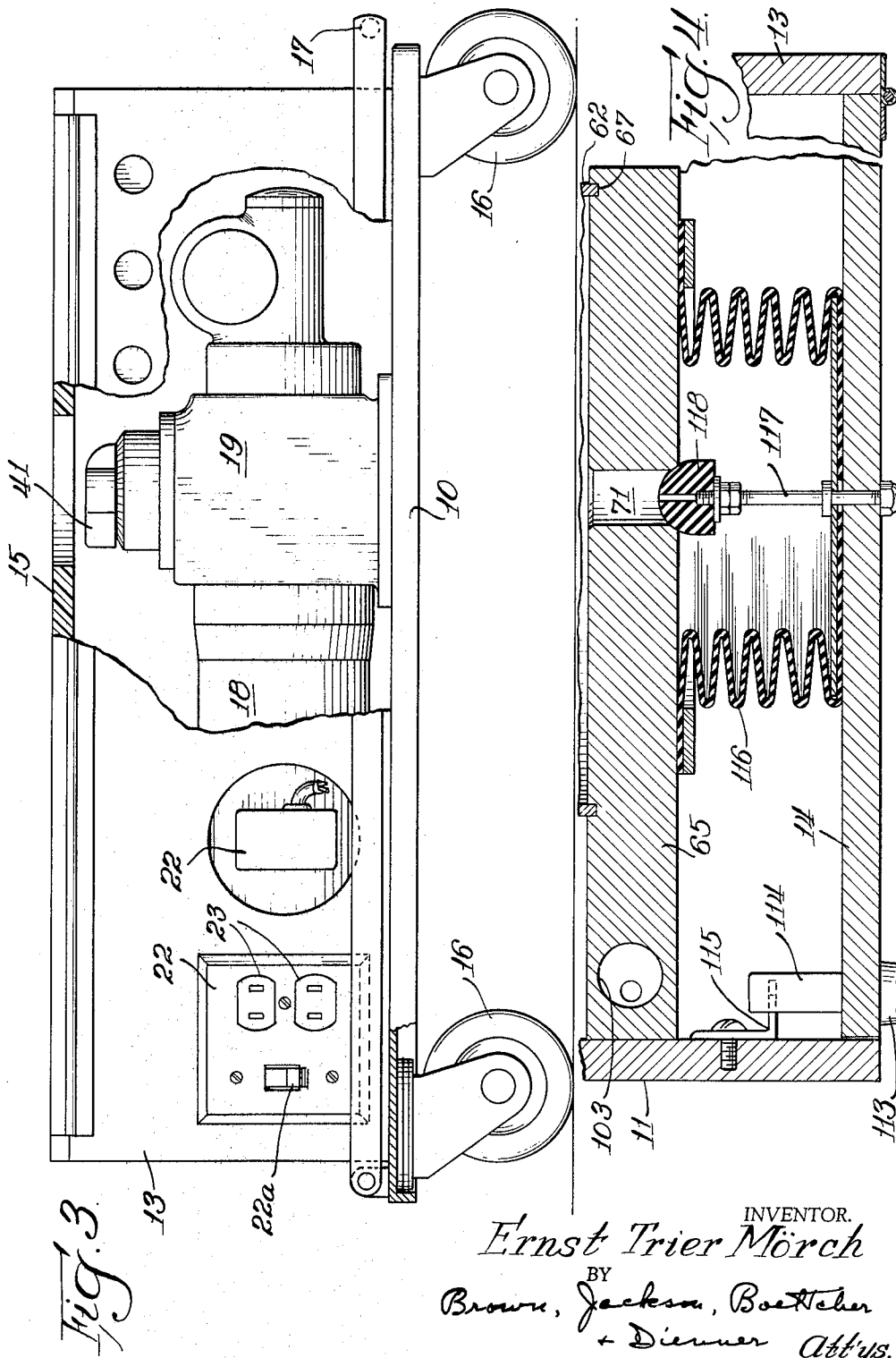
E. T. MÖRCH

3,225,758

PISTON TYPE RESPIRATOR

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7 Sheets-Sheet 3



INVENTOR.
Ernst Trier Mörch
BY
Brown, Jackson, Boettcher
+ Diemer Att'ys.

