

Aug. 6, 1968

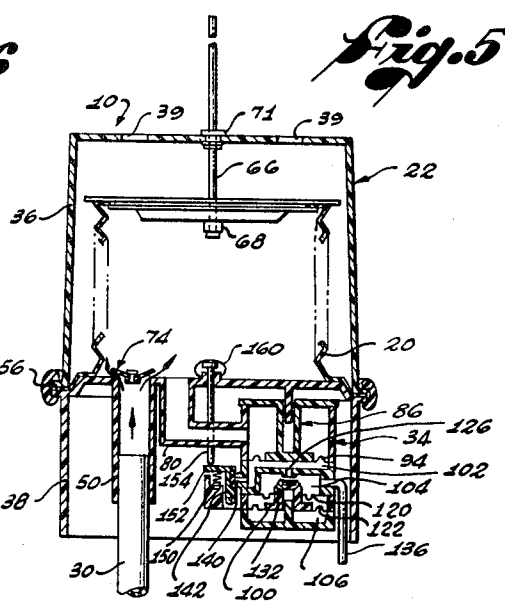
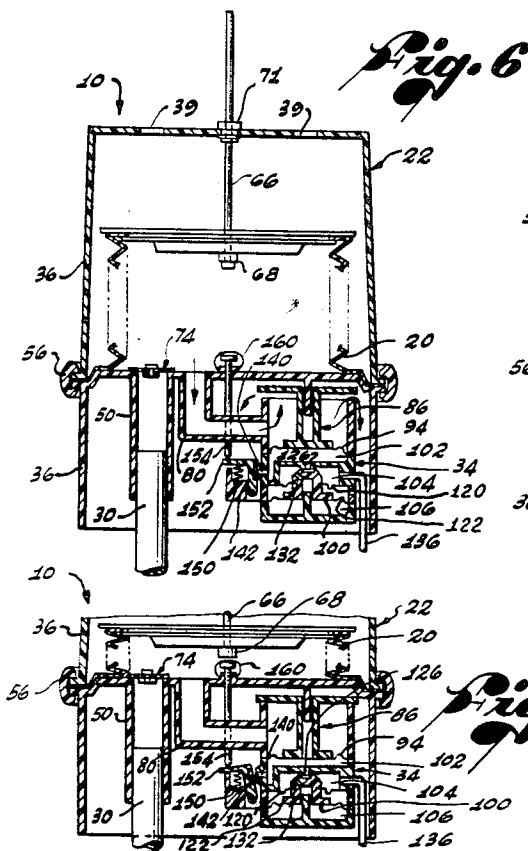
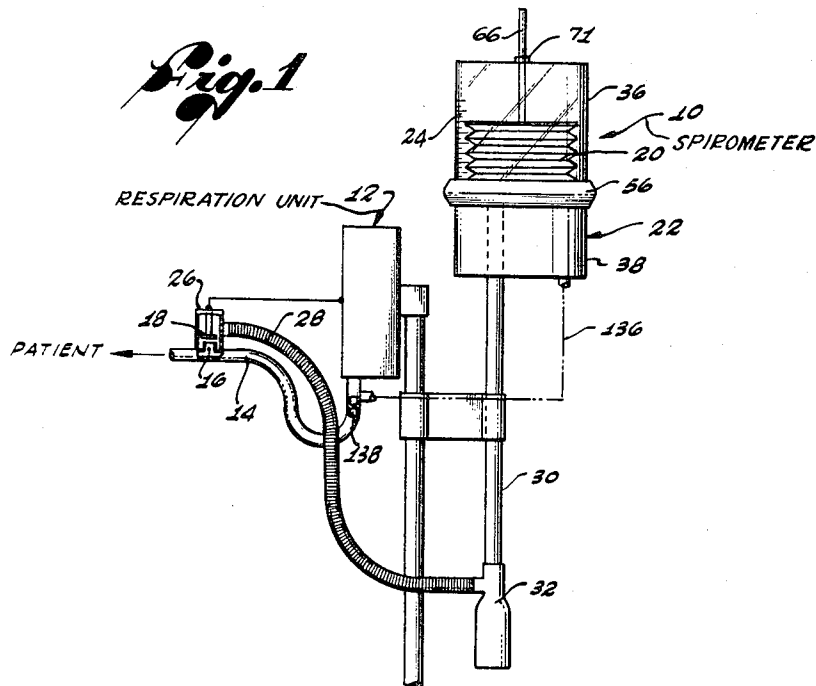
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3,395,699

