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Weigl

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[54] **RESPIRATOR SYSTEM AND METHOD**

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[52] **U.S. Cl.** **128/145.6;** 128/145.8

[51] **Int. Cl.²** **A61M 16/00**

[58] **Field of Search** .... 128/145.6, 142.2–142.4, 128/145.7, 145.8, 145.5, 146.4, 146.5, 188, DIG. 17, 203, 184

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[57] **ABSTRACT**

A respirator system and method in which a constant pressure plenum communicates through a gas bleeder with the patient gas supply system. The bleeder is adjustable so that a gas flow can be established from the plenum to the gas conduits at a level sufficient to compensate for leaks from the patient's mouth and trachea, but less than that required by the patient during voluntary inhalation. The pressure inside the conduit system, and hence in the patient's lungs, is thereby maintained at a level at least as great as a minimum desired amount. A discrimination between patient attempts at breathing and leaks from the conduit system is achieved by sensing the gas flow rate towards the patient, and actuating a breath assist function only in response to that flow rate equaling or exceeding the expected inhalation rate, without reference to the absolute pressure within the conduit system.

15 Claims, 6 Drawing Figures

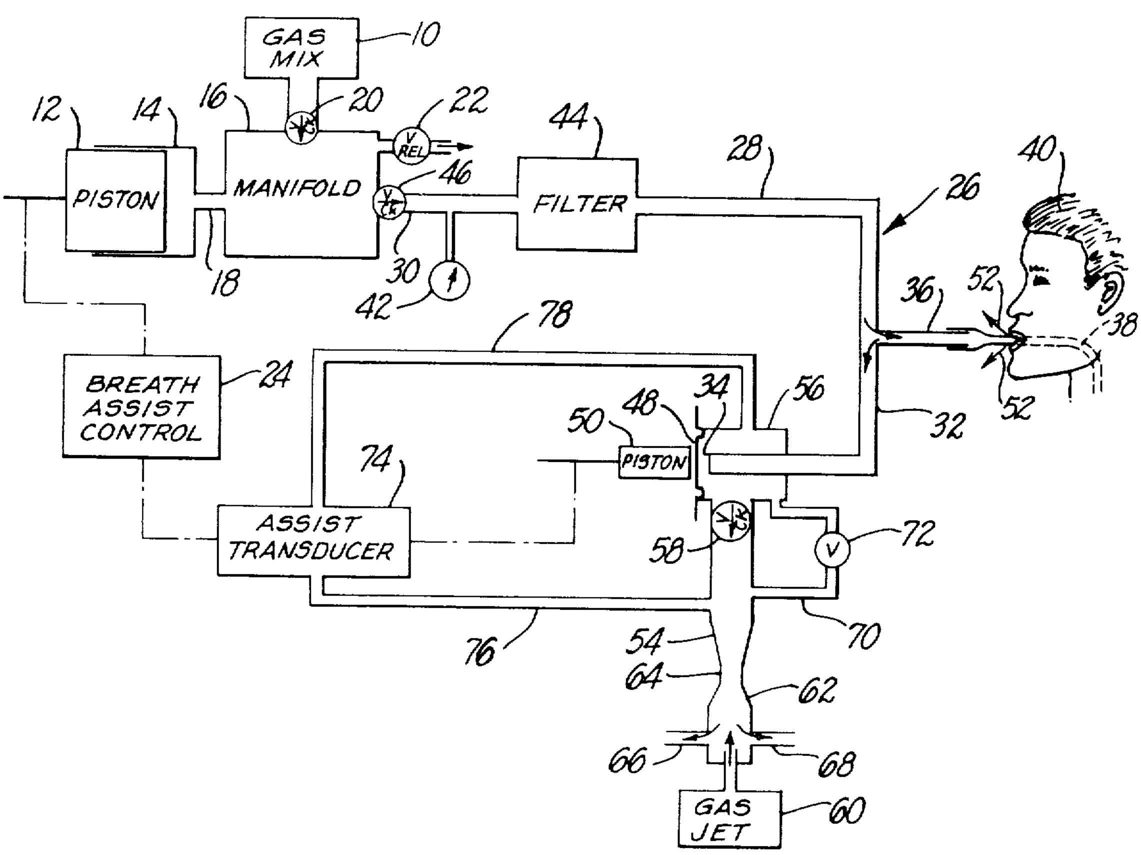


FIG. 1.

