United States Patent

[11] 3,556,095

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[73] Assignee **The United States of America as represented by the Secretary of the Army**

[54] **AUTOMATIC INTERMITTENT POSITIVE PRESSURE VENTILATOR**
15 Claims, 4 Drawing Figs.

[52] **U.S. Cl.** **128/145.8,** 128/142.2, 128/188
[51] **Int. Cl.** **A61m 17/00** A62b 7/00, A62b 7/04
[50] **Field of Search** 128/145.8, 145, 145.1, 145.5, 188, 191, 142.2

[56] **References Cited**
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2,924,215	2/1960	Goodner	128/145.6
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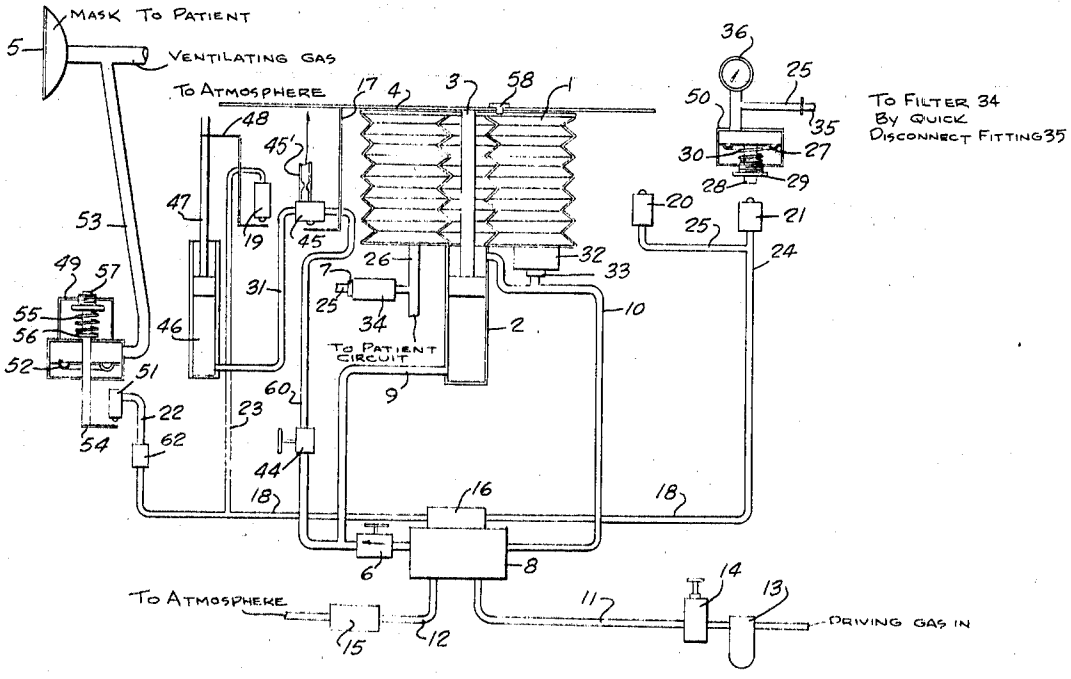
ABSTRACT: This invention concerns itself with improvements in a medical ventilator which is disclosed in my U.S. Patent No. 3,251,359. In particular, a spill valve, a timing cylinder and a variety of pneumatic components with connecting circuitry are added to the existing circuitry of my prior medical ventilator enabling the ventilator to be employed both in a rebreathing system (as in a closed circuit anesthesia system) and a nonrebreathing system, and as an assister or as a controller during the ventilating process.

The invention described herein may be manufactured and used by or for the Government for governmental purposes without the payment to me of any royalty thereon.