SPIROMETER

Filed April 28, 1965

3 Sheets-Sheet 1



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SPIROMETER

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3 Sheets-Sheet 2

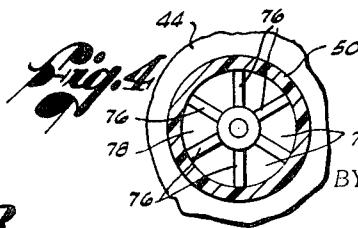
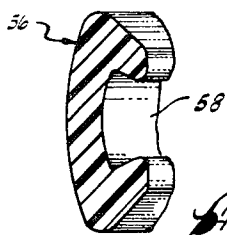
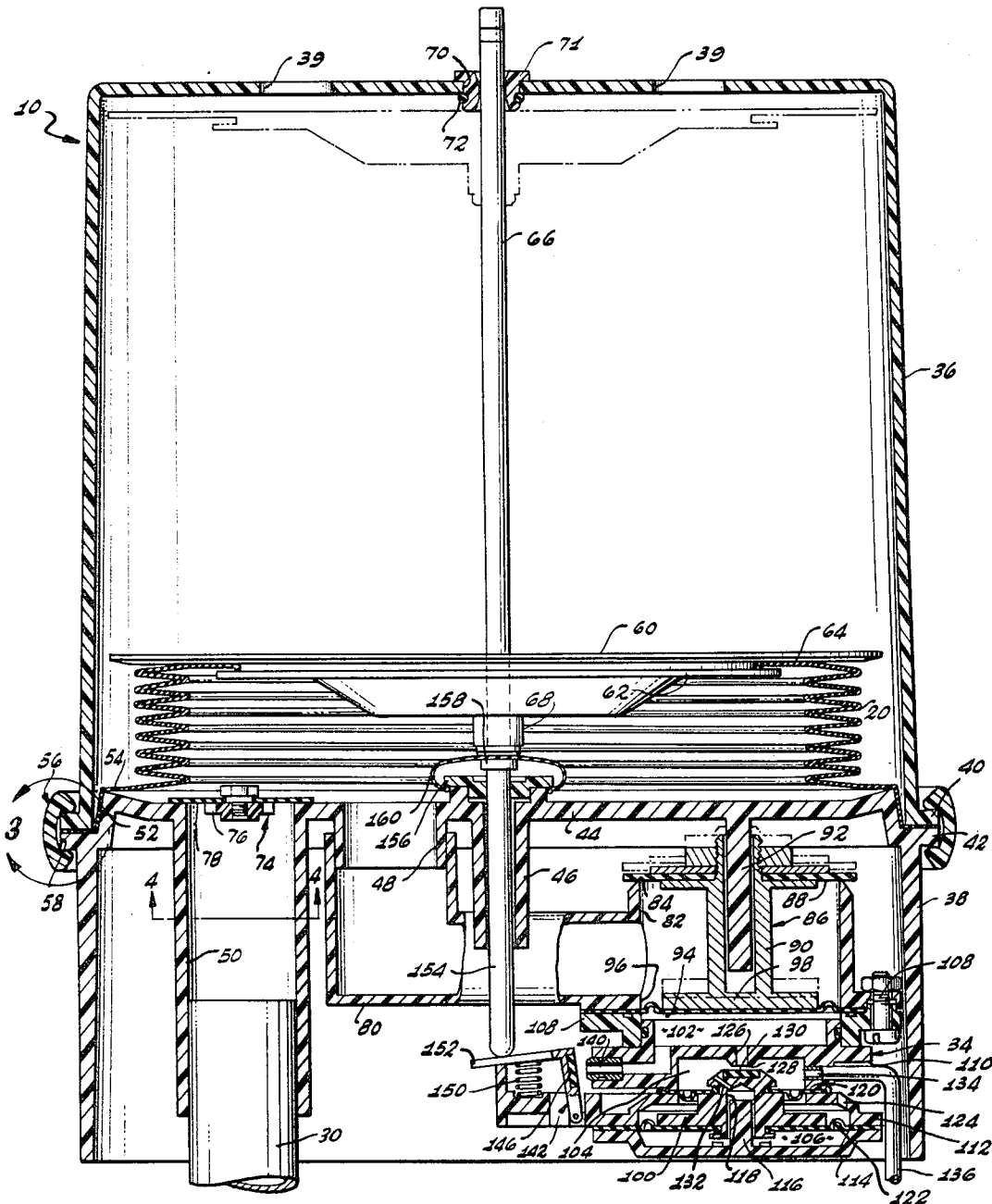


Fig. 2

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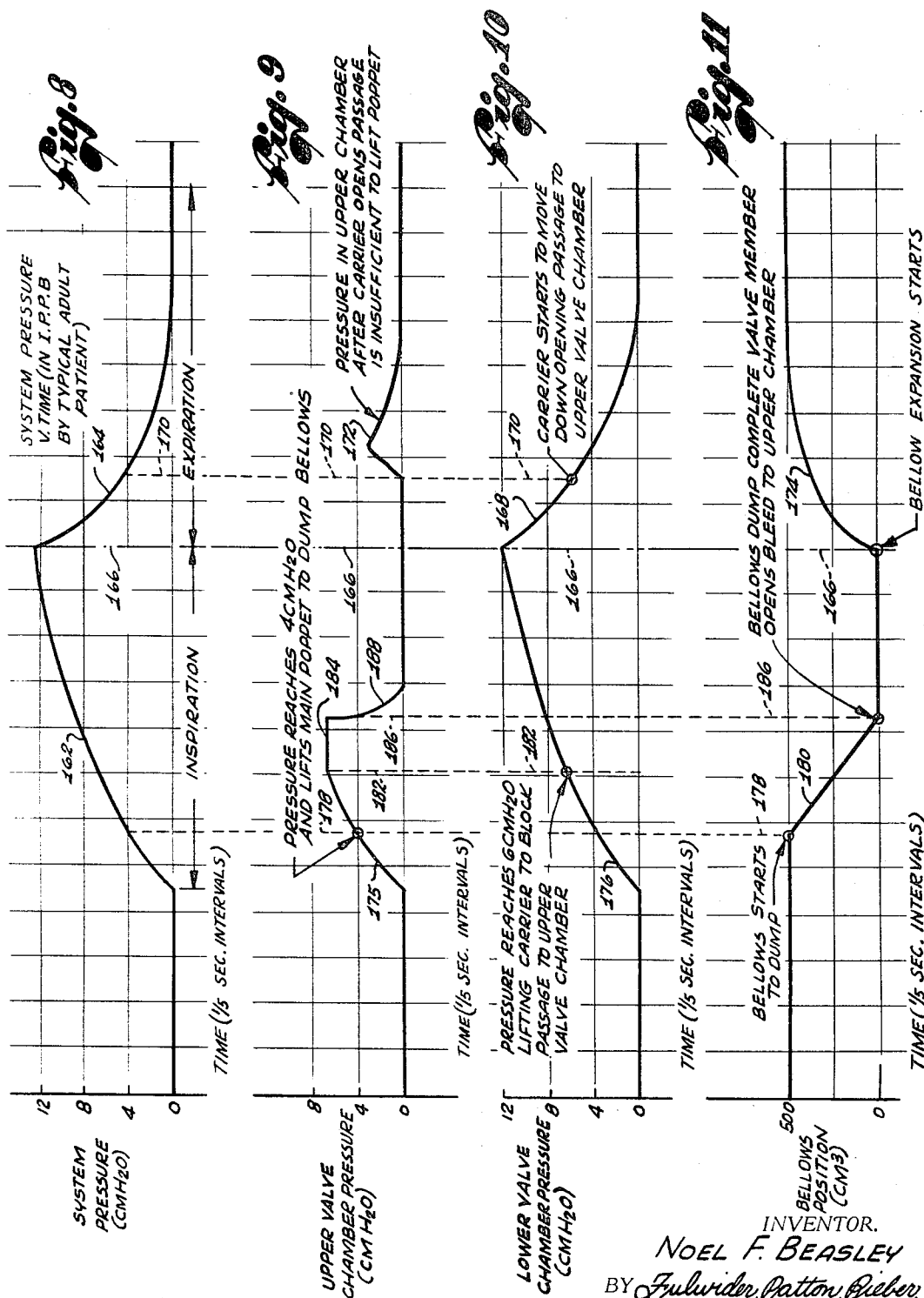
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SPIROMETER