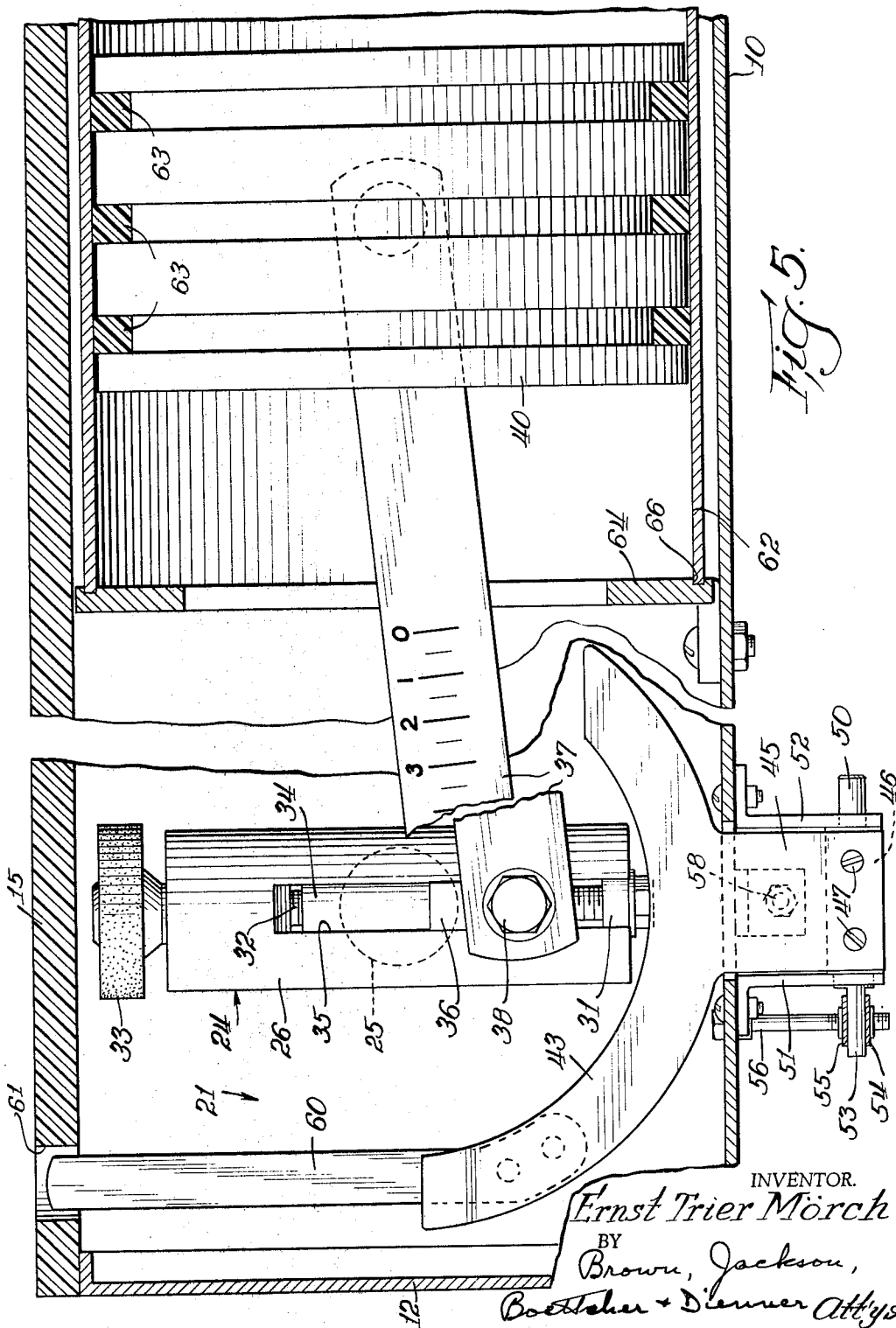
Dec. 28, 1965

E. T. MÖRCH
PISTON TYPE RESPIRATOR

3,225,758

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Dec. 28, 1965

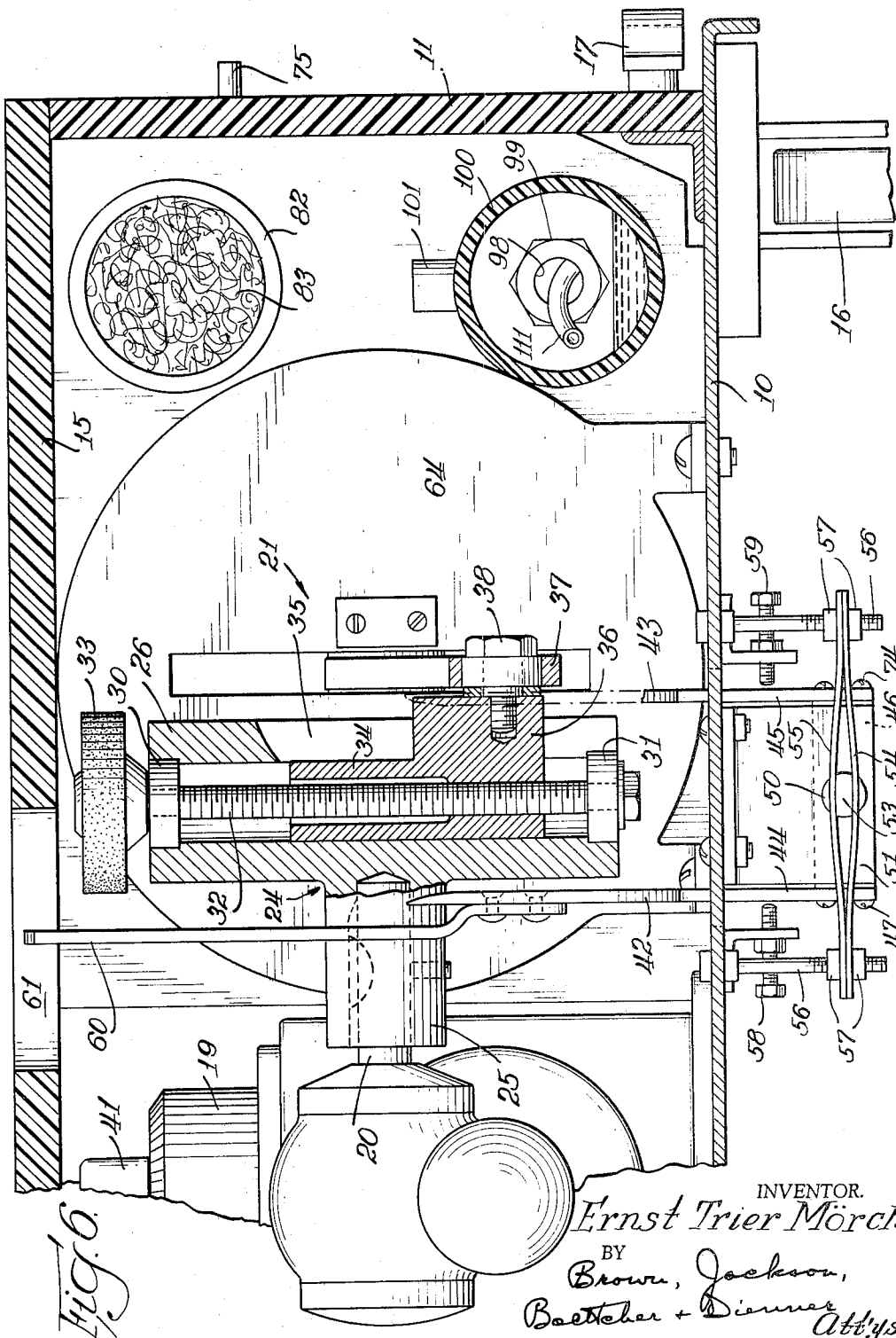
E. T. MÖRCH

3,225,758

PISTON TYPE RESPIRATOR

Filed Dec. 30, 1959

7 Sheets-Sheet 5



INVENTOR.

Ernst Trier Mörch

BY

Brown, Jackson,

Boettcher + Diener Att'ys.

Dec. 28, 1965

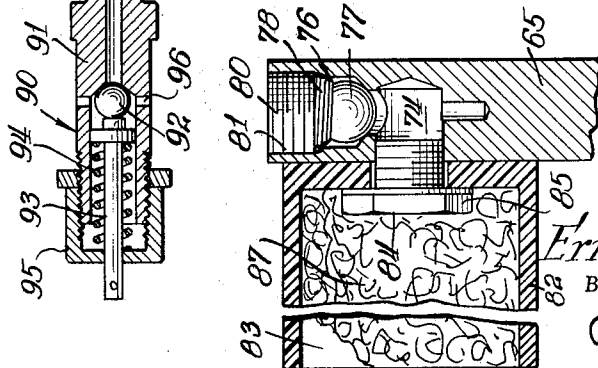
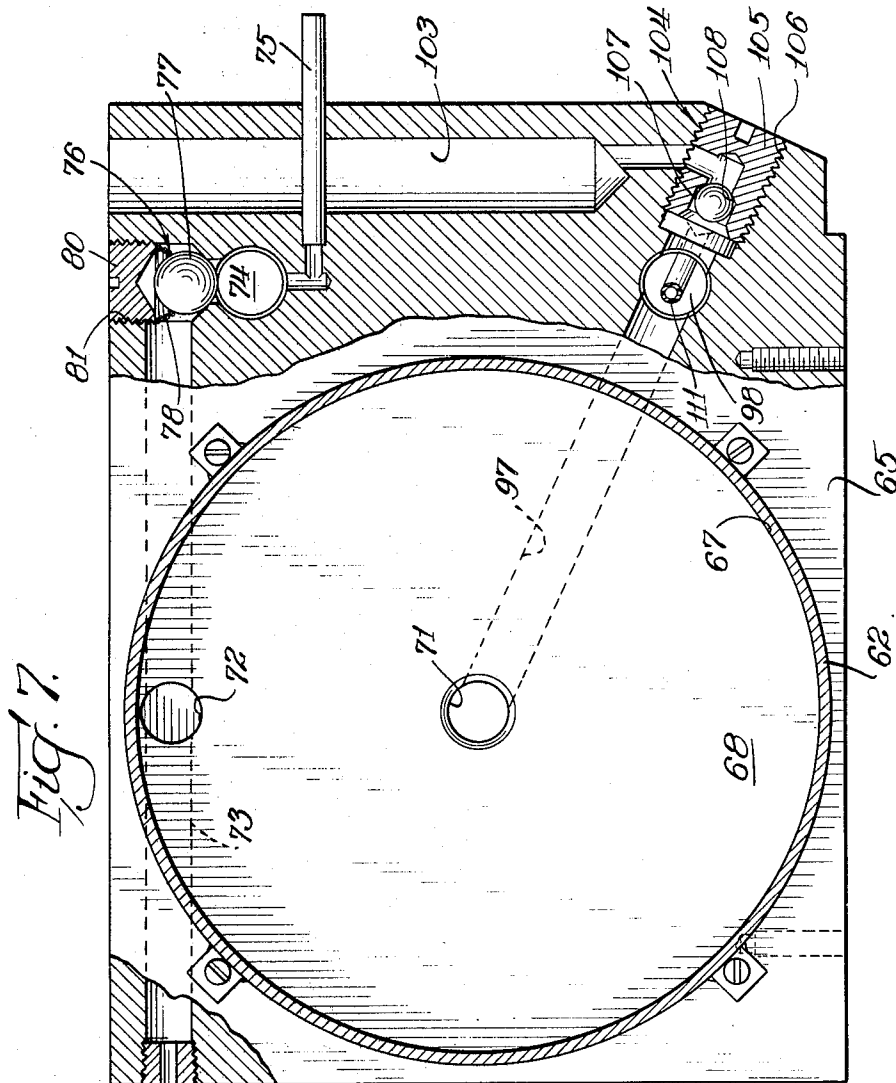
E. T. MÖRCH

3,225,758

PISTON TYPE RESPIRATOR

Filed Dec. 30, 1959

7 Sheets-Sheet 6



INVENTOR.
Ernst Trier Mörch
BY *Brown, Jackson,*
Boettcher & Diener
Att'ys.