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SHEET 1 OF 2

FIG. 1

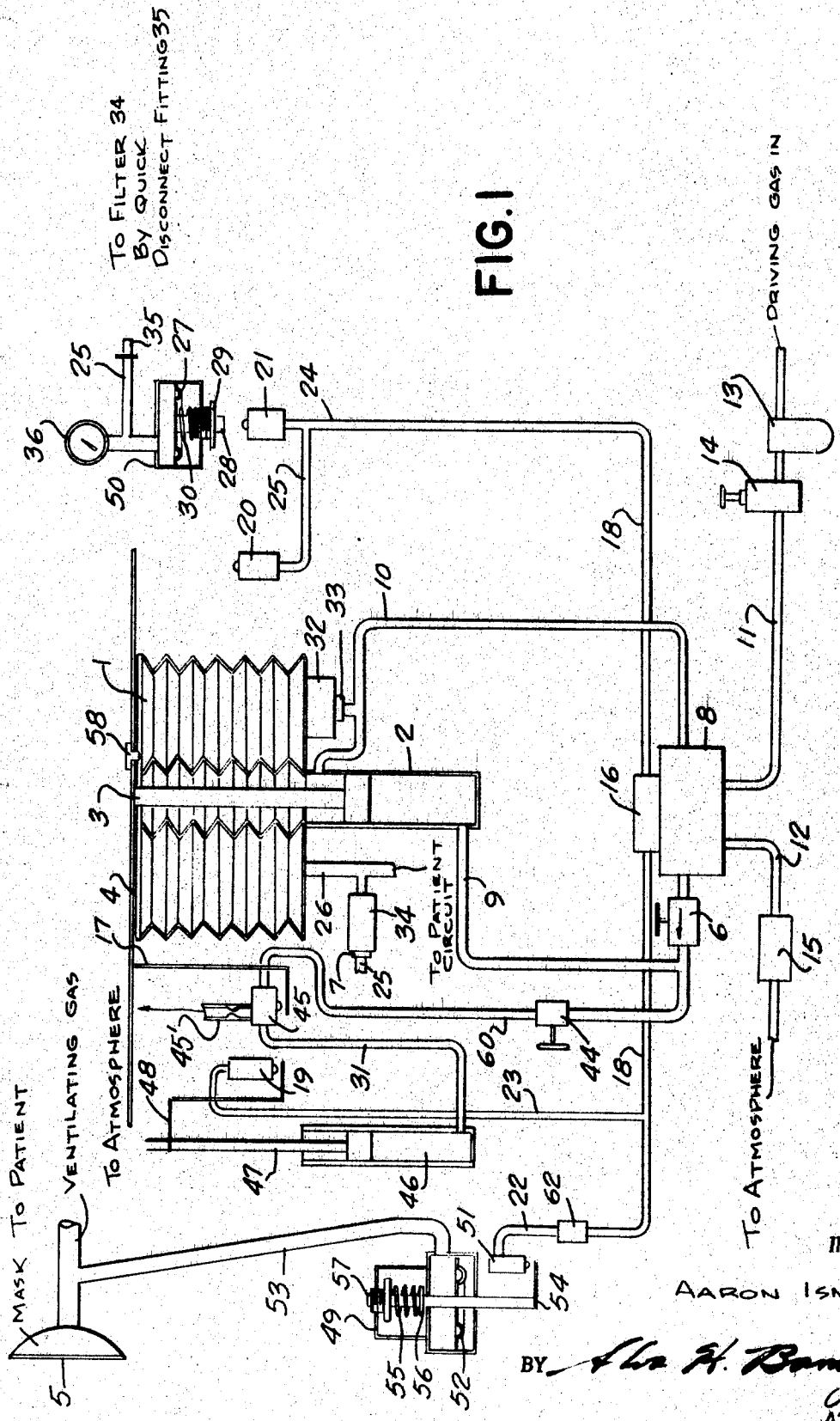

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FIG. 2

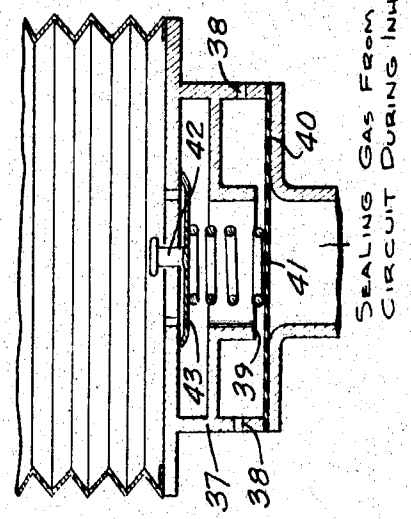


FIG. 4

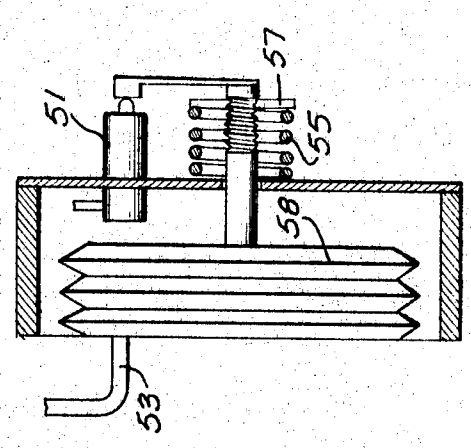
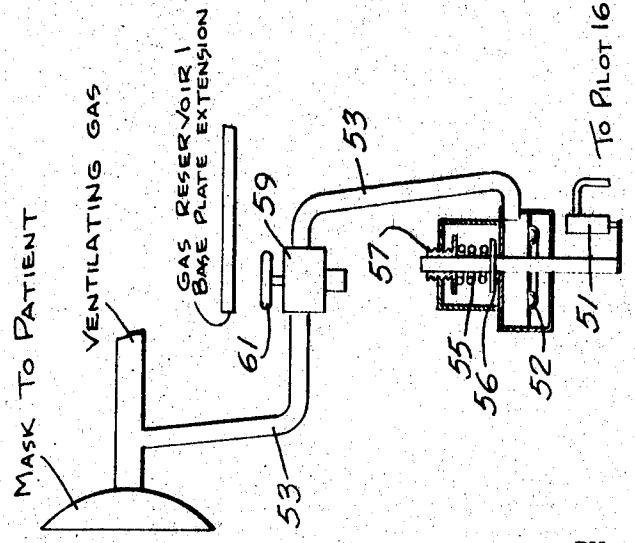


FIG. 3



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AUTOMATIC INTERMITTENT POSITIVE PRESSURE VENTILATOR

BACKGROUND OF THE INVENTION

The present invention concerns itself with medical ventilators used to either aid or control the breathing of a patient. Ventilators normally control the volume, pressure and rate of administration of ventilating gas fed to the patient. However, prior art ventilators have not been designed to permit the patient's breathing cycle, even if erratic, to control the ventilating operation. The present invention is designed to accomplish the above in addition to having a number of other capabilities.

SUMMARY OF THE INVENTION

The present invention is an improvement in the design of the medical ventilator covered in my U.S. Pat. No. 3,251,359. The invention adds a novel combination of pneumatic components and pneumatic circuitry to my earlier medical ventilator to achieve new versatility in ventilating systems. By the addition of a spill valve, a timing cylinder, associated pneumatic circuitry and bleeder valves with their associated aneroid assemblies, a ventilator system is created which can be employed in a rebreathing or a nonrebreathing capacity and as an assister or as a controller. In addition, the system is responsive to any erratic rhythm in the breathing cycle of a patient.

It is an object of this invention to permit the use of the ventilator as an assister in which the patient may trigger the start of inspiration at any time during the cycle of operation and thus receive ventilation assistance in lieu of the machine controlling the ventilation whereby the patient is forced to breathe in unison with the device and according to a predetermined rhythm of breathing.

Another object of the invention is to provide a safe, effective automatic ventilator that can be used by an anesthesiologist in combination with an anesthesia machine in a closed rebreathing circuit.