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3 Sheets-Sheet 3



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1

3,395,699

SPIROMETER

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13 Claims. (Cl. 128—2.08)

ABSTRACT OF THE DISCLOSURE

A spirometer continuously operable to monitor the tidal volume of respired gas. An expansible-contractible bellows mounted within a transparent viewing dome receives gas expired by a patient during the expiratory phase of a breathing cycle and expands to afford a visual indication of tidal volume. Valve means, responsive to the positive pressure of gas delivered to the patient during the inspiratory phase of the subsequent breathing cycle, opens an outlet to the atmosphere to permit the bellows to return to its contracted condition during that phase. Upon such return, the valve means is automatically closed to block such outlet, thereby conditioning the bellows for receipt of expired gas during the expiratory phase that follows.

This invention relates to respiration apparatus and, more particularly, to an improved spirometer or device for measuring the volume of respired gas.

A spirometer is especially useful in conjunction with ventilation of a patient where, by way of example, paralysis of the lung-thorax system, which enables a patient to breathe spontaneously, is present. Such a device is also useful in administering intermittent positive pressure breathing therapy. In the first instance, a patient's life may depend on artificial ventilation and, thus, quite obviously, it is of utmost importance to know whether ample gas is being supplied to the lungs. Similarly, with intermittent positive pressure breathing therapy, the effectiveness of the therapy depends upon a sufficient volume of gas being delivered to the lungs and, hence, it is of importance to have reliable volumetric measurements.

Determination of the volume of respired gas, commonly known as tidal volume, can be accomplished by measuring the volume of gas supplied by the delivery apparatus to the patient during the inspiration phase of the breathing cycle or, alternately, measuring the volume of expired gas. Assuming there were no leaks in the delivery apparatus, in the patient's system or at the connection between the two, the measurements would be substantially identical. It is generally agreed, however, that it is preferable to measure the volume of expired gas. This is true for the reason that in practice leaks frequently occur, particularly between the delivery apparatus and the patient, as, for example, where the face mask presses against the face. Should this be the case, a measurement of the gas supplied by the delivery apparatus would not be an accurate indication of that actually supplied to the lungs. On the other hand, the measurement of the expired gas would afford a more reliable indication.

Problems have been encountered with spirometers heretofore available for measuring tidal volume of expired gas. Among these problems are that many of them are unreliable and prone to malfunction. Others are so complex and costly as to render their widespread use prohibitive. Moreover, an operational problem inherent in virtually all devices heretofore available for this purpose is that they do not continuously monitor the patient's respiration. That is, it is necessary to reset them after a single cycle of operation.

In view of the foregoing, it is a primary object of this

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invention to provide an improved spirometer which overcomes the aforementioned problems inherent in the devices of the prior art.

A more specific object is to provide an improved spirometer capable of effective use in continuously monitoring the tidal volume of expired gas.

Another object is to provide a spirometer of the type described which is durable and reliable in operation, and which affords an accurate visual indication of such volume.

A further object is to provide a spirometer of the type described which imposes no appreciable resistance to expiration and, accordingly, may be used effectively even with patients of low vitality.

A still further object of the invention is to provide an improved spirometer of the type described capable of accomplishing all of the foregoing objects, yet which is relatively simple in construction and capable of being manufactured at low cost.

These and other objects, features and advantages of the invention will be better understood by referring to the following detailed description taken in conjunction with the accompanying drawings in which:

FIGURE 1 is a semi-schematic view of a respiration system incorporating the spirometer of the invention;

FIGURE 2 is a vertical, medial section of the spirometer illustrated in FIGURE 1;

FIGURE 3 is a view on an enlarged scale of a portion of the annular cuff illustrated in the area encircled by the line 3 in FIGURE 2;

FIGURE 4 is a fragmentary sectional view taken along the line 4—4 of FIGURE 2;

FIGURE 5 is a semi-schematic view illustrating the condition of the spirometer during the terminal portion of the expiration phase of the breathing cycle;

FIGURE 6 is a view similar to FIGURE 5, in which the spirometer is shown in the position occupied during the initial portion of the inspiration phase of the breathing cycle;

FIGURE 7 is a view similar to FIGURES 5 and 6, showing the spirometer in the condition occupied during the terminal portion of the inspiration phase and at the start of the expiration phase; and

FIGURES 8 through 11 are curves illustrating certain aspects of typical operation of a respiration system incorporating the spirometer of the invention.

Referring to the drawings and, in particular, to FIGURE 1, numeral 10 designates the improved spirometer of the invention. It is shown as operatively connected in a system including a positive pressure respiration unit 12. The unit 12 may be of any suitable type, such as those currently marketed by Bennett Respiration Products, Inc., as Model PR-1, or as disclosed in my co-pending application Ser. No. 268,704 and entitled Respiration Apparatus. The construction of the respiration unit 12 forms no part of the present invention and, therefore, is not described herein in detail.