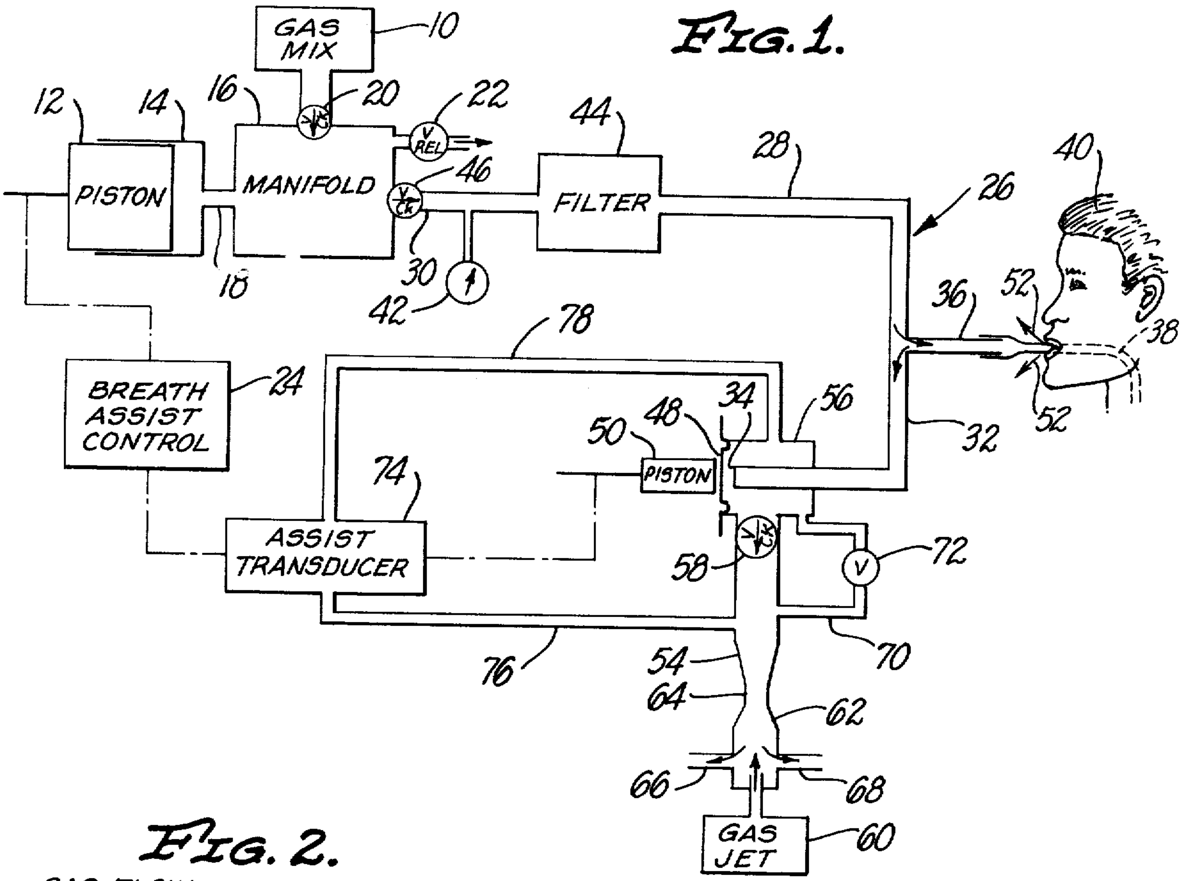


FIG. 2.

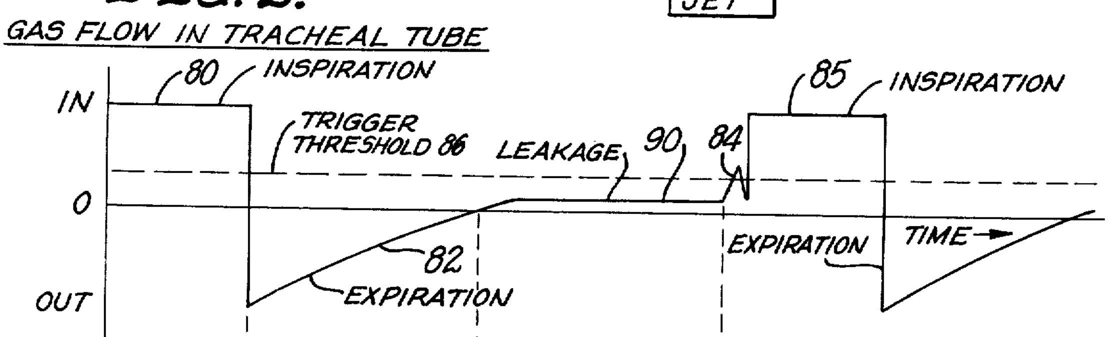


FIG. 3.