Another object of the present invention is to permit the removal of the breathing circuit components from the device permitting sterilization of the components prior to use on a patient.

Another object of the present invention is to provide a series of removable breathing circuits so sized that they may be efficiently matched to patients of different capacities, that is infants, children or adults.

Another object of this invention is to provide safe and effective ventilation by having the unit change from a volume cycled to a pressure cycled device as determined by the patient's needs.

The final object of this invention is to provide a ventilator system whose rate of cycling and volume of deliverable gas are so related that a variation in one provides a corresponding variation in the other such that the rate (of cycling) times the volume (of deliverable gas for each stroke) remains a constant.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram of the present invention depicting its features and capabilities;

FIG. 2 is a vertical sectional view of the spill valve used in the ventilating system;

FIG. 3 is a sketch partly in section of a three-way valve arrangement incorporated to separate the assister circuit from the reservoir circuit during the expansion of the reservoir; and

FIG. 4 is a sketch partly in section of a bellows arrangement which can replace aneroid 49.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 depicts the preferred embodiment of the present invention. The ventilator system depicted in FIG. 1 can be used as either a controller or as an assister, and on either pressure cycling or volume cycling, and is either a rebreathing or a nonrebreathing system. The system is designed to automatically switch from volume cycling to pressure cycling and vice versa depending upon the needs of the patient. A trained anesthetist decides whether or not the system is to be used as a controller or as an assister, and whether or not in a rebreathing or a nonrebreathing capacity. Once determined, the appropriate system settings are made.

Variable volume ventilating gas reservoir 1 of the ventilating system is driven by piston 3 which moves within pneumatic actuated driving cylinder 2. A four-way valve 8, a pilot 16 and a flow control valve 6 operate as the control system over the incoming gas. A filter 13 and a pressure regulator 14 are contained within incoming driving gas pressure line 11 while muffler 15 is connected to exhaust line 12. Lines 9 and 10 feed from control valve 6 and four-way valve 8 respectively into driving cylinder 2 in such a way as to control the movement of piston 3. Spill valve 32 is connected between line 10 and gas reservoir 1. Line 18 is a take off from pilot 16 and feeds into branches 22, 23, 24 and 25 which terminate at bleeder valves 51, 19, 21 and 20 respectively. Aneroid assembly 49 is capable of triggering bleeder valve 51, bar 48 is capable of triggering bleeder valve 19, bar 4 is capable of triggering bleeder valve 20, and aneroid assembly 50 is capable of triggering bleeder valve 21. Line 60 branches off line 9 at control valve 6. Line 60 contains needle valve 44 and three-way valve 45. Line 60 terminates at timing cylinder 46 which contains piston 47. Bar 48 is attached to piston 47 and is capable of actuating bleeder valve 19. Aneroid assembly 50 with its biased diaphragm 27, pressure gage 36, quick disconnect fitting 35, actuator 28, adjusting screw 29 and spring 30 make up the switching means by which the system switches from volume cycling (actuation of bleeder valve 20) to pressure cycling (actuation of bleeder valve 21) and vice versa. Aneroid assembly 49 with its biased diaphragm 52, spring 55, collar 56 adjusting screw 57 and actuator 54 make up the switching means which enable the system to operate as an assister. Three-way valve 59 and its actuator 61 (FIG. 3) may be inserted into line 53 to serve as a control means.

The ventilating system of the present invention adds versatility and additional capabilities to prior art ventilating system concepts. The system can be used either as a controller, that is, a device which forces a patient to breathe as the system directs, or as an assister, that is, a device which aids a patient in his breathing (inhalation) according to the patient's own respiratory demands.

When a patient is placed under the control of the ventilator, a decision is made as to whether or not to use the ventilator as a controller or as an assister. This determination is made by a trained anesthetist. Assuming that the determination is made to use the ventilator as a controller, and in a nonrebreathing mode, valve 62 is sealed which in effect removes aneroid assembly 49 from the system. Before the patient is placed under the control of the ventilator, the anesthetist needs to make additional adjustments to the ventilator. First, valve 6 is adjusted to the desired rate of flow of the driving gas from valve 8 thus controlling the rate of inspiration. Valve 44 is adjusted to the desired rate of flow thus controlling the rate of exhalation, that is, the rate of flow of gas to timing cylinder 46. Aneroid 50, the pressure cycling triggering means, is set by adjusting screw 29 to the desired maximum pressure setting which will be permitted to exist in the patient circuit before the system switches from volume cycling to pressure cycling. An easy way to obtain the proper setting is to block line 26, the patient circuit line, observe pressure gage 36 to see at what pressure actuator 28 engages bleeder valve 21 and to adjust screw 29 so that actuator 28 strikes bleeder valve 21 at the desired pressure as read on gage 36. The ability to switch automatically from volume cycling to pressure cycling when the pressure in the patient's respiratory system reaches a maximum level is desirable as excessive pressure in the patient circuit can be dangerous to the patient for a number of reasons. First, excessive pressure resulting from the over inflation of the patient's lungs can damage lung tissue. Second, should the excessive

pressure in the patient circuit be due to a stoppage in the windpipe, the continued attempt at completing the full inhalation cycle is undesirable and can be dangerous. By automatically switching to pressure cycling, that is, beginning the exhalation cycle based upon pressure readings before a full inhalation cycle is completed, the ventilator does not further complicate the breathing obstruction but rather increases the respiration rate. The increase in breathing rate is beneficial under such circumstances, as by this action, obstructions can be eliminated.