Dec. 28, 1965

E. T. MÖRCH
PISTON TYPE RESPIRATOR

3,225,758

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7 Sheets-Sheet 7

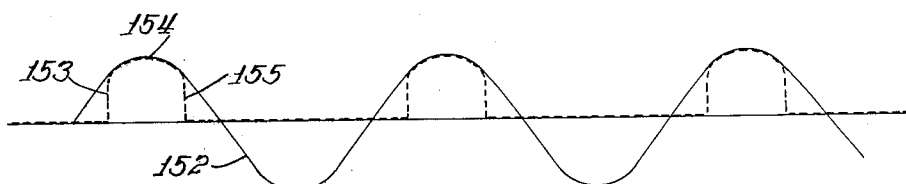
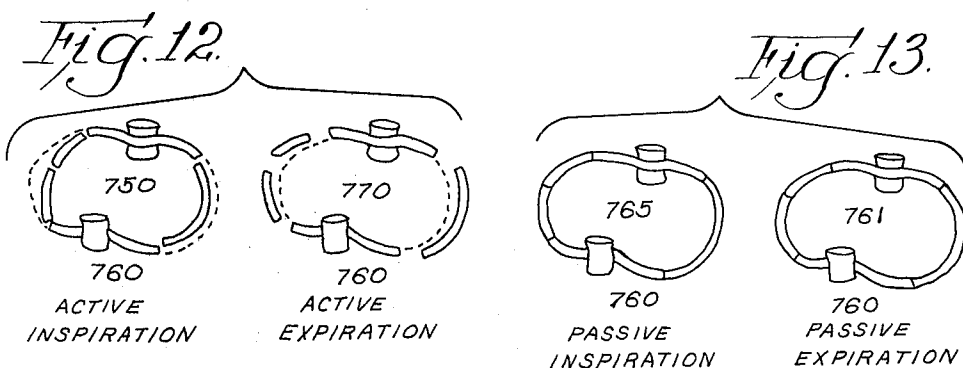
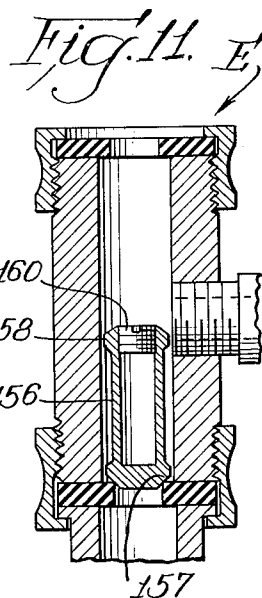
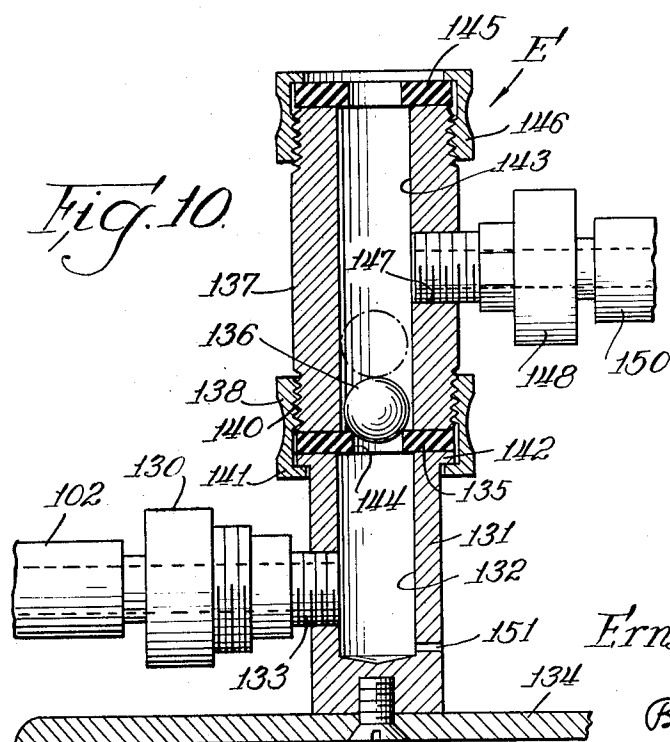


Fig. 14.



INVENTOR.
Ernst Trier Mörch
BY *Brown, Jackson,
Boettcher & Diener*
Att'ys.

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3,225,758

PISTON TYPE RESPIRATOR

Ernst Trier Mörch, 5816 Blackstone Ave., Chicago, Ill.

Filed Dec. 30, 1959, Ser. No. 862,869

17 Claims. (Cl. 128—29)

The present invention relates, in general, to respirators, and in particular to new and improved respirator means for use on humans suffering disabilities of the human respiratory system, e.g., polio cases and accident cases involving critically crushed chests.

In my application for United States patent, Serial No. 573,514, entitled "Respirator," filed March 23, 1956, now Patent 2,969,879, issued January 31, 1961, I have disclosed respirator means which automatically produces positive and negative pressures in the lungs of a patient to substantially duplicate any respiratory condition and to exert complete control over the patient's respiration when necessary. This machine, as disclosed and claimed in my copending application, is particularly designed for use during surgery, especially thoracic operations. Under such conditions, respiration can be assisted and controlled, and the problems of thoracic surgery are in the hands of a team trained in these problems and constantly aware of the possible rapid changes in cardio-pulmonary dynamics.

My present invention, however, has an advantage over the respirator disclosed and claimed in my copending application, and over other prior art respirators, in that it is capable of handling thoracic injuries occurring at industrial sites or on highways far from medical centers. It is also capable of handling respiratory difficulties during thoracic surgery, as well as respiratory difficulties due to infections, such as poliomyelitis, muscle diseases, trauma to the brain, and head injuries, post-operative neurosurgical conditions, cerebral vascular accidents, respiratory depression (industrial poisons, suicide, overdosage of medications, and anesthetics), and in ventilatory insufficiency following pulmonary resection.

The general principle of treatment of these respiratory difficulties will be explained hereinafter once the mechanical features of my respirator are explained.

It can be seen that, in view of the applicability of my respirator for handling thoracic injuries at industrial sites and the like, as well as for its use in medical centers, it is of particular importance that my present invention be constructed small and compact, so that it will fit under any normal hospital bed and be readily transported, that it be rugged in construction, simple to operate, clean and assemble, and that it be operable without special knowledge or tools.

These are accomplished by my respirator and form some of the features and objects of my present invention.

More particularly, it is an object of this invention to provide an improved respirator that operates entirely on the principle of volume control, not on a pressure principle, and that also includes means for controlling the rate of respiration.

Briefly, my invention comprises a piston type pump driven by an electric motor and so constructed and arranged as to give a large stroke volume. The stroke volume of my invention is adjustable so as to regulate the pulsations of air or air-gas mixture directed to the patient. Pump speed is also adjustable to regulate the rate of the pulsations. Fresh air, air-oxygen, carbon dioxide-oxygen mixture or other gas mixture, is pumped according to my invention through a humidifier into an exhalator valve and thence into a face mask, endotracheal tube, or tracheostomy tube. Also, according to my invention, an exhalator valve is interposed near the mask or tube and so constructed and arranged as to provide

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proper timing, i.e., the proper pressure profile of gas, for optimal ventilation of the patient.

My exhalator valve is constructed and arranged to parts, like parts of which are inter-changeable, and to make the valve substantially symmetrical in various of its parts, so that little skill and no special tools are required to disassemble the device for cleaning and to re-assemble the same. This, too, is an important feature of my invention.

My machine is so constructed and arranged that mechanical failures are negligible, and a hand pump has been incorporated so that ventilation of the patient can be carried out in case of electrical power failure, or when transporting the patient, as by ambulance, aircraft, etc. This hand operability also forms a very important object of my invention in view of the fact that it can be used at industrial sites and during transport.

Other important features of my invention are the incorporation therein of safety means so that gas humidifying liquid will not flow to the patient, regardless of the careless handling and/or the position of the device, of means for controlling the stroke and the rate of reciprocation of the piston, which means are operable without stopping the machine, and of safety means in the gas circuit for preventing insufficient or excessive supply of gas to the patient despite careless handling of the gas supply, such as oxygen tanks and the like.

Further important features of my invention are the use of a standard commercially available motor and gear reduction box, the utilization of just two simple controls for controlling the rate and volume of gas supply, the provision of a construction such that no special tools or mechanical knowledge are required in normal use of the machine, and the provision of a hand pump that will operate at any phase of the stroke of the main pump in event of failure thereof.