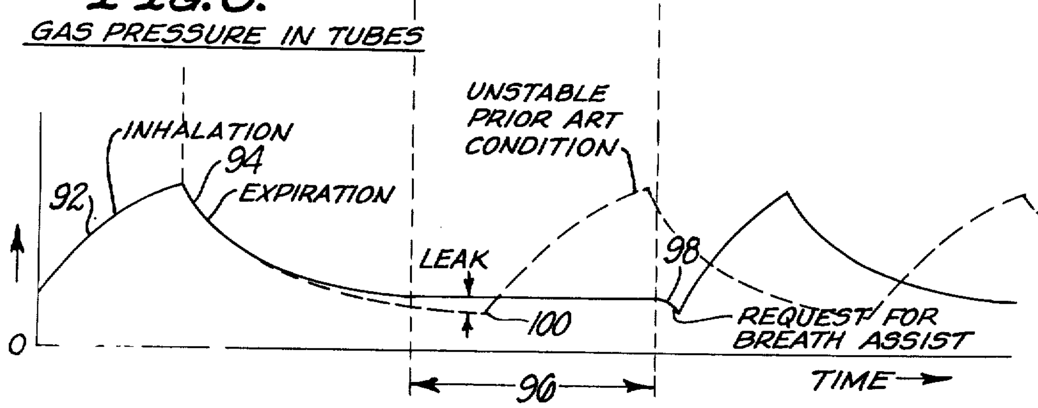
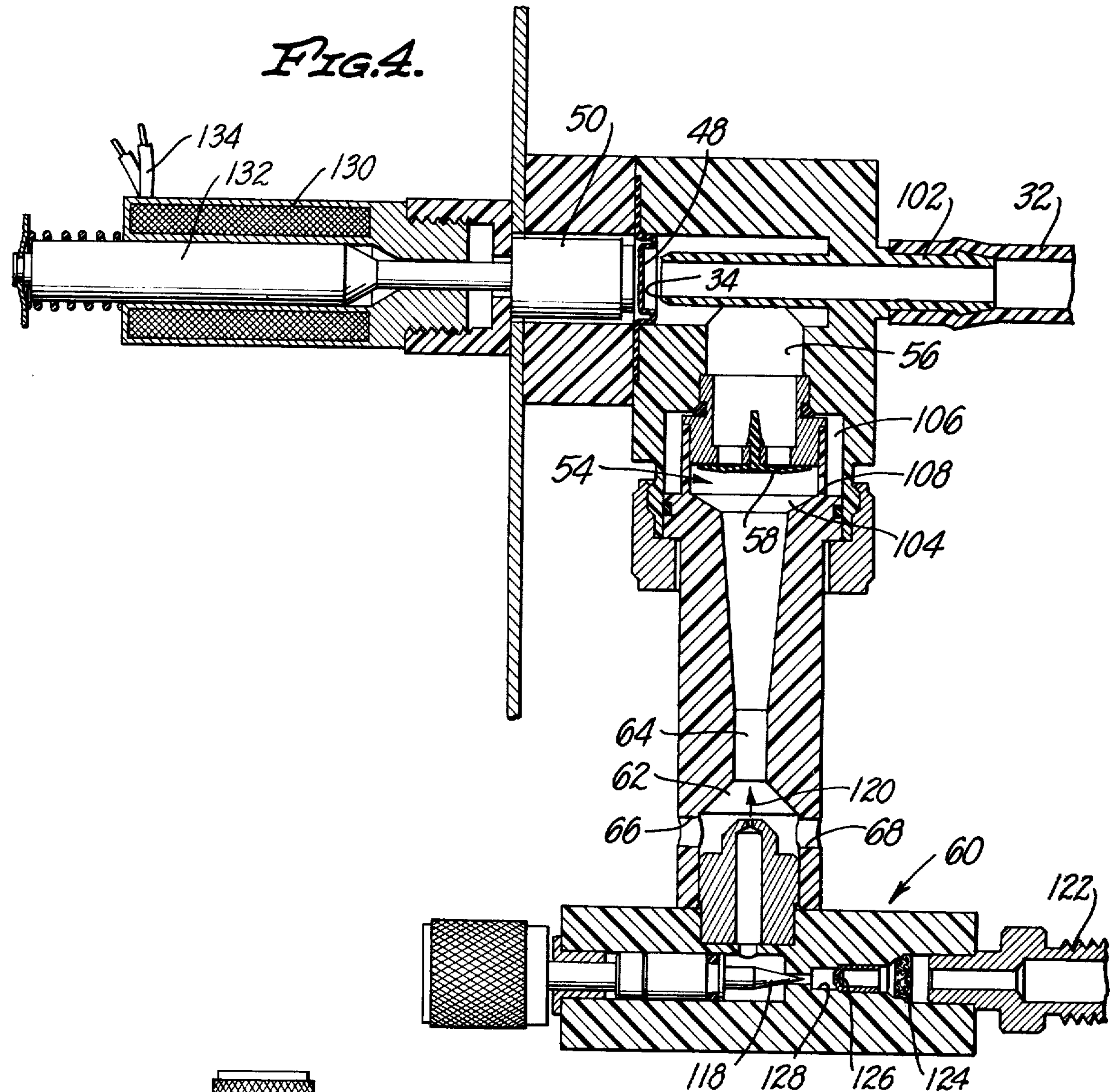