For present purposes, it is noted that the respiration unit 12 functions during an inspiration phase to supply a suitable gas to a patient through the main conduit 14 under a mild control pressure on the order of 10 to 60 centimeters of water. This is followed by a passive phase in which the pressure is rapidly released, preferably to about ambient pressure, to allow the patient to expire. In this latter or expiration phase, the patient expires through an outlet passage 16 in the main conduit 14. During the inspiration phase of the cycle, the outlet passage 16 is closed by an inflatable valve 18 supplied with positive pressure, by the unit 12, whereas during the expiration phase, the valve 18 is depressurized to open the outlet passage 16.

Expired gas is directed to the spirometer where it is collected in an expansible-contractable bellows 20 (FIGURES 1 and 2) to expand the same. The bellows 20 are mounted within a transparent viewing section or dome of a case 22, so as to afford a visual indication of tidal volume for that cycle. Volume is ascertained by observing the extent to which the bellows 20 rises between its lower and upper limit positions, illustrated in full in phantom lines, respectively, in FIGURE 2. Suitable index markings, such as those illustrated at 24 in FIGURE 1, are provided on the sidewall of the case 22 to enable a person to make an accurate quantitative determination.

Flow of gas from the outlet passage 16 to the spirometer takes place through a path including, in series, a manifold 26 disposed about the outlet passage 16 and the exhalation valve 18, a flexible hose 28, and an elongated and generally vertically arranged conduit 30. Preferably, removable moisture-collection trap 32 is provided at the low end of the conduit 30, so as to collect moisture that condenses and collects therein. As will be readily appreciated, the gas expired by a person contains substantial moisture, especially where a nebulizer or other similar accessory device is being used.

An important operational feature of the present spirometer is that it operates continuously to monitor the patient's breathing. That is, the gas expired during each breathing cycle is collected within the bellows 20 to expand them an extent corresponding to the volume expired. To accomplish this and still afford accurate readings, it will be understood that it is necessary that the bellows 20 dump and completely return to its lowermost position, illustrated in full lines in FIGURE 2, during the inspiration phase of the cycle. Furthermore, it is necessary that the outlet from the bellows be closed at the instant the expiration phase commences in order that the full volume of expired gas will be collected. Valve means 34 (FIG. 2) for accomplishing this important function are provided.

Tuning now to the detailed construction of the spirometer, as illustrated in FIGURE 2, it will be seen to include the case 22 mounting the bellows 20 and the valve means 34. The case 22 comprises a generally cylindrical member formed in separable upper and lower sections 36 and 38, the upper section serving as the transparent viewing dome and the lower section as a mounting frame for the valve means. The upper section 36 is generally closed at its upper end and open at its lower end, and for mounting purposes it is formed with an annular outturned flange 40 at its lower end. Venting of the compartment defined by the upper section is achieved by apertures 39 in its upper end wall.

The lower section 38 of the case has a like annular outturned flange 42 adjacent its upper end arranged to mate with the flange 40 for mounting purposes. Formed integrally with the sidewall of the lower section 38 at an orientation transverse of the axis of the case and at a location adjacent the flange 42 is a configured partition or wall 44. It, in turn, is formed centrally with a downwardly projecting sleeve 46 and at radially outwardly spaced locations, a downwardly projecting outlet and inlet couplings 48 and 50. The periphery of the partition 44 is shaped to provide a frusto-conical surface 52 that extends downwardly to and connects with the sidewall of the lower case section 38 adjacent the flange 42.

Preferably, the case 22, as well as the various other parts of the spirometer, including the valve means 34, are formed of a material which is strong, durable, corrosion-resistant and non-contaminating to the respired gas. Various plastics have been found to be well suited. Not only do they have the desired physical properties, but they are readily adapted to economical forming methods.

The bellows 20 are formed of a highly flexible and lightweight material in order to expand and contract readily in response to gas flow to and from its interior. Moreover, in order to insure that no appreciable back

pressure is imposed by the bellows 20, which would tend to restrict free expiration of the patient, the diameter of the bellows is large in relation to its range of vertical movement. Preferably, a pressure of less than one centimeter of water is sufficient to expand the bellows 20 to its upper limit position.

Mounting of the bellows 20 in the case 22 is conveniently accomplished by forming it with a radially outwardly extending flange 54 at its lower end. The flange is positioned down over the frusto-conical surface 52 on the partition and its marginal edge is interposed between the mating flanges 40 and 42 on the case sections. To insure a good gas-tight seal for the bellows, as well as to join the case sections securely together, an annular sealing ring or cuff 56 (FIGURE 3) is provided. The ring 56 is formed of a resilient, deformable material, such as rubber, and has an inwardly facing groove 58 that is arranged to receive in gripping engagement the mating flanges 40 and 42 of the case sections in the manner illustrated in FIGURE 2. Preferably, in order to further enhance the connection, the flanges 40 and 42 taper or progressively increase in thickness from inside out and the corresponding portions of the ring 56 are so shaped as to tightly grip and retain assembly with the flanges.

The upper end of the bellows 20 is closed by a disk-like member 60 formed with a circumferential groove 62. An inwardly directed flange 64 is received in tight-fitting relationship within the groove 62. The member 60, in turn, is press-fit on an elongated and vertically oriented guide rod 66 formed with a radial enlargement 68 at its lower end.

At its upper end wall, the upper section of the case is formed with a central bore 70 through which the guide rod 66 extends. To enhance the bearing engagement, a bearing sleeve 71 is secured in place in the bore 70 by any suitable means, as by the resilient ring 72. With this mounting arrangement, it will be appreciated that the guide rod 66 maintains the plates 60 and 62 and, hence, the upper end of the bellows, substantially horizontal during its vertical travel and insures that an accurate volumetric reading is afforded.