Another adjustment made by the anesthetist is the physical location of bleeder valve **19** and valve **45**, and bleeder valve **20** with respect to the completely collapsed position of reservoir **1**. It is desired to have reservoir **1** operate between its completely exhausted position and some expanded position rather than some partially filled position of reservoir **1** and an equally increased volume location. That is, it is desired if one-half of a reservoir of gas is to be put into and taken from a patient, to have the reservoir physically fluctuate between zero capacity and one-half capacity rather than from one-half capacity to full capacity. Although the same volume of air is circulated, an untrue reflection to the anesthetist of the patient's condition exists when at the completely inhaled position of the reservoir, additional gas remains within the reservoir. What occurs is that the unused gas in the reservoir is added "compliance" to the patient's lungs, thus reflecting a state of greater compliance than actually exists. By having the reservoir completely exhausted at the point of maximum inhalation, a truer reflection of the compliance within the patient's lungs is achieved and a truer representation of the patient's condition exists. Bleeder valve **20** is positioned so that bar **4** strikes it when reservoir **1** is completely collapsed. Bleeder valve **19** and its associated valve **45** are jointly positioned so that valve **45** is actuated by bar **17** at the maximum point of expansion for reservoir **1** with respect to a particular desired volume.

Should it be desired to use the system as an assister, that is, as an aid to inhalation, valve **62** is opened bringing aneroid **49** into the system while valve **44** is closed thus eliminating valve **45**, timing cylinder **46**, piston **47** and bleeder valve **19** from operation within the system. During the assister operation, the patient controls his rate of inhaling and exhaling. Assistance to inhaling is provided when the patient begins to inhale. The drop in pressure in line **53** due to the beginning of inhalation by the patient triggers bleeder valve **51** via aneroid **49**. Bleeder valve **51**, upon actuation, will always find reservoir **1** at its expanded state since the system will cycle to that point and stop to await the actuation of bleeder valve **51**.

Valve **59** (FIG. **3**) may be placed into line **53** to achieve a time delay between the point in time when the patient begins to inhale and the point in time when bleeder valve **51** is actuated and the system actually assists. This delay is desirable to prevent false pressure variances from the patient from triggering the assister when in fact inhalation is not desired.

An additional safety feature may be employed in the above procedure. By not completely sealing valve **44**, the anesthetist is able to guarantee that should the patient fail to inhale on his own within a certain period, say five seconds, the controller aspect of the system will be employed automatically by the actuation of bleeder valve **19** due to the inclusion within the system of timing cylinder **46**, piston **47** and valve **45**. This is accomplished by setting valve **44** so that in 5 seconds an amount of gas sufficient to fully extend piston **47** is permitted to pass. Thus bleeder valve **19** is actuated within five seconds should the patient's breathing fail to actuate bleeder valve **51** sooner.

The ventilator system is also capable of being employed in either a rebreathing mode or a nonrebreathing mode. The determination as to whether or not the system would be used as a rebreathing system or as a nonrebreathing system is made by the anesthetist. The converting of the system from rebreathing to nonrebreathing is accomplished by the use of fastener **58**. When fastener **58** attaches piston **3** to reservoir **1**, the system is in the nonrebreathing mode of operation. When fastener **58** is unfastened, the system is in the rebreathing mode of operation. Whether or not piston **3** and reservoir **1** can move independently of each other is only pertinent when discussing the inflation of reservoir **1** and the movement of piston **3** out of cylinder **2** (exhalation), since the movement into cylinder **2** by piston **3** will, with or without fastener **58** fastened, force reservoir **1** to contract.

In rebreathing cycling, fastener **58** is unfastened thus permitting piston **3** to move out of cylinder **2** independently of the expansion of reservoir **1**. For this system, the capability of independent movement in this direction between piston **3** and reservoir **1** is essential. Since piston **3** is designed to rapidly move out of cylinder **2** so that in the nonrebreathing mode of operation reservoir **1** fills quickly so that sufficient gas is immediately available should bleeder valves **21** or **51** be actuated, a means to permit the independent movement of piston **3** and reservoir **1** is required when a rebreathing mode of operation is employed. This independent capability is required as the rapid expansion of reservoir **1** in the rebreathing mode of operation would quickly exhaust the patient's lungs, possibly collapsing them. In addition, a large negative pressure would be generated in the patient circuit, and if in the assister mode of operation, the assister would be tripped (bleeder valve **51** actuated by aneroid **49**) causing oscillation of reservoir **1** near its fully extended position thus preventing the individual from receiving effective ventilation. With fastener **58** unfastened, reservoir **1** can expand at a rate independent of the movement of piston **3** and no false negative pressure is generated to trip the assister mode of operation.

There are times when it is desirable to generate a small negative pressure within reservoir **1** during the expansion of the reservoir to aid the patient during the exhalation phase. This is conveniently accomplished with a controller-assister as shown in FIG. **1** with a few minor modifications. The unit is fabricated so that the elements can be mounted in an inverted position to that shown in FIG. **1**. The gas reservoir then has an assist from gravity while extending. If the base plate of the reservoir is weighted, then any degree of selected negative pressure can be obtained during the extension process. Since the negative pressure generated can trip the assister, leading to the undesirable results described above, a means is required to isolate the assister from the gas reservoir circuit during extension of the reservoir. This is conveniently accomplished by the addition of a three-way valve **59**, as shown in FIG. **3**.

The three-way valve **59** is located in the assister line **53**. In its normal open position, the mask section of line **53** is sealed, whereas the assister position of line **53** is open to the atmosphere, so that no difference of pressure can exist across diaphragm **52** and bleeder valve **51** cannot be actuated. If the actuator **61** of valve **59** is depressed, then the two sections of line **53** are connected and the atmosphere port of the valve is closed. An inspirator effort on the part of the patient can then actuate the diaphragm **52** causing the bleeder valve **51** to initiate an inhalation phase. The valve **59** is physically arranged to be moved simultaneously with three-way valve **45** and bleeder valve **19**, so that is is always in proper location for any given volume setting. An extension of the gas reservoir base plate is made to strike actuator **61** of the three-way valve **59** at the point of maximum extension of the gas reservoir. In this manner the assister circuit is isolated from the gas reservoir and the patient circuit until the gas reservoir is completely filled as a result of patient inhalation through the anesthesia machine absorber and makeup gas. Thereafter an inspiratory effort on the part of the patient can trigger the assister.