FIG. 4.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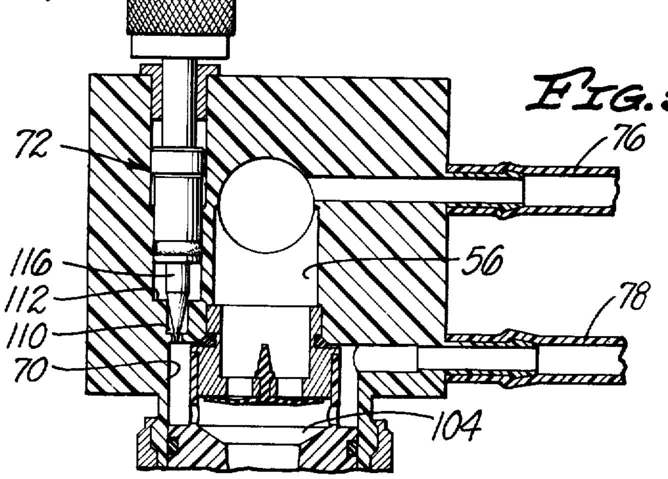
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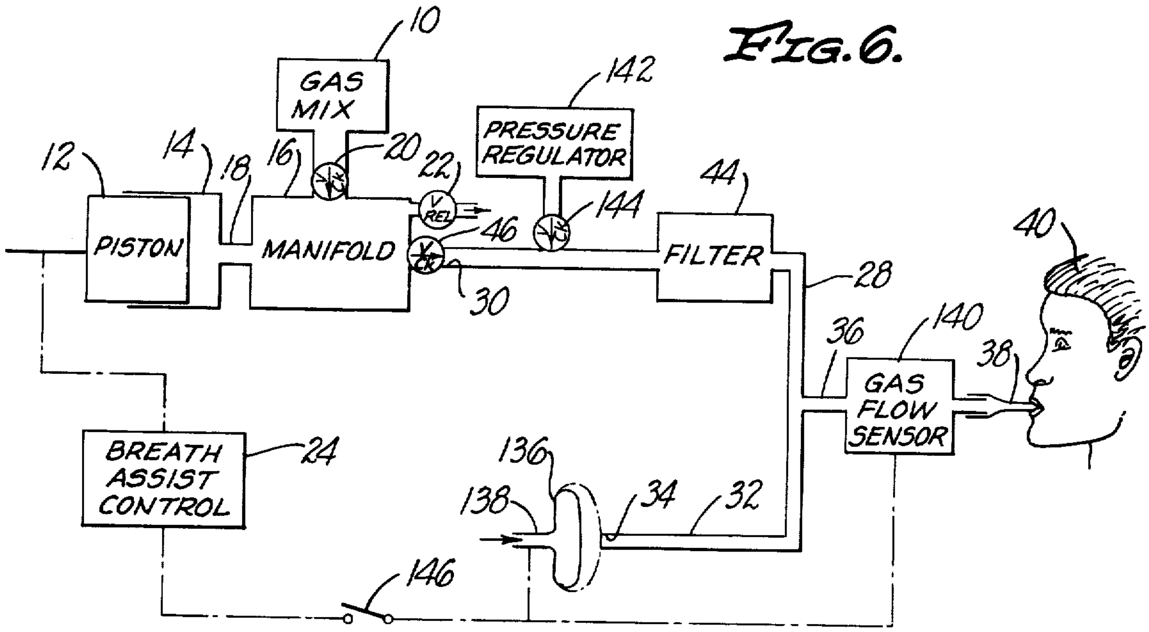
FIG. 5.

FIG. 6.


GAS MIX
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PISTON
MANIFOLD
V REL
V CK
FILTER
GAS FLOW SENSOR
BREATH ASSIST CONTROL
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RESPIRATOR SYSTEM AND METHOD

BACKGROUND OF THE INVENTION

This invention relates to medical respirator systems, and more particularly to positive pressure respirator systems having a breath assist mode in which delivery of gas to the patient is initiated when the patient attempts to inhale.

Respirator systems are known in which a breath assist function is actuated to deliver a certain volume of gas to the patient when he or she indicates an attempt to breathe by inhaling gas from the gas supply conduit system. A common method of identifying a patient request for breath assistance involves a measurement of the gas pressure within the conduits; the patient's suction reduces the pressure to a level below a predetermined threshold, triggering the breath assistance apparatus into operation. A controlled volume of air is then forced through the supply system to the patient's lungs, following which the patient exhales and then attempts to breathe again, retriggering the breath assistance apparatus. An override control is generally included with the respirator to actuate breath assistance should the patient fail to voluntarily inhale within a certain time limit.