Flow of expiration gas to the interior of the bellows 20 is through the inlet coupling 50, which, in turn, is connected to the conduit 30. Disposed within the opening of the coupling 50 to the bellows 20 is a check valve 74, illustrated in FIGURES 2 and 4, which serves to permit flow to the bellows, but blocks flow in the opposite direction. The valve 74 is of any suitable type, and here comprises a spider-like frame 76 and a thin, flexible flapper or disk 78 disposed on the upper side thereof. Such a construction is preferred in order to minimize resistance to flow to the bellows.

Outlet flow from the bellows 20 to permit contraction is through the coupling 48 and a manifold 80 connected thereto, such flow being controlled by the valve means 34. Adjacent its outlet end, the manifold 80 is formed with an upwardly facing outlet port 82 with a valve seat 84 at its upper end. Closure of the port 82 is accomplished by means of a vertically movable poppet 86 arranged to make sealing engagement with the seat 84. The poppet 86 here comprises a sealing disk 88 carried by a flanged collar 90 and engageable with the seat. The collar 90 is centrally bored and vertically slidable on a cylindrically shaped guide post 92 projecting downwardly from the partition 44. Gravity serves normally to bias the poppet 86 downwardly into sealing engagement with the seat 84 to block flow from the bellows 20.

For purposes of actuating the poppet 86 upwardly to open the outlet port 82 and thereby permit the bellows to contract, actuating means including a diaphragm 94 are provided. As may be seen in FIGURE 2, the diaphragm 94 is disposed in sealed relationship in a lower opening 96 in the manifold 80 at a location below the poppet 86, and engages a horizontal plate 98 formed on the lower end of the collar 90. Thus, it will be seen that as the di-

aphragm 94 is urged upwardly, the poppet 86 is caused to move off its seat 84 to open the outlet port 82. In order that poppet 86 may move upwardly off the seat independently of the diaphragm 94 for reasons that will be explained below, it is unattached with respect to the plate 98.

Actuation of this diaphragm 94 to so move the poppet 86 is accomplished with a pneumatic valving system including a plurality of connected chambers and a vertically movable carrier 100. These chambers include an upper chamber 102 of which the diaphragm 94 serves as an upper, movable wall, a central chamber 104, and a lower chamber 106, the latter chambers 104 and 106 being separated by the carrier 100. The chambers are formed by a plurality of suitable configured parts including an annular collar 108 secured to the underside of the manifold 80 as by nut-bolt assemblies 109, a flanged plate 110 secured to the collar and defining a wall between the upper and central chambers 102 and 104, an intermediate collar 112 secured to the underside of the plate 110, and a base plate 114 secured to the collar 112. These various collars and plates are secured to one another by any suitable means, as by a plurality of screws (not shown).

The carrier 100 comprises a disk-like member disposed between the intermediate collar 112 and base plate 114 and cooperable therewith to serve as a movable wall between the central and lower chambers 104 and 106. Support of the carrier against tilting during its vertical movement is afforded by an upwardly projecting guide post 116 on the base plate 114 and associated bore 118 in the carrier. Mounting of the carrier 100 is achieved by a pair of horizontally arranged and vertically spaced diaphragms 120 and 122. Each diaphragm is secured in sealed relationship adjacent its inner periphery to the carrier. The outer periphery of the upper diaphragm 120 is interposed between the engaging surfaces of the plate 110 and collar 112 and, similarly, the outer periphery of the diaphragm 122 is interposed between engaging surfaces of the collar 112 and plate 114. Venting of the annular space between the diaphragms is achieved by a bleed passage 124 in the collar 112.

It is to be noted that the effective area of the lower chamber 106 acting on the lower side of the carrier 100, is somewhat greater than the effective area of the central chamber 104 acting on its upper side. Thus, when the imbalance of pressure in the chambers 104 and 106 is such as to overcome the gravity force urging the carrier 100 downwardly, the carrier moves upwardly.

A passage 126 is provided between the central and upper chambers 104 and 102 at a location centrally thereof. Moreover, the passage 126 has a downwardly facing valve seat 128 at its lower end which is engaged by the carrier 100 when the latter is moved upwardly so as to block the passage 126. Preferably, to enhance the seal, a resilient, deformable pad 130 is press-fit in a groove in the upper end of the carrier 100. Communication of the central and lower valve chambers 104 and 106 is through a path including a restricted passage 132 through the carrier 100 communicating with the bore 118 and, hence, with the lower chamber 106. The passage 132 is sized so that with the pressures encountered in use, a time delay occurs once pressure is supplied to the central chamber 104 before the carrier 100 moves upwardly to seal off the upper chamber 102. This is to insure that the poppet is fully opened before the upper chamber 102 is sealed off by the carrier.

A pressure signal for actuating the valve means 34 is supplied to the central chamber 104 through a lateral passage 134 in the plate 110, such passage being in communication with the main conduit 14 of the respiration unit 12 through a conduit 136, as illustrated in FIGURE 1, as may be seen in that figure, the conduit 14 is restricted downstream of the junction with the conduit 136

as at 138. This is to insure that ample pressure signal is supplied to the valve means 34 to properly actuate the same under all operating conditions.

In order to relieve pressure in the upper valve chamber 102 to cause the poppet 86 to close, an outlet passage 140 is provided through the plate 110, such passage normally being blocked by a pivotal valve member 142 engageable with a valve seat at the exit of the passage. As with the carrier 100, a resilient, deformable sealing pad 146 is press-fit in corresponding groove in the valve member 142 to enhance the seal. Closure of the valve member 142 is accomplished by a compression spring 150 disposed between a lateral extension on the collar 112 and a horizontal actuating arm 152 on the valve member 142.

Actuation of the valve member 142 to open the outlet passage 140 is by a plunger 154 slidably disposed in the centrally located sleeve 46 in the partition 44. A bearing flange 156 is press-fit in a projection aligned with the upper end of the sleeve 46, so as to engage in bearing contact with the circumference of the plunger 154. The latter is formed with a flanged head 158 at its upper end and engageable at its lower end with the arm 152 of the valve member 142. To insure against the escape of gas through the sleeve 46, a highly pliable sealing cup 160 is disposed around the flange 156 to seal off the interior of the bellows.