Other and more particular objects and advantages of my invention will be apparent to those skilled in the art from the following description and drawings forming a part hereof and wherein:

FIGURE 1 is a perspective view illustrating a respirator means constructed in accordance with the teachings of my invention and showing its compactness and its capability of being pushed under most hospital beds so that it does not occupy any functional floor space;

FIGURE 2 is a plan view illustrating the internal arrangement of one embodiment of my respirator means;

FIGURE 3 is a side view, partly in section and partly in elevation, of my respirator, the view illustrating the variable speed power source for the piston pump forming a part of my respirator;

FIGURE 4 is a fragmentary horizontal section illustrating a hand pump arrangement forming part of my respirator and usable in the event that the power source illustrated in FIGURE 3 is rendered inoperative or the respirator is being transported;

FIGURE 5 is a fragmentary vertical section, on an enlarged scale, illustrating the piston pump and the means for varying the stroke thereof;

FIGURE 6 is a vertical cross-section of my respirator, the view particularly illustrating the stroke regulating means;

FIGURE 7 is a cross-sectional view taken substantially on line 7—7 of FIGURE 2 and illustrating the end wall and the intake and exhaust valves of the pump;

FIGURE 8 is a fragmentary sectional view illustrating in further detail the means for admitting air to the pump;

FIGURE 9 is a fragmentary sectional view of the means for introducing water into the humidifier and of the means for causing the gas pumped by the respirator to pass through the humidifier;

FIGURE 10 is a vertical section of one embodiment of the exhalator valve forming part of my invention;

FIGURE 11 is a fragmentary vertical section of another embodiment of my exhalator valve;

FIGURE 12 is a schematic representation of the action of ribs broken in several places during active (patient's) respiration;

FIGURE 13 is a schematic representation of the action of broken ribs during passive respiration under the direction and control of my respirator means; and

FIGURE 14 is a diagram of the pressure profile of my respiratory means.

Referring to the drawings, and particularly to FIGURE 1, I have illustrated my invention in connection with a normal hospital bed B to show the size and adaptability of one embodiment thereof. It can be seen that my respirator means, indicated in its entirety as R, with its exhalator valve E, is relatively small and compact and will normally fit under an average hospital bed. Exhalator valve E is in communication with a tracheostomy tube T (or an endotracheal tube or a face mask). It may therefore be placed where it will not be an obstruction to the necessary medical and nursing staff, and with this arrangement the patient can be cared for and examined, even though the patient is incapable of normal or active respiration. It can also be seen that my invention obviates tractions normally required in cases of chest injuries, and that it also obviates the necessity for iron lungs in polio cases. Obviously, tractions, iron lungs and the like, make examination and normal care by the hospital staff difficult, if not impossible, and their obsolescence by my invention also is an important feature thereof.

Turning now more particularly to the details of my respirator means, attention is directed to FIGURES 2 and 3. My respirator means comprises, generally, a base 10 provided with three upright side walls 11, 12, 13, a hinged side or end wall 14, and a hinged top cover 15, the latter of which is preferably transparent. The purpose of the hinged wall 14 will be explained in detail hereinafter. On the bottom of the base 10 are suitably mounted conventional castor wheels 16, and the base 10 is provided with a hinged handle 17, for conveniently transporting the respirator.

Within the four walls 11-14, I have provided an electric motor 18 and a variable speed drive 19, the output shaft 20 of which is connected to a stroke regulating means, indicated in its entirety at 21. The motor 18 and variable speed drive means 19 are readily available commercially, and the latter may be of the type described and shown in U.S. Patent No. 2,535,409 to L. A. Graham, issued December 26, 1950.

Also on side wall 13 I have provided suitable electric supply and control means including connection boxes 22 for connecting motor 18 to a source of electric power, a switch 22a to control the supply of current to the motor, and convenience outlets 23 so that, where desired, my device will provide outlets for other devices.

The stroke regulating means 21 is a variable crank, and as more clearly shown in FIGURES 2, 5 and 6, comprises a T-shaped arm 24 having its main leg 25 fixedly attached to the shaft 20 and having its cross member or arm 26 internally bored. At its ends the cross arm is counterbored to receive a pair of bearing means of any conventional type, illustrated at 30 and 31. These bearing means journal a screw 32, having a friction wheel 33 affixed to one end thereof outwardly of the arm 26. Rotation of the friction wheel 33 will cause rotation of the screw 32 which in turn causes movement of a piston rod carrier or cam 34. Cam 34 is suitably internally threaded so as to mate with the threads of the screw 32 and ride thereon. The arm 26 is suitably slotted, as indicated at 35, for reception of an extension 36 on the cam 34, whereby the cam is held against rotation and is caused to be moved radially of the shaft 20 when the screw 32 is rotated. The extension 36 of the cam 34 is in turn pivotally

connected to a piston rod 37 in any suitable manner, as by a bolt 38 secured to the extension 36 and defining a crank pin for the rod.

From the above description it will be appreciated that upon rotation of the T-shaped member 24 by the variable speed drive shaft 20, reciprocating motion is imparted to the piston rod 37 by reason of the fact that its connection to the T-shaped member 24 is eccentric to the axis of rotation of the shaft 20. Piston rod 37 is suitably connected to a piston 40 later to be described in detail. It is important to note that the T-shaped arm 24, the piston rod 37 and the connections thereof are relatively thick and heavy so that if such items as bottles, glasses, or the like were accidentally dropped into the device when the cover was removed, the arm would crush the same without stopping; the motor and drive being powerful enough to do this. It is also important to note that while the variable speed drive shaft 20 is rotating, the r.p.m. of the shaft 20 may be changed in a conventional manner through the control knob 41 as explained in more detail in the aforementioned patent. Also, it is the object of this invention to accommodate variation in the stroke of the piston rod 37 and piston 40 while the machine is in operation.

In the latter respect, the wheel 33 has its peripheral surface covered with a suitable friction material, such as rubber, and it can be seen that, upon rotation of the arm 24, the wheel orbits to define a circle. At the lower segment of this defined circle, I have provided a pair of segments 42 and 43. These segments are plates corresponding to approximately one-half of the circle defined by the wheel 33 orbiting about the shaft 20 and are adapted to be alternately engaged to said wheel.

The segments 42, 43 are each provided with a downwardly extending arm 44, 45 which extends through a suitable aperture in the base 10. These extensions or arms 44, 45 are suitably attached as by screws 47 to a cross bar 46 which serves to space the segments 42, 43 from each other a distance slightly greater than the diameter of the wheel 33, and to dispose the segments to opposite sides of the orbital path of the wheel. This spacing permits the wheel 33 to orbit about the shaft 20 without normally engaging either segmental plate 42 or 43. Bar 46 is provided centrally thereof with a shaft 50 extending parallel to the planes of the extensions 44 and 45. The shaft 50 is journaled in the depending arms of a pair of angle irons 51 and 52 which are secured to the lower side of the base 10 to opposite sides of the aperture through which the extensions 44 and 45 project. The angle irons 51 and 52, with shaft 50 and bar 46, thus serve to hold the segment plates 42, 43. The shaft 50 is flattened at one end, as at 53, and is disposed between a pair of leaf springs 54, 55. The flattened portion 53 provides a camming action with respect to the leaf springs 54, 55 and the springs provide means for retaining the segments 42 and 43 in their normal position spaced to opposite sides of the orbital path of the wheel 33. Movement of the plates 42 or 43, in one direction or another, will cause the shaft 50 to rotate about its axis, spreading the leaf springs 54, 55, with the result that the springs will return the plates 42, 43 to their normal position upon release of the plates.

Springs 54 and 55 are suitably apertured at their ends to receive a spring retaining and adjusting means in the form of bolts 56 and nuts 57 attached to the base plate 10. On the opposite sides of the extensions 44 and 45, I have provided suitable adjusting mechanism in the form of set screws 58 and 59, the purpose of which is to regulate the maximum movement of the plates 42, 43. As can be seen in FIGURES 5 and 6, one of the segments (42 as shown) is provided with an arm 60 which extends upwardly substantially midway of the top cover 15, the latter being provided with an aperture 61 through which the arm 60 may be operated.

It can be seen from FIGURE 6 that movement of the

arm 60 to and fro will selectively cause the segments 42 and 43 to be moved into the orbital path of movement of the wheel 33, whereby the segments will be selectively engaged by the peripheral surface of the rotatable frictional wheel 33, thereby to rotate the wheel and the screw 32. This latter, in turn, changes the position of the connection of the piston rod 37 relative to the axis of rotation of the shaft 20 and, of course, this will change the stroke of the piston 40. By moving one segment into the path of the wheel, the cam 34 is caused to move radially outwardly of the shaft 20 to increase the stroke. By moving the other segment into the path of the wheel, the cam is caused to move radially inwardly to decrease the stroke of the piston. In either case, the wheel engages the segment only during approximately one-half of its orbital time, thereby to facilitate precise control over the stroke of the piston and the output volume of the pump.