While presently available systems can function adequately in a loss-less environment, a dangerous situation can develop if there are gas leaks from the supply conduit. Such leaks often develop at the end of the flexible tube inserted into the patient's trachea, since the trachea does not provide a perfect seal for the tube, and gas can escape out through the patient's mouth rather than being delivered to the lungs. In this event, there is a continuous loss of gas from the supply conduit that can lead to an accumulating drop in pressure therein during expiration phases of the respirator cycle. Should the pressure drop to a level below the preset threshold, a false triggering signal is delivered to the breath assistance apparatus, which accordingly delivers an additional quantity of gas before the patient is ready to receive it. Such premature breath assistance has resulted in an unstable runaway condition in which the breath assistance apparatus cycles at several times the normal breathing rate, causing a buildup of pressure within the patient's lungs above a safe amount. The patient does not have sufficient time to relieve the excess pressure by exhaling, and if the condition is not quickly observed and corrected may suffer serious lung damage or worse.

A related problem with known respirator systems relates to the maintenance of a minimum pressure level in the lungs of patients who suffer from diseases which cause a shrinking of the alveolar sacs. In such conditions, it is important to maintain the lung pressure at a level at least sufficient to keep the sacs expanded. Some of this pressure can be lost, however, if there are leaks in the gas conduit system, such as the abovedescribed tracheal tube leak. Even if a runaway breath assistance condition is avoided, the pressure loss may be large enough to allow the sacs to shrink to an unacceptable size.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a novel and improved respirator system and operating method for delivering quantities of gas in response to patient need.

Another object is the provision of a novel and improved respirator system with the ability to discriminate between gas leaks and a patient request for breath assistance, and to operate a breath assistance function only in response to patient need.

A further object of the invention is the provision of a novel and improved respirator system having means to maintain the pressure in the gas supply conduit system at a level at least as high as a predetermined minimum pressure, regardless of gas leaks from the supply system.

Another object is the provision of a novel and improved respirator system having a high degree of sensitivity in the detection of a patient request for breath assistance, with the detection mechanism being independent of the absolute pressure within the supplied conduit system.

Still another object is the provision of a novel and improved method of operating a respirator system in such a way as to achieve the above-stated objects.

In the accomplishment of these and other objects, a respirator system is provided that includes gas conduit means having an inlet port, an outlet port, and a patient supply tap intermediate to the inlet and outlet ports for conducting gas to the patient. The inlet port receives gas from a recyclable gas charging means during inhalation phases of the patient's breathing. Any outward flow of gas from the conduit system through the inlet port is blocked during expiration phases by a first valve means, while a second valve means blocks any inward flow of gas through the outlet port during inhalation phases. A pressure plenum with associated means for positively maintaining the pressure therein at a predetermined level provides a gas source to compensate for leaks, the gas flowing through a bleeder means into the conduit means when the pressure in the conduit means falls below the said predetermined level. A gas flow sensing means senses the flow of gas towards the patient during the expiration phase and produces a signal that actuates a control for the charging means when the gas flow exceeds a predetermined threshold flow rate, due to the onset of inspiration by the patient. The bleeder means provides a substantially unrestricted gas flow path from the plenum into the conduit means for flow rates up to a maximum which is approximately equal to the said threshold flow rate. Gas leaks from the patient supply tap which do not exceed the said threshold flow rate are thereby replenished by a compensating gas flow into the conduit means from the plenum, without actuating the charging means, while the pressure in the conduit means is maintained at a level which is substantially at least equal to the predetermined plenum level despite such gas leaks.

The operating method contemplated by the present invention comprises sensing the gas flow rate towards the patient through the conduit means when the inlet port is blocked by the first valve means, supplying gas to the conduit means during expiratory phases to compensate for gas leaks from the patient supply tap, limiting such compensating flow to a rate no greater than the patient's expected voluntary inhalation flow rate, and actuating the charging means control to operate the charging means when the sensed gas flow rate exceeds a predetermined threshold level which is no greater than the patient's expected voluntary inhalation flow rate.

In a particular embodiment of the invention, the outlet port or expiratory end of the conduit means is engaged to maintain the conduit pressure at or above the desired minimum level by connecting the bleeder means between the plenum and the said outlet port. In this embodiment, the gas flow sensor comprises a pressure differential sensor which is operably connected to sense pressure differences between the plenum and the outlet port. The bleeder means includes an adjustable flow restriction means adapted to produce a predetermined pressure differential across the bleeder when the gas flow rate therethrough equals the threshold flow rate for actuating the charging means. As the bleeder means provides the only gas inlet into the conduit during expiration phases, the said pressure differential may be equated to a voluntary inhalation by the patient. The bleeder means enables an equilization of pressure between the plenum and the conduit means for normally encountered leaks that do not exceed the threshold flow rate, thereby preventing an accumulation of gas loss from the conduit means and a resulting false triggering of the charging means.

More detailed aspects of this embodiment include the provision of a second plenum that communicates with the conduit means during expiration phases through the outlet port thereof, substantially equalizing the conduit means pressure with the second plenum pressure. A check valve separates the two plenums and permits a unidirectional gas flow from the second to the first for the removal of expired air from the system. The plenums are respectively enclosed within first and second chambers, with a jet means provided to direct a substantially constant velocity gas jet through a venturi and into the first chamber for maintaining the pressure in said chamber at a substantially constant level. A third chamber is interposed between the jet means and the venturi, and includes at least one outlet orifice for venting gas expired by the patient.