An alternate assister arrangement is shown in FIG. **4**. In this arrangement a bellows **58** replaces the diaphragm **52**. An inspirator effort by the patient causes the movable plate of the bellows to retract against the bias of spring **55** leading to the actuation of bleeder valve **51**. The adjusting nut **57** presets the bias of spring **55**, thereby fixing the magnitude of inspiratory effort required by the patient to initiate inhalation. An advantage of this arrangement is that the anesthesiologist can

depress the bellows 58 by fingertip and manually initiate inhalation at any portion of the exhalation cycle. Indeed, he can close valve 44 completely disabling timing cylinder 46 and use the bellows of the assister to manually "bag" the patient using a form of power-bagging in which the volume and rate of contraction of the bag can be preset using the available controls of the ventilator.

In actual operation, the preferred embodiment has driving gas entering the system via line 11 after passing filter 13 where the air is cleaned and the moisture is automatically removed from the incoming driving gas thus preventing the entry of contaminants into the system. Pressure regulator 14 is also placed in line 11 and is preset at a given pressure, such as 25 p.s.i. Pressure regulator 14 thus permits the ventilating system to be connected to a driving gas source whose pressure is greater than that pressure under which the ventilating system is designed to operate.

Line 11 feeds gas into a conventional four-way, two position valve 8. Depending upon the position of valve 8, line 11 either feeds into line 9 and line 10 is connected to line 12 or line 11 feeds into line 10 in which case line 9 is connected to line 12. Lines 9 and 10 run between valve 8 and driving cylinder 2. Lines 9 and 10 enter driving cylinder 2 at opposite ends of the cylinder such that piston 3 reciprocates between the two openings. Flow control valve 6 is inserted into line 9. Flow control valve 6 permits a regulated free flow of air in one direction (as designated by the arrow in FIG. 1), but allows only a controlled variable restrictive flow in the opposite direction. Thus the contraction of reservoir 1 (inhalation) is damped to any desired extent and thus reproduces a realistic breathing cycle.

Assuming that valve 8 is initially set such that line 11 feeds into line 9 and line 10 feeds into exhaust line 12 and the system is being used as a nonrebreathing controller, the driving gas of line 11 is fed into driving cylinder 2 via line 9 forcing piston 3 outward from cylinder 2. Piston 3, being attached to the variable volume gas reservoir by screw 58, thus causes reservoir 1 to expand. The expanding movement of reservoir 1 causes a patient, who is under the care of the system, to exhale since this is a closed system and line 26 connects reservoir 1 with the patient via mask 5. The expansion of reservoir 1 due to the driving of piston 3 is accomplished rapidly since lines 10 and 12 offer no resistance to the discharge of air from driving cylinder 2. In the assister mode of operation, it is essential that reservoir 1 fill rapidly at the start of the exhalation phase so that an adequate volume of ventilating gas is available to the patient should he attempt at any point in time to initiate inspiration. If the reservoir was allowed to expand slowly, then an inspiration could be initiated by the patient when reservoir 1 was only partially filled resulting in an insufficient amount of ventilating gas reaching the patient. It would then be possible for the system to reach an unstable condition in which the patient initiates an inspiration at smaller and smaller reservoir volumes, causing the reservoir to oscillate in the retracted position and severely impede ventilation to the patient.

Line 26 connects reservoir 1 with patient mask 5. Line 26 thus carries either the exhaled gas from the patient into the expanding reservoir 1 or the inhaled gas of the patient from a compressing reservoir 1. Spill valve 32 is connected between reservoir 1 and line 10. Spill valve 32 is open when line 11 is connected to line 9 which occurs during the expansion of reservoir 1 which causes the exhalation of the patient. With spill valve 32 open, reservoir 1 is open to the atmosphere and air is permitted to fill reservoir 1 as the reservoir expands.

FIG. 2 is a schematic diagram of the spill valve 32, enlarged to give constructional details. The spill valve consists of a valve housing 37 fitted with a series of holes 38 connecting the interior of the housing to the atmosphere When sealing gas under pressure from line 10 is applied to the spill valve 32, the rubber diaphragm 40, which is normally biased open by means of spring 41, is forced upward against the valve seat 39 sealing the interior of the spill valve from the atmosphere. When sealing gas pressure is released (line 11 connected to line 9), the spring 41 returns the diaphragm 40 to the open position and the interior of the ventilating gas reservoir 1 is effectively open to atmosphere via rubber check valve 42. If, during the time the spill valve is open, the pressure within the ventilating gas reservoir 1 is greater than atmospheric, excess gas can spill out of the reservoir via the spill valve to the atmosphere. Similarly, during the time the spill valve is open, if the pressure within the ventilating gas reservoir 1 is below atmospheric, room air can be sucked into the reservoir through the orifice 43 in the check valve 42. The orifice is provided to restrict the rapid entry of air into the reservoir thereby permitting a negative pressure to exist within the reservoir. There are times when it is desirable to achieve a rapid pressure drop in reservoir 1 at the start of exhalation by the patient as such a pressure drop permits unimpeded passive exhalation by the patient. If a negative pressure is not required, the check valve 42, with orifice 43, may be omitted, thereby permitting relatively unrestricted flow between the reservoir and the atmosphere when the spill valve is open, and causing only slight negative pressures to be induced in the reservoir due to reservoir expansion.