It is important to note that I have so constructed and arranged my stroke regulating means as to permit variation of the stroke of the piston 40 and hence the volume of the output of the pump while the respirator is in operation. This, with the variable speed transmission which may be changed while the respirator is in operation, assures wide adaptability of my device for use clinically.

Turning now to FIGURES 5 and 7, where I have illustrated my piston pump in more detail, it can be seen that the pump comprises the previously identified piston rod 37 and piston 40, the latter reciprocating in a cylinder 62 and being provided with piston rings 63 (three shown) of any suitable material, such as nylon, Teflon, and the like. A pair of plates 64 and 65, each having a circular groove 66 and 67 to respectively receive the ends of the circular cylinder 62, form end walls for the pump and are suitably attached to the base 10. Plate 65 forms the end wall for the pumping chamber 68. End wall 64 is vertically slotted centrally thereof to permit the reciprocation of the piston rod 37 and serves to support the cylinder 62 (FIGURE 5). The other end plate 65, in addition to being an end plate which supports the opposite end of the cylinder 62 and defines a part of the pumping chamber 68, is provided with an inlet and outlet to the pumping chamber, as will now be described.

As more clearly illustrated in FIGURES 4 and 7, end plate 65, within the periphery of the groove 67, is bored to provide a centrally located outlet 71 and an inlet 72. In the embodiment illustrated, the inlet 72 is located near the top of the end plate 65 and communicates with a horizontally extending bore 73. At one end of this horizontally extending bore 73, I have provided an inlet 74 for air, or air-oxygen mixture, and an inlet 75 for oxygen, both of which operate through a conventional spring or gravity biased one-way inlet valve, indicated in its entirety at 76. The inlet valve 76 preferably comprises a ball 77, a spring biasing means 78, and a threaded cap 80, which is received in the threaded bore 81; the latter serving as a means for regulating the compression of the spring. Thus, on the intake stroke of the piston, air introduced into the inlet 74 from a filter, such as illustrated at 82 in FIGURE 8 in open communication therewith, will open the inlet valve 76 to allow air into the passage 73 and pump inlet 72. Filter 82 in the illustrated embodiment of my invention comprises an open-ended cylinder providing a filter inlet 83 and having a filter outlet 84 comprising a hollow screw 85 threadably received in the end plate 65. Screw 85 also serves to attach the filter to the end plate. The filter means 87 may be gauze or the like, and the side walls 11, 12, and 13 and/or cover 15 are apertured to allow air to be communicated to the filter inlet 83.

When oxygen is needed, oxygen may be introduced from the oxygen inlet pipe 75 through the inlet 74, past the inlet valve 76, and into the pump inlet 72. It is to be noted that oxygen or other gas or gas mixture so intro-

duced is permitted to communicate with the air inlet means. Oxygen inlet pipe 75 is extended outwardly beyond the side walls of the respirator and provided with suitable couplings to permit connection to conventional oxygen tanks.

At the end of passage 73 opposite the inlet valve 76, I have provided still another one-way valve assembly 90 which, in this embodiment, provides a safety valve for the maximum pressure of the pump. This safety valve 90 comprises a bored valve body 91, a ball 92, a valve piston 93, and a spring 94 which serves to urge the valve piston 93 and ball 92 against its seat. The compression of the spring 94 may be varied by reason of the screw type cap 95 which is threadably received over the valve body 91, as illustrated. Thus, should the pressure in the pumping chamber 68 exceed a value selected by the compression of safety valve spring 94, the ball 92 will be urged off its seat, allowing the pressure to be released from valve outlet 96. The operation of the valve 90 is as thus described, even though it is in the inlet side of the pump. In this embodiment, the valve is separate from the end plate 65, although it could be formed as part of the plate, if thought necessary or desirable.

The pump outlet 71 is in open communication with a bore 97 which in turn communicates with end plate outlet 98 which is in communication with a humidifier 100, more clearly illustrated in FIGURE 6. The outlet port 98 is preferably defined by a hollow screw 99 (FIGURE 9) which serves to affix one end of the humidifier to the end plate 65.

Humidifier 100 comprises a relatively long hollow cylinder preferably of a length to extend from plate 65 to end wall 12 and preferably approximately $\frac{1}{3}$ to $\frac{1}{2}$ full of water, and in open communication with the plate outlet 98. Air or air-oxygen mixture from pump outlet 71 passes through the plate outlet 98, over the water in the humidifier 100, through the humidifier outlet 101 to which a conventional hose 102 (FIGURE 1) is attached, and thence to the exhalator valve E, later to be described.

As previously mentioned I have provided a novel means of filling the humidifier 100, as well as a safety means incorporated in the humidifier, so that a patient will not be drowned, regardless of the position of the respirator.

As to the humidifier filling means, the end plate 65 is bored vertically, as illustrated in FIGURE 7 at 103, and is counterbored so as to be in communication with a water inlet valving means 104. This valving means 104 comprises a valve body 105 threadably received in a threaded angularly disposed bore 106, and is provided with a ball valve 107. The ball 107, in the embodiment illustrated, is urged against its seat 108 by gravity, as well as by the force of the air discharging into the humidifier 100 during the compression stroke of the piston. When water is introduced into the bore 103, the weight of the water at least during the suction phase of the pump, will serve to urge the ball 107 off of its seat 108, so that water may enter into a flexible tube 111. This tube in turn extends into the humidifier through the humidifier inlet 98, as more clearly illustrated in FIGURE 9. I have found that while the weight of the water is sufficient to lift the ball 107 off its seat 108, the valve does not block the water tube 111, and permits the humidifier to be filled to its proper height with water during operation of the machine.

Turning now in particular to FIGURE 2, it can be seen that the humidifier outlet 101 is disposed at the top and in a central location longitudinally of the humidifier, whereby water cannot be discharged through the tube 102 despite movement and/or tilting of the respirator.

As previously mentioned, I have also provided my respirator means with a hand pump which may be used in the event there is a power failure which stops the motor 18, or during transport of the respirator as by ambulance or aircraft or to and from operating rooms

and the like. This hand pump is illustrated in detail in FIGURE 4 and will now be described.

As can be seen in this figure, the end plate 65 is located inwardly of and spaced from the hinged end wall 14. This wall 14 is hinged by any suitable means to permit oscillatory movement of the wall, and the wall is provided at its swingable end with a latch, illustrated in its entirety as 113. This latch serves normally to attach the hinged side wall 14 to the front wall 11 and is locked by the horizontally extending lock means 114 and the angle iron 115, suitably attached to the side wall. Where necessary or desirable, the latch may be released and employed as a hand grip so that the end wall 14 will serve as a pump handle. Centrally of the end wall 14, and on its inner side, there is provided a bellows 116 affixed at one end in sealed relationship against the end plate 65 on the side thereof opposite the pump chamber 68. Bellows 116 is also sealably attached to the inside surface of the end wall 14. A bolt, indicated at 117, is located centrally of the bellows 116 and extends from the end wall 14 to support, at its inner end, a stop cock 118, of any suitable resilient material, which fits in sealing relationship against the pump outlet 71 previously described.

When the latch 113 is closed, the stop cock 118 seals the pump outlet 71 so that air under pressure from the pump is directed into the humidifier. However, when the latch is unlocked and the wall 14 is oscillated, the stop cock 118 is unseated and the wall 14 serves to actuate the bellows 116. In this case, the piston 40 is stopped and the bellows performs the function of a hand pump, to force air, as well as oxygen where the latter is thought necessary or desirable, through the humidifier 100 and into the humidifier outlet 101. It is to be noted that since the hand pump utilizes the same pump outlet 71 it serves to function relative to the water inlet, the oxygen inlet, and the air inlet in a manner identical to that of the piston 40.

Turning now to the exhalator valve E, which is illustrated in detail in FIGURES 10 and 11, it can be seen that the flexible hose 102 is provided with a conventional coupling 130 which communicates with the base 131 of the valve E. The base 131 is internally axially bored, as at 132, and is provided at one side thereof with an inlet 133 to which the coupling 130 is secured. The valve includes a flat stand portion 134 so that the valve base 131 can be held upright. At the upper end of the base 131, I have provided a conventional washer 135 of any suitable material, preferably resilient, such as rubber, or rubber-like material, which serves as a seat for valve means 136. This washer 135 is sandwiched between valve base 131 and a valve chamber member 137 by a threaded cap member 138 threadably cooperating with external threads 140 on the outer periphery of the valve chamber member 137. This threaded cap member 138 has a radially inwardly extending flange 141 which co-operates with a radially outwardly extending flange 142 on the valve base 131 by overlapping the latter. Obviously, tightening of the cap member sealably affixes the washer 135 between the chamber member 137 and the valve base 131. This valve chamber 137 is centrally bored as at 143 to permit the valve means 136 to rise and fall, thereby to effect opening and closing of the port 144 defined by the washer.