In another embodiment of the invention, a sensing means is interposed in line with the patient supply tap to directly sense the gas flow towards the patient during expiration phases. In this embodiment, the pressure within the conduit means may be maintained at or above the desired minimum level by means of a simple pressure regulator communicating with the conduit means at any convenient location.

BRIEF DESCRIPTION OF THE DRAWINGS

Further advantages and features of the present invention will be apparent to those skilled in the art from the ensuing detailed description thereof, taken with the accompanying drawings, in which:

FIG. 1 is a partially schematic diagram of a respirator system constructed in accordance with the invention;

FIG. 2 is an illustrative graphical representation of a typical gas flow cycle encountered in a tube inserted into a patient's trachea and supplied with gas by a respirator system which incorporates the present invention, illustrating the effect of a gas leak at the end of the tube;

FIG. 3 is an illustrative graphical representation of the gas pressure inside the conduit system during cyclical operation of a respirator, with the pressure pattern characteristic of the present invention shown in solid lines and that of an unstable condition encountered in the prior art in dashed lines;

FIG. 4 is a sectional view in frontal elevation of the pressure control and sensing apparatus provided in one embodiment of the invention;

FIG. 5 is a sectional view in right-side elevation of the upper portion of the apparatus shown in FIG. 4; and

FIG. 6 is a schematic diagram of another embodiment of the invention.

DETAILED DESCRIPTION OF PARTICULAR EMBODIMENTS

Referring to FIG. 1, there is shown an embodiment of the invention in which an air or air-oxygen mixture is delivered to a conduit system by a conventional charging apparatus which includes a gas mix box **10** in which gas is mixed to the desired composition, a piston **12** slidably lodged in a cylinder **14**, and a manifold **16** from which gas is supplied to the delivery system. The piston **12** sucks in air from the manifold **16** through a connecting pipe **18** during backstrokes, producing a pressure drop in the manifold **16** that draws in air from mix box **10** through a check valve **20**. An adjustable pressure relief valve **22** is located in the manifold **16** to assure that the gas delivered to the patient does not exceed the pressure setting of the relief valve. The piston **12** moves forward in response to an actuating signal from a breath assist control switch **24**, delivering a volume of gas from the manifold **16** to the patient supply system. The gas volume may be either a preset amount or determined dynamically by measuring the patient's lung pressure and stopping piston movement when that pressure reaches a desired level.

The conduit means for guiding the flow of gas to and from a patient includes a plastic tubing network, generally indicated by numeral **26**, in a T configuration. One branch **28** of the T functions as an inlet or inhalation tube, the end of which is open and fitted over an orifice in manifold **16** to form an inlet port **30** for the tube network. The other branch **32** serves as a gas outlet or expiration tube and has an open end comprising a gas outlet port **34**. A spur tube **36**, which may be equated to the stem of the T, is tapped into the tube network at a location intermediate the inlet and outlet ports **30** and **34**, and provides a conduit for both inhaled and expired gas. An additional plastic tube **38**, which may be referred to as the tracheal tube, is tightly fitted over tube **36** and passed down the trachea of the patient **40** to conduct air to and from the patient's lungs. Associated with the inlet branch **28** is a pressure gauge **42** and a filter or humidifying device **44** to treat the supplied gas before delivery to the patient. The tracheal tube **38** is generally introduced through the mouth, but under certain circumstances it may be directed through a nasal passage, or surgically inserted directly into the trachea.

Gas blocking devices are provided at either branch end of the tube network **26** to insure that gas will flow through the inlet branch only in a direction from the manifold **16** to the patient, and through the outlet branch **32** only from the patient to the outlet port **34** (expect for certain triggering and leakage flows discussed below). The flow blocking mechanism or inlet branch **28** comprises a check valve **46** set in the inlet port **30**, while the blocking mechanism for outlet branch **32** comprises the combination of a diaphragm **48** and a reciprocal piston **50** aligned to alternately flex the diaphragm **48** to a position blocking outlet port **34** and to release the diaphragm to a non-blocking position.

There will frequently be a small clearance between the tracheal tube 38 shown in FIG. 1 and the patient's trachea, resulting in a certain loss of gas from the patient-respirator complex that escapes up through the trachea around the tracheal tube 38 and out the patient's mouth, such gas losses being indicated in the figure by arrows 52. To compensate for these gas losses without subjecting the patient to the risks inherent in prior respirator systems, a structure is provided at the outlet port 34 that includes first and second chambers 54 and 56, mutually partitioned by a check valve 58 that enables a unidirectional gas flow from the chamber 56 to chamber 54. The second-mentioned chamber 56 completely surrounds the outlet port 34 so that all gas entering or leaving the said port must also pass through chamber 56, fixing the pressure in outlet branch 32 whenever the outlet port 34 is unblocked. Diaphragm 48 forms one wall of the chamber 56, the other chamber walls conveniently being formed from a plastic mold.