The spill valve is an essential part of a ventilator intended to be used in a rebreathing mode as in a closed circuit anesthesia system. In this type of circuit fresh oxygen or other gas may be fed into the loop continually. If there are no spill facilities, and if the gas input exceeds the gas leakage in the system, there will be a build up of dangerous gas pressure in the circuit. With the ventilator cycling, an increase in pressure due to a continued build up of gas in the system will cause the ventilator to pressure cycle at continually shorter strokes (not due to high patient impedance, but due to undesirable ventilating gas pressure build up) until the reservoir 1 chatters at its upper position and the unit ceases to ventilate leading to death of the patient. From the previous description of the operation of the spill valve, it can be seen that at the start of inhalation the interior of reservoir 1 is always brought to reference atmospheric pressure, with excess gas spilled out of the circuit during the entire exhalation phase. The pressure within the reservoir on inhalation is then due to the pressure induced within the reservoir due to contraction of this reservoir plus the pressure due to the makeup gas being fed into the system. With reasonable gas input and comparative short ratio of inhalation time to the entire cycle (inhalation plus exhalation) time, the pressure within the reservoir is never permitted to become large enough either to impair ventilation or interfere with the proper function of the ventilator. If makeup gas is less than that lost by leakage in the system, atmospheric air will spill into the reservoir via the spill valve during the exhalation phase to bring the reservoir to reference atmospheric pressure at the start of inhalation. It is therefore seen that the spill valve has the important function of controlling the reservoir pressure at the end of exhalation by connecting the patient to atmosphere during the exhalation phase through the ventilating gas reservoir 1 thereby establishing a reference pressure for the closed system.

Pilot 16 controls the switching of valve 8. Line 18 with branch lines 22, 23, 24 and 25 connects bleeder valves 51, 19, 21 and 20 respectively with pilot 16. The actuation of any of the bleeder valves causes pilot 16 to switch valve 8. A switch of valve 8 results in a reversal in the feeding of the driving gas to cylinder 2 and thus a reversal in the movement of piston 3. The final result is the change in the movement of reservoir 1 and thus a shift in the breathing cycle at that moment from either inhalation to exhalation or vice versa.

The normal operative cycle has reservoir 1 cycling between bleeder valves 19 and 20. When bar 4 strikes bleeder valve 20, the compression limit (maximum point for inhalation) of reservoir 1 has been reached. When bar 17 strikes the actuator of valve 45, the expansion limit (maximum point of exhalation) of reservoir 1 has been reached. There is a direct time relationship between the movement of bar 17 and the movement of bar 48, and the actuation of valve 45 and the actuation of bleeder valve 19 such that in describing the movement

of bar 17 and the actuation of valve 45 one is in effect describing the movement of bar 48 and the actuation of bleeder valve 19.

As previously stated, piston 3 is extended rapidly when driving gas enters cylinder 2 via line 9 as lines 10 and 12 offer no resistance to the flow of gas. Although the rapid expansion of reservoir 1 is desirable so as to provide for a sufficient amount of gas to be available should the patient almost immediately trigger inhalation after the system started to automatically initiate exhalation, a delay is required between the time when reservoir 1 is fully extended and the time bleeder valve 19 is actuated under normal breathing conditions. This delay is essential to permit the patient to sufficiently exhale as in normal breathing. The time delay must be adjustable, and once set, it must be directly proportional to the length of the downward stroke (inhalation) of the ventilating gas reservoir 1. The proportional requirement is essential if the system is to be permitted to change from a volume cycled to a pressure cycled unit.

The delay is achieved in the following manner. Line 60 is a take off of line 9. Line 60 contains needle valve 44 and three-way valve 45. Line 60 terminates into timing cylinder 46. Piston 47 reciprocates within cylinder 46. Bar 48 is attached to the end of piston 47 and is capable of actuating bleeder valve 19. As gas is fed into line 9, it also is fed into line 60. The gas into line 9 causes the rapid expansion (exhalation) of reservoir 1. The gas in line 60 must pass through needle valve 44 which is adjustable and capable of varying the rate of flow of the driving gas from line 9. Valve 44 can also be closed so as to completely cut out timing cylinder 46, etc., from the system.

When reservoir 1 and piston 3 are fully extended, bar 17, which is attached to bar 4, has been positioned so as to actuate three-way valve 45. Before actuation, valve 45 seals line 60 and connects line 31 to orifice 45' and the outside atmosphere. When valve 45 has been actuated by bar 17, line 31 is connected to line 60 and orifice 45' is sealed. Thus when reservoir 1 and piston 3 have been fully extended, bar 17 actuates valve 45 thus permitting gas to flow into line 31 and timing cylinder 46. As gas is fed into cylinder 46, piston 47 is driven out of cylinder 46. Bar 48 is moved by piston 47, and with piston 47 at the fully extended position, bar 48 actuates bleeder valve 19. According to the rate at which gas is permitted to pass through valve 44, a variable time delay is able to be achieved between the time when reservoir 1 and piston 3 reach their maximum expanded positions and the time when bleeder valve 19 is actuated.

When bleeder valve 19 is actuated, valve 8 switches the flow of driving gas causing reservoir 1 and piston 3 to contract. Bars 4 and 17 are moved downward together. When bar 17 is moved downward, valve 45 is released causing line 60 to be sealed and for line 31 to be connected to orifice 45'. Orifice 45' is designed to offer a slight resistance to the flow of gas. The resistance is sufficient to prevent piston 47 from sliding back into cylinder 46 without the application of an external force. Bar 4 is positioned so that as it moves downward, it encounters bar 48. Bar 4 provides a sufficient force to overcome the resistance offered by orifice 45', and thus as bar 17, and reservoir 1 and piston 3 move, bar 48 and piston 47 proportionately move. The result is a proportional time relationship between the movement of reservoir 1 and piston 3, and the means for actuating bleeder valve 19.