At the upper end of bore 143, I have provided another washer or valve seat means 145 affixed to the end of the chamber member 137 by a valve cap 146. Since washer 145 and valve cap means 146 are respectively identical to the washer 135 and cap member 138, no further description thereof is necessary.

Centrally of the chamber member 137, that is, operatively behind the valve means 136, a threaded bore 147 is provided to receive a threaded coupling 148 of a type similar to the coupling 130. Coupling 148 is in open communication with still another flexible tubing 150 so that air, or air-oxygen mixture, introduced into the valve

base 131 under pressure will serve to lift the valve means 136 off its seat and raise it up against the upper washer 145. At that time, bore 132 is in open communication with the flexible hose 150 which in turn is connected to the patient, by means of a tracheostomy tube T, or an endotracheal tube or a face mask. The valve means 136, operating up and down in the chamber 137, provides a pressure profile for the air, or air-oxygen mixture, under pressure from either of the pumps, as will be understood from the explanation hereinafter.

It is also to be noted in connection with the exhalator valve E that the valve base 131 is provided with still another safety means, indicated at 151, which comprises a bore communicating with the internal bore 132 in the side wall of the base. This safety means 151 acts to prevent any accumulation of water in the bore 132 which might act to clog the tracheostomy tube T and drown the patient. It also acts as still another check in addition to the safety means provided in the humidifier 100.

As is to be appreciated from the previous description of the pumps, they provide a suction stroke and a pressure stroke, so as to deliver a positive pressure (more than atmospheric pressure) and a negative pressure (less than atmospheric pressure) at the outlet thereof. During the suction stroke, air or air-oxygen mixture is introduced into the pump inlet 72 from the means previously described and, on the pressure stroke, the air or gas is urged out the outlet 71. During the suction stroke, the operation of the valve means 136 serves to prevent reverse flow of air through the humidifier 100 and the outlet 71, and during the pressure stroke, the valve means 76 serves to prevent any air, or air-oxygen mixture, from returning to the inlet 74, as can be appreciated. Thus, normally, alternately positive and negative pressures are created by the pump, whichever one is in operation. The pressure profile thereby produced between the maximum positive and minimum negative pressures, if plotted against time in a graph, would appear as a sinusoidal wave, such as illustrated in FIGURE 14 at 152. However, during the positive pressure stroke the air, or air-oxygen mixture, entering into the valve base 131 is required to overcome the influence of gravity on the valve means 136. Obviously, this requires work, which in turn serves as a time lag between the opening of the valve port 144 and the time pressure is first introduced into the valve base 131. This is represented by the vertical dotted lines at 153 in FIGURE 14. Once the valve seat is opened, however, by the pressure in the valve base 131, the valve means is urged against the top washer 145 to close the opening therein. Thus, air, or air-oxygen mixture is free to enter the flexible hose 150 at a maximum positive pressure as represented at 154 in FIGURE 14. As can be appreciated, as soon as the maximum compression stroke is completed and the suction stroke begins, again the influence of gravity on the halving means 136 will come into play, tending to pull the valve means 136 downwardly, closing the bore 144. Thus, as soon as the pressure in the valve base 131 is sufficiently low so as not to be able to overcome gravity on the valving means 136 a rapid drop will occur, as is illustrated at 155 in FIGURE 14. Since the valve means 136 closes the port 144, the negative pressure part of the pump curve, such as illustrated in FIGURE 14, is not influential on the tube 150. The pressure profile or flow of air, or air-oxygen mixture, in the tube 150 thus will be a substantially squared half sine wave, such as illustrated in dotted lines in FIGURE 14.

As can be appreciated from the above explanation, the influence of gravity on the valve member 136 of the exhalator valve E can be an important factor in the operation of the valve. Consequently, different valve means may be employed depending upon the respiratory cycle to be developed. In FIGURE 10, I have depicted a single steel ball in solid lines as the valve 136. If a heavier valve is required, two balls may be employed

as indicated in dotted lines. For a lighter valve, a ball of lighter material may be employed. Thus the time element between the vertical pressure profile segment 153 and 155 can be varied where thought necessary or desirable. This forms, in connection with the variable speed means 19, and the variable stroke means 21, still another variation in the control of my respirator.

Turning now to FIGURE 11, I have illustrated another valving means for the valve E comprising a hollow tubular flanged member 156, having end flanges 157 and 158. Flanges 157 and 158 will seat against the washer 135 and the upper washer 145 in a manner identical with the ball valving means 136 in the previously described embodiment. Valve 156 is provided with a screw 160 and is hollow so that additional weights could be placed in the valve body member to regulate the time element in the pressure profile, as previously described, in lieu of the additional ball or balls in the ball valving means 136.

It is important to note, in connection with my exhalator valve E, that the valve is made up of interchangeable parts, preferably of conventional washers and couplings, whereby such items as the washer 135 could be replaced by the washer 145 and vice versa. Too, valve chamber 137 could be reversed from the position shown and the members 138 and 146 could be used interchangeably. Thus, the exhalator valve E is easy to clean, requires no special knowledge of valves, requires no special tools, and could be put together without any special knowledge primarily because of the inter-changeability of the parts. This forms an important feature of my invention.

Having thus described all of the interrelated and working parts of my invention, I will now describe briefly its function and operation so that an operator will realize the theory and practical manner of using my respirator.

Briefly, my respirator acts to provide hyperventilation to counteract any paradoxical respiration and overriding of any fractured ribs. It is a combination of two factors, mechanical and biochemical.

The mechanical factor is as follows:

With an uninjured chest, the bellows action of the diaphragm and the accessory respiratory muscles work to draw and expel air to and from the lungs. The bony support of the chest wall expands and the diaphragm descends, reducing the pressure in the chest (intrathoracic) to subatmospheric so as to permit air at atmospheric pressure (extrathoracic) to enter the lungs. The return of the chest wall and ascent of the diaphragm increases the intrathoracic pressure to superatmospheric, causing the air to be expelled.

When the bony support of the chest wall is broken, as illustrated as an example in FIGURE 12, the respiratory action of the diaphragm and the accessory respiratory muscles is markedly reduced. As the diaphragm descends reducing intrathoracic pressure, the extrathoracic atmospheric pressure, serves partly to push in the softened chest walls as indicated at the left in FIGURE 12, thereby compressing the lungs still further by reason of the fact that the bony support of the chest wall has been broken. This reduces the amount of air inspired into the lungs, if any, or in effect, enormously increases the amount of dead air space in the lungs. In active respiration with a broken chest wall, as the diaphragm ascends to increase the intrathoracic pressure above atmospheric pressure extrathoracically, the broken chest wall bulges outwardly, as illustrated at the right in FIGURE 12, so that very little air is actually expired from the lungs. Thus, a large proportion of the air remains within the confines of the lungs and pendulates back and forth with expiration and inspiration in a so-called paradoxical motion. This poor ventilation immediately leads to an inadequate absorption of oxygen and an inadequate elimination of carbon dioxide and the body responds to these stimuli by attempting to increase the rate and depth of respiration. With the volume of

respiration so limited an increased rate of respiration provides vary little benefit because of the poor volume of exchange. Most of the air motion takes place within the dead air space which has been tremendously increased by the paradoxical motion of the chest wall. To improve ventilation and relieve the hypoxia and hypercarbia that initiate a lethal chain of events, the chest wall must be stabilized.

Traction devices have been tried to relieve this paradoxical motion by holding out the chest walls so that a patient may adequately ventilate himself. However, adequate stabilization of the chest walls has often been impossible because the chest wall is crushed. Too, as can be appreciated, such traction methods utilizing screws, wires, pins, or tongs, are painful and make it difficult, if not impossible, to give proper nursing care to the patient. Also, such methods are not available immediately, nor can they be brought to the scene of an accident where proper emergency treatment may be needed.

It can also be appreciated that demand flow apparatus, relying on the requirements of the patient's ability to demand are inadequate because many chest injuries and brain damage, etc. may block the patient's ability to demand.