The pressure inside chamber 54 is maintained at a constant level by means of a gas jet source 60 that delivers a steady jet stream through openings in the longitudinally opposed walls of a third chamber 62 to a venturi 64 that opens into the first chamber 54. The gas jet source 60 is adjustable within a range enabling the pressure inside chamber 54 to be set at between zero and 15 centimeters H_2O gauge (70 centimeters H_2O equaling approximately 1 pound per square inch). The third chamber 62 is provided with four orifices in its transverse walls, two of which are shown in the drawings and identified by reference numerals 66 and 68, through which gas exhaled by the patient may be expelled from the respirator system.

A bleeder conduit or line 70 is connected between chambers 54 and 56, with an adjustable needle valve 72 forming a restriction in the bleeder line to limit the gas flow rate from chamber 54 to chamber 56 (gas flows in the opposite direction, from chamber 56 to chamber 54, are transmitted through check valve 58, which forms a parallel bypass to the bleeder line 70 in this flow direction). The needle valve 72 may be adjusted from a full-open position, at which the gas flow through the bleeder line 70 is substantially unrestricted, to a completely closed position.

A transducer 74, shown in FIG. 1, senses the pressures in chambers 54 and 56 through connecting tubes 76 and 78, respectively, and compares the two sensed pressure. When the pressure in chamber 54 exceeds that in chamber 56 by a predetermined threshold amount for which the transducer 74 is set, control signals are transmitted from the transducer to the breath assist control 24 for actuation of the breath assist mechanism, and to the piston 50 causing that piston to move against the diaphragm 48 and block the outlet port 34. The pickup level of transducer 74 for triggering the breath assist mechanism is adjustable within a range of, for example, 0.05 centimeter H_2O to 1.0 centimeter H_2O. The needle valve 72 and transducer 74 are set at levels determined by the expected voluntary inhalation flow rate produced by the patient 40 such that gas flows through bleeder line 70 from chamber 54 to chamber 56 are substantially unrestricted by needle valve 72 for flow rates that do not exceed the expected inhalation flow rate. For such flow rates, the pressure inside chambers 54 and 56 are substantially identical, and transducer 74 will not produce a control signal. Should a back flow be established through outlet branch 32 towards the patient that exceeds the expected inhalation flow rate, needle valve 72 restricts the flow rate of gas through bleeder line 70 to a level less than that which is necessary to equalize the pressure between chambers 54 and 56, thereby producing a pressure differential between the two chambers that causes transducer 74 to produce a control signal.

Cyclical gas flows to and from the patient and the gas pressure within the conduit network are illustrated respectively in FIGS. 2 and 3. Referring first to FIG. 2, the cyclical respirator operation is assumed to be initiated when piston 12 is actuated by breath assist control 24 to move forward into cylinder 14, producing an inflow of gas to the patient as indicated by line 80. When the patient has inspired a sufficient quantity of gas, the respirator system switches to an exhalation mode in which gas is expired from the patient's lungs, through tube 36, and out the outlet port 34, as indicated by line 82. When the patient has expelled a full quantity of gas, the respirator system pauses until the patient inhales gas from the tube network in an attempt to draw breath, the initial inhalation attempt being indicated by the in-flow surge 84. With a proper adjustment of the needle valve 72 and transducer 74, this surge will exceed the trigger threshold 86 at which the transducer 74 is set, producing a signal to actuate the breath assist mechanism and initiate another gas charge 88 into the respirator tube network, thereby starting another breath cycle. It should be noted that a substantial amount of gas leakage, as indicated by line 90, may be tolerated from the tube network without triggering the transducer 74 to actuate the breath assist mechanism, so long as the leakage is not so gross as to exceed the trigger threshold level 86.

The gas pressure pattern in the respirator tubes is illustrated in FIG. 3 against the same time scale as that of FIG. 2. The pressure increases along line 92 as gas is charged into the tube in response to a trigger signal, reaching a peak at the end of the charging period and then gradually declining along line 94 to a level not less than the minimum required to adequately expand the alveolar sacs. The pressure pattern produced by the present invention is shown in solid lines. During the interval 96 following full breath expiration but preceeding the beginning of the next inhalation, the pressure in the tubes remains steady and does not drop below the minimum desired level, despite the continuous leakage from the tracheal tube during this period, because a replenishing flow of gas is supplied to the tubes through bleeder line 70 and chamber 56. A slight dip in pressure 98 occurs when the patient attempts to inhale, this dip resulting from the patient's intake rate exceeding the rate at which replenishing gas can be supplied through bleeder line 70. Although slight, the pressure dip 98 is sufficient to actuate the highly sensitive transducer 74 to produce a control signal, recycling the breath assist mechanism. It can be seen from the drawing that the tube pressure is maintained at a substantially constant value during the interval 96, and successful breathing is achieved. By contrast, an unstable condition that may occur with prior art respirator systems is indicated in dashed lines. Such prior art systems that do not employ compensating gas supply mechanisms will gradually undergo an accumulating pressure loss during an expiration phase due to the gas leak. As the breath assist mechanism for these systems is commonly responsive to the pressure within the tubes, rather than to the gas flow rate measured by the present invention, a point may be reached at which the pressure drop is sufficient to actuate the breath assist mechanism, and a new charge of gas is supplied to the system before the patient is ready to receive it. This occurrence is indicated at point **100** in FIG. **3.** It may lead to an unstable condition in which the the patient does not have sufficient time to exhale before the next charge of gas. The pressure inside the lungs which is generally somewhat less than the tube pressure but follows a similar rise and fall pattern, can thereby build up to the point at which a pneumothorax occurs.