Valve 44 is set to obtain the desired delay time. By restricting the flow of gas to cylinder 46, a delay in actuating bleeder valve 19 is achieved. If the time delay (valve 44) is set for 5 seconds, then after the ventilating gas reservoir rapidly expands and valve 45 is actuated by bar 17, it will take 5 seconds before the bleeder valve 19 is actuated to initiate the inspiration phase. This is satisfactory operation during volume cycling, but assume that the patient impedance is high and unit pressure cycles so that bleeder valve 21 is actuated by means of the biased diaphragm 27 prior to complete contraction of the ventilating gas reservoir, for example if it is contracted half way. At this time the cycle frequency should double to compensate for the halved stroke to maintain the flow of a constant volume of ventilating gas to the patient during a given time interval. However, with a nonproportional time delay, the reservoir upon assuming pressure cycling at half stroke will expand rapidly and then a time delay of 5 seconds will occur before the inspiration is again initiated. This failure to increase cycle frequency, to compensate for reduced stroke, provides the patient with a reduced amount of ventilating gas per unit of time at the time when he is impeded and has the greatest requirement for such gas. If however, the time delay is reduced proportionally with the reduction in the stroke of the reservoir, so that a 2½ second delay occurs, then the cycling frequency will be increased to compensate for the halved stroke. It is therefore essential that the time delay be adjustable so that it can be set by the operator at full reservoir stroke; and that once set, the time delay becomes automatically directly proportional to the length of stroke of the ventilating gas reservoir. If the ventilating gas reservoir is retracted fully, then the timing cylinder piston 47 starts completely retracted and must have complete travel at a predetermined rate of speed before it can actuate the bleeder valve 19. If on the other hand, pressure cycling occurs, leading to contraction of the gas reservoir at its halfway point, then the piston 47 of the timing cylinder will start at its half extended position, and will take one-half of the time previously required to travel the required distance to actuate the bleeder valve 19. The arrangement described thus provides a time delay directly proportional to ventilating gas reservoir stroke.

In accordance with the invention, the ventilator system is capable of automatically switching from volume cycling to pressure cycling when a high casualty impedance, that is a high pressure, exists in the casualty circuit. In reality, the system switches from using bleeder valve 20 as the inhalation limit governing the movement of reservoir 1 to the using of bleeder valve 21. Pressure tap line 25 is connected to reservoir outlet line 26. A pressure gage 36 is included in line 25 to monitor the pressure appearing in the casualty circuit. Bacterial filter 34 is inserted in line 25 to ensure that gage 36 and biased diaphragm 27 are not contaminated by the patient when a closed rebreathing circuit is used. Line 25 is connected to a spring biased diaphragm 27, which is provided with an actuator 28 which is directly opposite to bleeder valve 21.

Ventilating gas reservoir 1 can be started on its upward motion (exhalation) by actuation of either bleeder valve 20 or 21. When the casualty impedance is low such that the ventilation can be accomplished without the pressure in the casualty circuit exceeding a predetermined preset pressure setting, such as 60 cm H_2O, the reservoir 1 is volume cycled between bleeder valves 19 and 20. However, if the casualty impedance is high, such that ventilation can only be accomplished with the pressure reaching the preset value, then this pressure being exerted through line 25 will cause the diaphragm 27 to expand downward and cause the actuator 28 to actuate bleeder valve 21. This actuation of bleeder valve 21 through the sensing of the casualty circuit pressure results in a shorter stroke in the ventilating gas reservoir 1, but at a correspondingly higher stroke rate. This pressure cycling continues until the casualty impedance is reduced below a predetermined value which causes insufficient pressure to act on diaphragm 27 to actuate bleeder valve 21, at which point the unit automatically resumes volume cycling. The predetermined or preset pressure for changing the mode of operation from volume cycling to pressure cycling, and vice versa, is adjustable by means of adjusting screw 29 which controls the amount of bias offered by spring 30.

A quick disconnect fitting 35 is provided for the connection of line 25 to filter 34. Reservoir 1 is also capable of being detached from bar 4. Line 10 can be disconnected from spill valve 32 using quick disconnect fitting 33, and line 25 can be disconnected from filter 34 using quick disconnect fitting 7. Thus, reservoir 1, complete with patient circuit outlet 26, filter 34 and spill valve 32 can be removed from the system

and sterilized using conventional sterilization techniques. The removability of the reservoir from the system also permits the interchangeability of reservoirs of various sizes. This interchangeable feature permits the use of a family of sizes of reservoirs so as to more efficiently match the capacity of the reservoir with the capacity of the patient under care. A typical gas reservoir for use on adults may have a maximum capacity in excess of 1,600 ml whereas for newborn infants a reservoir of a capacity of 200 ml would be required.

The ventilators previously described can be fabricated to offer ranges of adjustable parameters, such as:

Bellows volume: 100 to 1600 cc
Switching pressure: 10 to 60 cm h_{20};
Switching pressure: 10 to 60 cm H2O
Inspiration period:
Expiration period: 0.4 to 10 seconds
Assist negative pressure: −0.5 to −4 cm H2O

By employing different sizes of ventilating gas reservoirs, different ranges of adjustable parameters can be obtained.

I claim;

1. A mechanical ventilator comprising:
a. a variable volume ventilating gas reservoir;
b. pneumatic circuitry for driving from an external driving source said reservoir;
c. patient circuitry leading from said reservoir to the patient;
d. a valve for controlling within said pneumatic circuitry the direction of flow of said external driving source;
e. a pilot responsive to pressure variation and capable of switching said valve when a pressure variation occurs;
f. a first valve for actuating said pilot to cause said reservoir to expand;
g. a second valve for actuating said pilot to cause said reservoir to expand;
h. a third valve for actuating said pilot to cause said reservoir to contract;
i. a fourth valve for actuating said pilot to cause said reservoir to contract;
j. a first actuating means for actuating said first valve wherein said first actuating means is responsive to the volume of said reservoir;
k. a second actuating means for actuating said second valve wherein said second actuating means is responsive to the pressure within the respiratory system of the patient;
l. a third actuating means for actuating said third valve wherein said third actuating means is responsive to the volume of said reservoir; and
m. a fourth actuating means connected in said patient circuitry for actuating said fourth valve including an aneroid assembly and an operator connected to said aneroid assembly for coaction with said fourth valve, whereby upon actuation of said fourth valve the ventilator assists the patient in breathing responsive to self-initiated inhalation of the patient.