According to my invention, I overcome the above-stated disadvantages by forcing controlled hyperventilation of the patient. In practice, I use an uncuffed tracheostomy tube to take particular advantage of the high stroke volume of my respirator. The uncuffed tracheostomy tube permits leakage of air through the larynx which, in turn, has other desirable effects, namely, a safety device against excessive pressures in the lungs, and prevention of accumulation of secretions in the trachea by blowing them toward the mouth where they are easily accessible to the nursing staff. Thus, with the uncuffed tracheostomy tube inserted as illustrated in FIGURE 1, a high amount of air is pushed into the lungs under a pressure which exerts a general, evenly distributed outward push of all of the softened parts holding them in their normal position, as illustrated in FIGURE 13. Any excess air flows out the mouth and/or larynx of the patient. This is called passive mechanical inspiration. During passive exhalation by using my respirator, the intrathoracic pressure simply drops towards atmospheric pressure due to venting of the tube 150 and thus the lungs to atmosphere via the port 145 in the valve E. Because the patient is apneic, no voluntary diaphragm action occurs by this mechanical means, and consequently no negative intrathoracic pressure develops to produce paradoxical motion. In other words, alternating positive and subatmospheric intrathoracic pressures during active respiration are replaced by a fluctuating positive intrathoracic pressure, as depicted by the numerals in FIGURE 13, so that the only rib motion is in their normal arcs while they passively ride over a cushion of air as the lungs expand and contract. All overriding and grinding of the broken ribs, as illustrated in FIGURE 12, is stopped by this method.

As to the biochemical factor involved in the use of my machine it has been found that the cardiac output was not decreased by intermittent positive pressure respiration, provided that the inspiratory phase and the expiratory phase are properly controlled. In other words, normal cardiac output depends mostly on the pressure profile, in terms of the length of the inspiratory and expiratory phases, and the mean intrathoracic pressure. A proper pressure profile allows for adequate recovery of circulation during expiration so that the blood flow remains normal, even over wide ranges. This is accomplished by balancing the stroke volume and the rate of respiration against the patient's tracheal-broncheal resistance and pulmonary compliance whereby a proper profile is maintained for each patient. As can be appreciated, therefore, the regulation of my respirator while in motion by the

proper control of the rate of reciprocation and the stroke of the piston is very important and can give the proper profile such as illustrated typically in FIGURE 14. Too, the balancing of the proper time element for the expiration and inspiration is accomplished by the valving means in my exhalator valve E.

With the use of the machine for hyperventilation, the carbon dioxide is washed out of the lungs. With the drop in carbon dioxide in the alveolar air, in the blood, and in the respiratory center, active respiration ceases. Hypoxia and hypercarbia, having previously aggravated pulmonary and cerebral edema, can now be corrected and the trend reversed. In other words, by hyperventilation the vicious cycle leading to death is broken by adequate ventilation. The chest wall follows the passive variations in pressure produced by my respirator, and paradoxical movements disappear. Briefly, it is found to be simple and safe to keep the body in a state of slight respiratory alkalosis to render the patient apneic so that the brain's respiratory center no longer controls the respiration. By adjusting the stroke volume and rate of my respirator to keep the alveolar carbon dioxide tension just at a level to render the patient apneic, we have been able to take advantage of this system. No serious deviations in blood chemistry have been found with prolonged mild alkalosis.

While the above description only briefly touches on the medical aspects of the machine, it is sufficient to enable those skilled in the art to understand the function and operation of my machine and how it can contribute to the treatment of severe crushing injuries in the chest by the use of continuous hyperventilation to produce alkalotic apnea to provide safe treatment and allow the survival of patients with seemingly hopeless prognosis. Similarly, patients suffering from polio may be sustained by the respirator of my invention, and in all cases, the patient's body is fully exposed for conventional hospital care.

While I have shown and described what I regard to be the preferred embodiments of my invention, it will be appreciated that various changes, rearrangements and modifications may be made therein without departing from the scope of the invention, as defined by the appended claims.

I claim:

1. In a respirator, a pump including a reciprocable piston and means for varying the displacement of said piston, said means comprising an elongate crank arm rotatable about a transverse axis, a cam member slidably but non-rotatably mounted on said crank arm for movement radially of said axis, said cam member being connected to said piston for reciprocating the same, a rotary drive member journaled on said arm and operatively connected to said cam member for moving the same relative to said arm, a drive wheel connected to said drive member and orbiting about said axis upon rotation of said arm, a pair of arcuate members conforming to and disposed to opposite sides of the orbital path of movement of said wheel, and means for selectively moving said arcuate members into the path of orbital movement of said wheel for causing said wheel to be rotated selectively in opposite directions thereby to move said cam member toward and away from said axis to vary the displacement of said piston during operation of the respirator.

2. In a respirator as set forth in claim 1, resilient means normally biasing said arcuate members to positions spaced outwardly from said wheel, whereby the wheel normally passes between said arcuate members without engaging either and the displacement of the piston is normally maintained constant.

3. In a respirator as set forth in claim 1, means spacing said arcuate members at a distance from each other greater than the diameter of said wheel whereby either one but not both of said members may be engaged with said wheel at one time.

4. In a respirator as set forth in claim 1, the extent of

each of said arcuate members being no more than about a semi-circle whereby variation of pump displacement is intermittent to facilitate precise adjustment.

5. In a respirator, a pump including a reciprocable piston and means for varying the displacement of said piston, said means comprising an elongate hollow crank arm having a longitudinal slot in the wall thereof, and mounted for rotation about a transverse axis, a cam member slidably mounted in said crank for movement radially of said axis, said cam member including an extension projecting through said slot for retaining said cam member against rotation relative to said arm, said extension being connected to said piston for reciprocating the same, a rotatable screw journaled in said arm longitudinally thereof and threaded through said cam member for moving the same relative to said arm, a drive wheel connected to said screw outwardly of one end of said arm and orbiting about said axis upon rotation of said arm, a pair of arcuate members conforming to and disposed to opposite sides of the orbital path of movement of said wheel, said arcuate members being spaced apart a distance greater than the diameter of said wheel and normally being positioned to accommodate free passage therebetween of said wheel, and means for selectively moving said arcuate members into the path of orbital movement of said wheel for causing said wheel to be rotated selectively in opposite directions thereby to move said cam member toward and away from said axis to vary the displacement of said piston during operation of the respirator.

6. In a respirator, a pump including a reciprocable piston and means for varying the rate of reciprocation and the displacement of said piston, said means comprising a rotatable drive shaft, an elongate crank arm secured to said shaft transversely thereof, a cam member slidably but non-rotatably mounted on said crank arm for movement radially of said shaft, said cam member being connected to said piston for reciprocating the same, a rotary drive member journaled on said arm and operatively connected to said cam member for moving the same relative to said arm, a drive wheel connected to said drive member and orbiting about said shaft upon rotation of said shaft, a pair of arcuate members conforming to and disposed to opposite sides of the orbital path of movement of said wheel, means for selectively moving said arcuate members into the path of orbital movement of said wheel for causing said wheel to be rotated selectively in opposite directions thereby to move said cam member toward and away from said shaft to vary the displacement of said piston during operation of the respirator, and means independent of the last-named means for varying the speed of rotation of said shaft during operation of the respirator.

7. In a respirator, a pump including a reciprocable piston and means for varying the rate of reciprocation and the displacement of said piston, said means comprising a rotatable drive shaft, an elongate hollow crank arm secured to said shaft transversely thereof, said arm having a longitudinal slot in the wall thereof, a cam member slidably mounted in said crank arm for movement radially of said shaft, said cam member including an extension projecting axially through said slot for retaining said cam member against rotation relative to said arm, said extension being connected to said piston for reciprocating the same, a rotatable screw journaled in said arm and threaded through said cam member for moving the same relative to said arm, a drive wheel connected to said screw outwardly of one end of said arm and orbiting about said shaft upon rotation of said shaft, a pair of arcuate members conforming to and disposed to opposite sides of the orbital path of movement of said wheel, said arcuate members being spaced apart a distance greater than the diameter of said wheel and normally being positioned to accommodate free passage therebetween of said wheel, means for selectively moving said arcuate members into the path of orbital movement of said wheel for causing said wheel to be rotated selectively in opposite directions

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thereby to move said cam member toward and away from said shaft during operation of the respirator to vary the displacement of said piston and the volume of respiration, a motor and variable speed transmission for rotating said shaft, and means on said transmission for varying the speed of rotation of said shaft during operation of the respirator thereby to vary the rate of respiration.