As may be seen in FIGURE 2, the radial enlargement 68 on the rod 66 carried by the bellows 20, engages the head 158 of the plunger 154 (with the sealing cup 160 therebetween) in its lowermost operating position, so as to urge the plunger downwardly and actuate the valve member. Conversely, when the bellows 20 fill and move upwardly away from the plunger 154, the spring 150 acts to pivot the valve member into closing relationship with the seat 144, urging the plunger upwardly. Accordingly, provided the bellows 20 is in other than its lowermost operating position, the outlet passage 140 from the upper chamber is blocked.

Operation

With the above-described structure in mind, it is believed that the invention can be best understood by tracing through a sequence of typical operation. Prior to use, the bellows 20 and various movable parts of the valve means 34 occupy the relative positions illustrated in full lines in FIGURE 2. Briefly recapitulating, the bellows 20 are in a fully contracted condition, the poppet 86 is seated to close the bellows outlet, the valve member 142 is open, and the carrier 100 is in a neutral position whereby the central and upper chambers 104 and 102 are in communication through the passage 126.

It is assumed for purposes of description that the respiration unit 12 has been suitably adjusted to deliver gas to the patient under a pre-set maximum control pressure of 12 centimeters of water. During operation, the system pressure rises and falls in accordance with the curve of FIGURE 8. As previously noted, FIGURE 8 depicts a typical breathing cycle for an adult patient and is used herein for illustrative purposes. The rising portion 162 of the curve corresponds to the inspiration phase of the breathing cycle, while the remaining portion 164 to the right of the vertical dot-dash line 166 corresponds to the relatively longer expiration phase of that cycle. As illustrated, system pressure is maximum (here 12 centimeters of water) at the termination of inspiration.

It is noted in passing that the spirometer 10 will function properly irrespective of whether operation commences with the inspiration or expiration phase of the cycle. However, the operation during the initial cycle is slightly different than operation during subsequent cycles. Assuming for descriptive purposes that inspiration first occurs, the respiration unit 12, of course, functions to deliver gas to the patient in accordance with the portion 162 of the curve of FIGURE 8. As positive pressure de-

velops in the system, a pressure signal will be transmitted through the conduit 136 to the central chamber 104 of the valve means. Flow of gas to the bellows 20 from the main conduit 14 is blocked by the exhalation valve 18. Since the carrier 100 is in a neutral position, pressurized gas will flow through the passage 126 into the upper chamber 102, which during this initial inspiration phase is vented to the exterior through the open bleed passage 140. Because of the relative sizes of the conduits and passages, back pressure will develop in the central and upper chambers 104 and 102 and gas will flow to the lower chamber through the restricted passage 132.

After a short time delay, the imbalance of pressures in the chambers 104 and 106 acting on the opposite sides of the carrier 100 is such as to overcome the gravity force urging it downwardly. This results in the carrier being moved upwardly into sealing relationship with the seat 128 to block the passage 126 in the manner shown in FIGURE 7. Once the carrier has moved into such sealing relationship, pressure continues to build up in the central and lower chambers 104 and 106 with the rising system pressure, here to the maximum of twelve centimeters of water. At the termination of the initial inspiration phase, the bellows 20 and the elements of the valve means 34 occupy the positions illustrated in FIGURE 7.

It is observed that all subsequent operations of the spirometer of the invention are in accord with a regular pattern. That is, operation during each successive inspiration and expiration phase is the same as during the preceding one. Following the initial inspiration, the patient commences breathing out through the port 16 in the main conduit 14, the exhalation valve being depressurized, whereupon the system pressure rapidly drops off, as indicated by the portion 164 of the curve in FIGURE 8. Expired gas is collected by the manifold 26 and passes through the hose 28 and conduit 30 and eventually into the bellows 20 through the check valve 74. The bellows, being sealed from the exterior, commence upward expansion in the manner shown in FIGURE 5 and illustrated by the plot in FIGURE 11. After the bellows have moved up a short distance, sufficient to release the plunger 154, the valve member 142 pivots to a closed position under the influence of the spring 150. Since the carrier 100 is in sealing relationship with the seat 128 blocking flow through the passage 126, the upper chamber 102 is sealed off in an unpressurized condition. Therefore, the poppet 86 remains seated.

Bellows expansion continues as system pressure along with pressure in the central lower valve chambers 104 and 106 rapidly decrease, as indicated by the portions 164 and 168 of the curves in FIGURES 8 and 10. Backflow through the conduit 136 permits the pressure in the valve chambers 104 and 106 to drop off. Comparing the corresponding portions 164 and 168 of the curves in FIGURES 8 and 10, it will be seen that the latter is somewhat flatter, this being because of the effect of the restricted passage 132 between the chambers 104 and 106.

After a considerable drop in system pressure during expiration, the pressure in the lower chamber is insufficient to maintain the carrier in its upper position. This occurs at the position indicated by the vertical dotted line 170 in FIGURES 8 through 10 when the pressure is approximately six centimeters of water. Accordingly, the carrier 100 is released and moves downwardly to open the passage 126 to the upper chamber. Flow of gas occurs into the upper chamber causing the pressure therein to rise slightly, as indicated by the portion 172 of the curve in FIGURE 9. However, the system pressure has, as may be seen in FIGURE 8, dropped to such an extent that it is not of a sufficient magnitude to open the poppet 86. The various parts of the spirometer occupy the positions illustrated in FIGURE 5 at this terminal portion of the expiration phase of operation.