2. The mechanical ventilator as described in claim 1 wherein said fourth actuating means is isolated from the patient's breathing cycles until said variable volume ventilating gas reservoir is fully extended.

3. The mechanical ventilator as described in claim 2 wherein the third actuating means provides for a variable time delay before actuating said third valve.

4. The mechanical ventilator as described in claim 3 wherein the variable time delay created by said third actuating means is directly proportional to the stroke of said variable volume ventilating gas reservoir.

5. The mechanical ventilator as described in claim 3 wherein the means for achieving said time delay before said third actuating means actuates said third valve comprises:
a. a first delay circuit emanating from said pneumatic circuitry;
b. a control valve within said first delay circuit to control the rate of flow of the ventilator's driving means;
c. a three-way valve, one of whose ports is attached to said first delay circuit;
d. a second delay circuit emanating from a second port in said three-way valve;
e. an orifice attached to the third port of said three-way valve, said orifice offering a resistance to the passage of air;
f. a timing cylinder into which said second delay circuit feeds;
g. a first bar affixed to the movable end of said reservoir and aligned to actuate said three-way valve whereby the connection of said second delay circuit to said orifice with said first delay circuit sealed is switched to the connection of said second delay circuit to said first delay circuit with said orifice sealed;
h. a timing piston-cylinder arrangement responsive to the setting of said control valve and to the setting of said three-way valve; and
i. a second bar affixed to said piston and aligned with said second valve so as to actuate said second valve when said piston is driven a predetermined distance out of said timing cylinder.

6. The mechanical ventilator as described in claim 5 wherein the resistance offered by said orifice to the passage of air is sufficient to prevent without the application of an external force said timing piston from moving into said timing cylinder when said three-way valve connects said second delay circuit to said orifice.

7. A mechanical ventilator comprising:
a. a variable volume reservoir;
b. a piston-cylinder arrangement for driving said reservoir;
c. a four-way valve for controlling the flow of the ventilator's driving means to said piston-cylinder arrangement;
d. a pilot which controls the setting of said four-way valve;
e. circuitry to carry the ventilator's driving means connecting said four-way valve with said piston-cylinder arrangement and arranged so as to cause the piston in said piston-cylinder arrangement to reciprocate within the cylinder;
f. patient circuitry leading from said reservoir to the patient;
g. a spill valve connecting said reservoir to the atmosphere;
h. a first valve capable of causing said pilot to switch said four-way valve thus reversing the movement of said reservoir;
i. structural means attached to said reservoir so as to actuate said first valve when said reservoir has been collapsed;
j. a second valve capable of causing said pilot to switch said four-way valve thus reversing the movement of said reservoir;
k. delay means capable of creating a delay in time between when said reservoir becomes fully extended and when said second valve is actuated; and
l. means for making said delay means directly proportional to the length of stroke of said variable volume reservoir.

8. The mechanical ventilator as described in claim 7 wherein said delay means can be varied to achieve any number of predetermined time delays.

9. The mechanical ventilator as described in claim 8 wherein said delay means for creating a delay in time between when said reservoir becomes fully extended and when said second valve is actuated comprises:
a. a first delay circuit emanating from said ventilator's circuitry;
b. a control valve within said first delay circuit to control the rate of flow of the ventilator's driving means;
c. a three-way valve, one of whose ports is attached to said first delay circuit;
d. a second delay circuit emanating from a second port in said three-way valve;
e. an orifice attached to the third port of said three-way valve, said orifice offering a resistance to the passage of air;
f. a timing cylinder into which said second delay circuitry feeds;
g. A first bar affixed to the movable end of said reservoir and aligned to actuate said three-way valve whereby the connection of said second delay circuit to said orifice

with said first delay circuit sealed is switched to the connection of said second delay circuit to said first delay circuit with said orifice sealed;

h. a timing piston-cylinder arrangement in which said timing piston reciprocates within said timing cylinder and dependent upon the setting of said control valve and upon the setting of said three-way valve; and

i. a second bar affixed to said timing piston and aligned with said second valve so as to actuate said second valve when said timing piston is driven a predetermined distance out of said timing cylinder.

10. The mechanical ventilator as described in claim **8** wherein said means for making said delay means directly proportional to the length of stroke of said variable volume reservoir comprises a third bar affixed to the movable end of said variable volume reservoir and aligned so as to apply a force which will overcome the resistance of said orifice and force the movement of said timing piston into said timing cylinder a distance equal to the amount of collapse of said reservoir.

11. The mechanical ventilator as described in claim **10** wherein said pilot is additionally responsive to the pressure within the respiratory system of the patient.

12 The mechanical ventilator as described in claim **11** wherein said pilot is additionally responsive to pressure variations of the patient's respiratory system indicative of self initiated inhalation.

13. The mechanical ventilator as described in claim **12** wherein means are provided to permit the independent movement between said variable volume reservoir and said piston of said piston-cylinder arrangement during exhalation of the patient.

14. The mechanical ventilator as described in claim **13** wherein said variable volume reservoir, said spill valve and said patient circuitry can be readily removed from the system for sterilization.

15. The mechanical ventilator as described in claim **14** wherein said variable volume reservoir is interchangeable with variable volume reservoirs of variable capacities.