8. In a respirator, the combination of a pump having an inlet and an outlet, a drive for said pump, a pressure relief valve associated with the pump for venting the same of excessive pressure, an inhalation-exhalation valve having an entrance and an outlet, a tracheostomy tube connected to said valve outlet having its free end adapted for insertion into a patient's trachea, outlet conduit means extending from the pump outlet to the entrance of said inhalation-exhalation valve, humidifying means adjacent the pump outlet for adding moisture to the air pumped through the outlet conduit means to the inhalation-exhalation valve, and means in the outlet conduit means adjacent to the inhalation-exhalation valve entrance for escape of moisture condensing from the moistened air in said conduit means comprising a collection area for said moisture located below said entrance and a port establishing communication between said collection area and the exterior through which moisture collecting in said collection area is discharged whereby the patient is protected against having an excessive supply of moisture delivered to him by operation of the pump.

9. In a respirator, a pump including a cylinder having an end wall and a piston reciprocable in said cylinder toward and away from said wall, means for reciprocating said piston, said cylinder including an inlet and an outlet each communicating with the space between said piston and said wall, an aperture through said wall, a hand operated pump secured to the side of said wall opposite said piston, said hand pump communicating with said aperture and having as its inlet and its outlet the said inlet and outlet of the first-named pump, and means releasably holding said hand pump in an inoperative position.

10. In a respirator, a pump including a cylinder having an end wall and a piston reciprocable in said cylinder toward and away from said end wall, means for reciprocating said piston, said cylinder including an inlet and an outlet each communicating with the space between said piston and said end wall, an aperture through said end wall, a bellows on the exterior of said wall in surrounding relation to said aperture and having as its inlet and its outlet the said inlet and outlet of said pump, means for operating said bellows, means for holding the bellows in inoperative position, and a valve carried by said bellows disposed in closing relation with said aperture upon disposition of the bellows in said inoperative position.

11. In a respirator, a casing including spaced side walls and an end wall movable relative to said side walls and adapted to be latched in a fixed enclosing position, a pump within said casing including a cylinder having an end wall disposed adjacent said end wall of said casing, a piston reciprocable in said cylinder to the side of the cylinder end wall opposite said casing end wall, means for reciprocating said piston, inlet and outlet ports in said cylinder end wall, an aperture through said cylinder end wall, a bellows disposed between and secured to said end walls in surrounding relation to said aperture, and a valve member carried by said casing end wall within said bellows, said valve member closing said aperture when said casing end wall is latched in said fixed position and being spaced from said cylinder end wall and said aperture when said casing end wall is unlatched, said casing end wall being reciprocable for constituting said bellows, a hand pump having as its inlet and its outlet the said inlet and outlet of said pump.

12. An exhalation valve for respirators comprising a valve body having a vertically disposed bore provided with an inlet adjacent its lower end for connection with

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the respirator, a first outlet to atmosphere above said inlet and a second outlet disposed between the inlet and said first outlet for connection with the patient, a first valve seat over said inlet and below said second outlet, a second valve seat between said outlets and aligned with said first valve seat, and a valve member freely movable between said seats adapted for alternately closing said inlet and opening said first outlet on the suction stroke of the respirator under the pull of gravity and to open said inlet and close said first outlet on the pressure stroke of the respirator so as to intermittently supply fluid under positive pressure from the respirator to the patient and in the intervals between to vent the patient to atmosphere.

13. An exhalation valve as set forth in claim 12, including means for varying the responsiveness of said valve member to the pressure pulsations of the respirator thereby to control the respiration of the patient.

14. In a respirator, a variable displacement piston pump having an inlet and an outlet, variable speed drive means for said pump, a one-way check valve in the inlet of said pump, an exhalation valve spaced from said pump and located adjacent the patient, said exhalation valve comprising a valve body having a first inlet, a second outlet to atmosphere and an outlet disposed between the inlet and said first outlet for connection with the patient, a first valve seat between said inlet and second outlet, a second valve seat between said outlets, and a valve member movable between said seats, a conduit extending from the outlet of the pump to the inlet of said exhalation valve, said valve member being responsive to the pressure pulsations produced by said pump for movement alternately from the first valve seat to the second valve seat and from the second seat back to the first seat thereby to control alternate supply of fluid from the pump to the patient and venting of the patient to atmosphere, means for varying the displacement of said pump for controlling the volume of respiratory fluid, means for varying the speed of said drive means for controlling the rate of respiration, and means for varying the responsiveness of said valve member to the pressure pulsations produced by said pump for controlling the pressure profile of the respiratory cycle.

15. In a respirator, a casing including side walls and an end wall hingedly connected to one of said side walls and adapted for latching engagement with the other side wall, a pump mounted in said casing longitudinally thereof, said pump including a cylinder having an end wall disposed adjacent the end wall of said casing, a piston reciprocable in said cylinder to the side of the cylinder end wall opposite the casing end wall, a piston rod extending from said piston out the opposite end of said cylinder, a motor and variable speed transmission mounted in said casing adjacent said cylinder and including an output shaft extending transversely of said piston rod, an elongate crank arm secured to said shaft transversely thereof, a cam member slidably but non-rotatably mounted on said crank arm for movement radially of said shaft and connected to said piston rod for reciprocating the piston, a rotary drive member journaled on said arm and operatively connected to said cam member for moving the same relative to said arm, a drive wheel connected to said drive member and orbiting about said shaft upon rotation of said shaft, a pair of arcuate members conforming to and disposed to opposite sides of the orbital path of movement of said wheel, means for selectively moving said arcuate members into the path of orbital movement of said wheel for causing said wheel to be rotated selectively in opposite directions thereby to move said cam member toward and away from said shaft during operation of the respirator to vary the displacement of said piston and thereby the volume of respiratory fluid, means independent of the last-named means for varying the speed of rotation of said shaft during operation of the respirator to vary the rate of respiration, said pump including an inlet and an outlet communicating with the space between said piston and the end wall of said cylinder, an aperture through said cylinder end

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wall, a bellows disposed between and secured to said end walls in surrounding relation to said aperture, a valve member carried by said casing end wall within said bellows, said valve member closing said aperture when said casing end wall is latched to said other side wall, said casing end wall being oscillatable about its hinged connection for constituting said bellows, a hand pump having as its inlet and its outlet the said inlet and outlet of said pump, a one-way check valve in the inlet of said pump, an exhalation valve spaced from said pump and located adjacent the patient, said exhalation valve including an inlet, an outlet to atmosphere, an outlet disposed between the inlet and said outlet to atmosphere for connection with the patient, a valve seat between said inlet and the outlet to the patient, a valve seat between said outlets, and a valve member movable between said seats, a conduit extending from the outlet of the humidifier to the inlet of said exhalation valve, the valve member of said exhalation valve being responsive to the pressure pulsations produced by said pump for movement alternatively between the first-named valve seat and the second-named valve seat thereby to control alternate supply of fluid from the pump to the patient and venting of the patient to atmosphere for controlling the pressure profile of the respiratory cycle.

16. An exhalator valve for controlling the pressure profile of gas delivered to a patient from a respirator pump which delivers a positive pressure greater than atmosphere on its compression stroke and a negative pressure less than atmosphere on its suction stroke, said valve comprising a dismountable and readily cleanable body having a vertically disposed valve chamber provided with an inlet adjacent its lower end for connection to the respirator pump, an outlet in the wall of said chamber above said inlet for connection to the patient and a port spaced above said outlet and venting to the atmosphere, a pair of vertically spaced valve seats in said chamber, the lower one being below the outlet and above the inlet and the upper valve seat being above the outlet and below the port, and a gravitally responsive valve closure body freely movable in said chamber between said two valve seats, said valve closure body resting on the lower valve seat on the suction stroke of the respirator pump so as to vent the patient to atmosphere through said port, being raised off said valve seat past the outlet to the upper valve seat under the posi-

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tive pressure of the respirator pump on its compression stroke to direct fluid under positive pressure to the patient and close said port, and being returned to the first valve seat past said outlet under the pull of gravity on cessation of said compression stroke, said valve member being of a weight to introduce a time lag between its opening of the inlet to the outlet and initiation of the compression stroke of the respirator pump and to rapidly close the inlet on cessation of said compression stroke whereby to produce a fluctuating positive respiration to the patient minimally influenced by the suction stroke of the respirator pump.

17. An exhalator valve as claimed in claim 16 having a liquid collection chamber disposed between the inlet and the first valve seat, and means communicating with said chamber for discharging liquid from said chamber to prevent accumulation thereof.

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RICHARD A. GAUDET, *Primary Examiner.*

HAROLD B. WHITMORE, *Examiner.*