The expiration phase continues in this manner until the initiation of the next inspiration phase. A character-

istic of a normal breathing cycle is that the expiration phase continues for a significant time period once outflow of gas is completed in what is sometimes termed the expiratory pause. During this expiratory pause, back flow of gas from the bellows 20 to the patient or loss of gas in the event of a leak is, of course, prevented by the check valve 74. The bellows remain substantially stationary in an expanded condition, as depicted by the portion 174 of the curve of FIGURE 11. Therefore, an observer has ample time to ascertain the bellows position and, with the aid of the index markings 24, accurately read tidal volume for that cycle.

By virtue of the bellows construction, there is no appreciable restraint to the patient's free expiration. Moreover, in the event the bellows should be restrained against the expansion for any reason, as by expanding upwardly to its upper limit position illustrated in phantom lines in FIGURE 2, the valve means 34 incorporates a safety feature to relieve pressure. As previously noted, the poppet 86 rests on the diaphragm 94, but in unattached relationship. Accordingly, when the pressure within the manifold 80 acting on the underside of the poppet 86 exceeds the force of gravity, it is urged up off its seat 84 to relieve the pressure. It has been found advantageous to weigh the poppet 86, so that relief takes place when the pressure within the bellows exceeds two centimeters of water.

This relief pressure is, of course, greater than the pressure (one centimeter of water) required to expand the bellows to its upper limit position. Accordingly, it will be understood that if for any reason the bellows 20 are expanded to the upper limit position, whereby further expansion is blocked, pressure might then build up. Should it exceed the predetermined relief pressure (two centimeters of water), venting of the bellows takes place by virtue of the poppet being lifted off its seat. Venting continues until the bellows pressure drops below the relief pressure, whereupon the poppet reseats itself. It is observed in passing that the bellows 20 are sized so that expansion to such upper limit position does not occur in normal operation.

Continuing with the operation of the spirometer, following the full expiration phase, the next inspiration phase is initiated. At the outset, the bellows 20 and the valve means 34 are in the conditions illustrated in FIGURE 5. As the system pressure increases, corresponding pressure increases occur in the upper and lower valve chambers 102 and 106, as indicated by the portions 175 and 176 of the curves of FIGURES 9 and 10, respectively. A pressure of approximately four centimeters of water in the upper valve chamber, indicated by the position of the vertical dotted line 178 (FIGURE 9), is sufficient to overcome the gravity force acting on the poppet 86 and the resilience of the diaphragm, with the result that the poppet 86 is urged up off its seat. This causes the bellows 20 to commence dumping, as indicated by the portion 180 of the curve of FIGURE 11.

A short time interval following the opening of the poppet 86, pressure in the lower chamber 106 reaches a level of approximately six centimeters of water, corresponding to the position of the vertical dotted line 182 in FIGURE 10, which pressure is sufficient to urge it upwardly to block the passage 126. FIGURE 6 shows the spirometer after this has occurred. Pressure is then trapped within an upper chamber 102, as may be seen from the horizontal portion 184 of the curve of FIGURE 9, and serves to maintain the poppet 86 unseated. The poppet-actuating means, including the chamber 102 and diaphragm 94, are thereby conditioned to be deactivated. The bellows 20 continue to contract with the valve means 34 in the condition of FIGURE 6, and the inspiration phase of the breathing cycle continues in the manner shown by the portion 162 of the curve of FIGURE 8.

When the bellows have contracted to their lower limit position, the valve member 142 is actuated to vent the upper chamber 102, causing the poppet 86 to return to

its seated position, as shown in FIGURE 7. This occurs at the position of the vertical dotted line 186 in FIGURES 9 and 11. Venting of the chamber 102 is depicted by the portion 188 of the curve of FIGURE 9. In effect, this results in the poppet-actuating means being deactivated and the spirometer is thereby placed in readiness for the next expiration phase of operation.

Subsequent operation occurs in an identical manner to that just described with the spirometer cycling in accordance with breathing phases of the patient. By virtue of this mode of operation, the patient's breathing is continuously monitored. A visual indication of the tidal volume of each breathing cycle is afforded. Moreover, this is advantageously accomplished without impairing the breathing function and without need of manual resetting or the like.

While one embodiment of the invention has been illustrated and described in considerable detail, it will be understood that this is only by way of illustration and that various changes in the details of construction of the arrangement of the various parts may be made without departing from the spirit and scope of the invention.

I claim:

1. A spirometer, comprising:

a case;

expandable-contractable bellows supported on said case and having an inlet and an outlet, said bellows being arranged to receive gas through said inlet and expel it through said outlet during movement between expanded and contracted conditions;

first valve means in said inlet permitting flow to said bellows, but blocking flow in the opposite direction;

second valve means for closing said outlet, said second valve means being movable to an open position to permit gas to be expelled from said bellows;

pneumatic actuating means responsive to a pressure signal for moving said second valve means to its open position; and

means responsive to said bellows moving to its contracted condition for causing said second valve means to move to its closed position.

2. A spirometer, comprising:

a case;

expandable-contractable bellows supported on said case and having an inlet and an outlet, said bellows being arranged to receive gas through said inlet and expel it through said outlet during movement between expanded and contracted conditions;

valve means normally closing said outlet, and being movable to an open position, so as to permit gas to be expelled from said bellows;

actuating means for urging said valve means to its open position;

conditioning means operable a predetermined time period after movement of said valve means to its open position for conditioning said actuating means to be deactivated; and

means responsive to movement of said bellows to its contracted condition for deactivating said so conditioned actuating means.

3. A spirometer, comprising:

a case;

an expandable-contractable bellows supported on said case and having inlet-outlet means and arranged to receive gas and expel it therethrough during movement between expanded and contracted conditions;

valve means normally preventing gas from being expelled from said bellows and being movable to an open position to permit the same;

means forming a pressure chamber for receiving a pressure signal from an external source;

actual means including a pressure-sensitive element disposed in said chamber for moving said valve means to its open position;

conditioning means operable a predetermined time period after movement of said valve means to its open position for blocking receipt of such pressure signal by said chamber; and

means responsive to movement of said bellows to its contracted condition for venting said chamber.

4. A spirometer, comprising:

a case;

expandable-contractable bellows supported on said case and having an inlet and an outlet, said bellows being arranged to receive gas through said inlet and expel it through said outlet during movement between extended and contracted conditions;

first valve means in said inlet permitting flow to said bellows, but blocking flow in the opposite direction;

second valve means for closing said outlet, said second valve means being movable to an open position to permit gas to be expelled from said bellows;

means forming a plurality of valve chambers including central, upper and lower chambers, there being a passage between said central and upper chambers, a relatively restricted passage between said central and lower chambers, and a vent passage from said upper chamber;

a movable carrier forming a common wall between said central and lower chambers, the effective area of said lower chamber acting on the lower side of said carrier being greater than the effective area of said central chamber acting on the upper side of said carrier, said carrier moving to an upper limit position responsive to a pressure increase in said lower chamber;

means responsive to movement of said carrier to its upper limit position for blocking the passage between said central and upper chambers;

pressure-sensitive means in said first chamber for moving said second valve means to its open position; and third valve means normally closing said vent passage and actuated to an open position upon movement of said bellows to its contracted condition.

5. A spirometer, comprising:

a case formed as a pair of separable sections including an upper transparent viewing section and a lower mounting section;

a pair of continuous mounting flanges formed, one each, adjacent the peripheries of said case sections and arranged to mate with one another when said sections are assembled;

an expandable-contractable bellows disposed in the viewing section of said case and formed at one of its ends with a radially projecting flange interposed in sealed relationship between said flanges and closed at its opposite end, said bellows having an inlet-outlet means for receiving gas and expelling therethrough during movement between expanded and contracted conditions;

valve means in said inlet-outlet means for controlling flow of gas therethrough; and

removable means engaging said flanges to retain said case sections so assembled.

6. The subject matter of claim 5 wherein said removable means includes a continuous cuff formed of a resilient, deformable material and arranged to engage said flanges in gripping relationship.

7. The subject matter of claim 5 wherein said second valve means is responsive to pressure in said bellows of a magnitude greater than a predetermined maximum to move to its open position.

8. The subject matter of claim 5 wherein the diameter of said bellows is large in relation to its range of travel between its contracted and expanded conditions.

9. A spirometer, comprising:

a case formed with a transparent viewing section with a hollow interior that is substantially closed from the exterior;

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means on said case forming a vent passage from the interior of said viewing section;

an expansible-contractable bellows with inlet-outlet means disposed in the interior of said viewing section, said bellows being arranged so that at least a portion thereof is visible from the exterior during expansion; and

valve means in said inlet-outlet means for controlling flow of gas therethrough.

10. A spirometer, comprising:

a case;

an expansible-contractable bellows disposed within said case with at least a portion thereof visible from the exterior, said bellows having inlet-outlet means for receiving and expelling gas therethrough during expansion and contraction; and

valve means in said inlet-outlet means for controlling flow of gas therethrough, said valve means venting said bellows to the exterior when the pressure therein reaches a predetermined level greater than that required to produce expansion thereof.

11. In a respiration system including a positive pressure respiration unit for delivering pressurized gas to a patient through a main conduit during an inspiration phase followed by an expiration phase during which the patient is permitted to expire through valved exhalation passage; a spirometer, comprising:

a case;

expansible-contractable bellows supported on said case and having an inlet coupled to said exhalation passage and an outlet, said bellows being movable between expanded and contracted conditions and arranged to receive gas expired by the patient through said inlet during the expiration phase to expand and to expel it through said outlet during the inspiration phase to contract;

valve means for closing said outlet and movable to an open position, so as to permit gas to be expelled from said bellows;

actuating means coupled to said main conduit and responsive to a pressure signal therefrom during the inspiration phase for moving said valve means to its open position; and

means responsive to contraction of said bellows for causing said valve means to close said outlet during said inspiration phase.

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12. In a respiration system including a positive pressure respiration unit for delivering pressurized gas to a patient through a main conduit during an inspiration phase followed by an expiration phase during which the patient is permitted to expire through a valved exhalation passage; a spirometer, comprising:

a case;

expansible-contractable bellows supported on said case and having an inlet coupled to said exhalation passage and an outlet, said bellows being movable between expanded and contracted conditions, and arranged to receive gas expired by the patient through said inlet during the expiration phase to expand and to expel it through said outlet during the inspiration phase to contract;

valve means normally closing said outlet and being movable to an open position;

means forming a pressure chamber coupled to said main conduit for receiving a pressure signal therefrom during the inspiration phase;

actuating means including a pressure-sensitive element disposed in said chamber and responsive to a pressure greater than a predetermined minimum therein for moving said valve means to its open position;

conditioning means operable following movement of said valve means to its open position for blocking communication between said chamber and said main conduit; and

means operable when the pressure in said main conduit during the expiration phase is less than said predetermined minimum and following such blocking of communication for venting said chamber.

13. The subject matter of claim 12 wherein said means for venting said chamber is operable only when said bellows is in its contracted condition.

References Cited

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SIMON BRODER, *Assistant Examiner*.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,395,699

August 6, 1968

Noel F. Beasley

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

Column 3, line 19, "low/end" should read -- lower/end --;
line 38, "Tuning" should read -- Turning --. Column 4, line
11, "it" should read -- its --. Column 5, line 74, "1, as may
be" should read -- 1. Preferably, as may be --. Column 6, line
18, "hearing" should read -- bearing --. Column 7, line 57,
"106," should read -- 106. --. Column 8, line 69, "Ohe" shoul
read -- The --. Column 10, line 40, "contacted" should read
-- contracted --. Column 12, line 8, "said and" should read
-- said case and --.

Signed and sealed this 30th day of December 1969.

(SEAL)

Attest:

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Attesting Officer

WILLIAM E. SCHUYLER, JR.

Commissioner of Patents