Referring now to FIGS. **4** and **5** for further details of the apparatus at the expiratory end of the tube network, chamber **56** is formed from a plastic block with a cylindrical tube **102** extending through one wall to form a mounting jack for outlet tube **32** on the exterior of the chamber, the other end of tube **102** forming outlet orifice **34** adjacent to flexible membrane **48.** The chamber **54** comprises an inner chamber **104** downstream of winged check valve **58** that communicates with a surrounding annular gas reservoir **106** through a port **108.** The bleeder line **70** of FIG. **1** comprises a passageway **110** through the chamber block, shown in FIG. **5,** a portion of which passageway is shaped to form a seat **112** for manually adjustable needle valve **72,** which is shown in a closed position. Highly sensitive adjustments may be made to the flow restriction produced by needle valve **72** by rotating the valve handle **114** to lift or lower the valve stem **116.** A similar needle valve **118** is provided in the gas jet mechanism to enable a precise control of the jet, indicated by arrow **120,** before entering the venturi **64.** Gas is introduced into the jet mechanism through a nozzle **122** at a pressure of approximately **50** psig, passes through a filter **124** and restriction orifice **126** to a smaller chamber **128** at a pressure in the order of **10–20** psig, and then proceeds through valve **118** for deflection upward to the chamber **62,** venturi **64,** and chamber **54.** The valve **118** is adjustable within a range which results in a gas pressure in chamber **54** of between zero and **15** centimeters H_2O gauge, as mentioned previously.

A solenoid **130** is arranged about a rearward extension **132** of the piston **50** to move the piston alternately into and away from the diaphragm **48,** blocking and opening outlet port **34.** The solenoid is connected by leads **134** for control by the transducer **74.**

In operation, the tracheal tube **38** is inserted into the patient's trachea and the respirator turned on with the needle valve **72** fully open. At this point, the flow of gas through bleeder line **70** from chamber **54** to chamber **56** will generally be substantially unrestricted, even for flow rates as large as that produced by the patient inhaling, and the breath assist apparatus will not respond to the patient's breathing. The needle valve **72** is then gradually closed until the restriction presented to the flow of gas through the bleeder line **70** during patient inhalation attempts is sufficient to produce a pressure drop that exceeds the threshold level of transducer **74,** thus triggering the breath assist apparatus into action. This point may be detected by observing when the pressure inside the conduit network, as indicated by pressure gauge **42,** first begins to follow the patient's rhythmic breathing rate and exhibits a cyclical pattern such as that shown in FIG. **3** With the needle valve **72** at this setting, the flow path through bleeder **70** is sufficiently

open to enable a replenishing gas flow from chamber **54** to chamber **56** and thence into the conduit network **26** to compensate for all except unusually large gas leaks from that network, without triggering the breath assist apparatus. At the same time, patient attempts to inhale will produce a pressure drop that does trigger the breath assist.

A full cycle of the respirator operation, beginning at a time just after the transducer **74** has sensed an attempt to breath, will now be described. At the beginning of the cycle to the solenoid, an energizing signal is transmitted from the transducer **74** over leads **134** to the solenoid **130,** producing a magnetic field that urges piston **50** against diaphragm **48** to close the outlet port **34.** The transducer **74** also transmits a control signal to the breath assist control switch **24,** which actuates piston **12** to move into cylinder **14,** thereby forcing gas out of manifold **16,** past check valve **46,** and into the conduit network through inlet port **30.** With the outlet port **34** closed, a volume of gas equal to that charged into the conduit system is forced out through tap **36** and the tracheal tube **38.** Most of this gas will be supplied to the patient's lungs, but some may be lost by leakage at the end of the tracheal tube **38.**

At the end of the inhalation phase, the piston **12** is retracted, drawing a new supply of gas into the manifold **16** from mix chamber **10,** and the patient begins to exhale. At about the same time, the energizing signal is removed from solenoid **130** and the piston **50** is spring urged back from diaphragm **48,** opening outlet port **34.** Check valve **46** blocks any outflow of gas through inlet valve **30,** so that all of the patient's expired gas flows through outlet port **34** into chamber **56,** through check valve **58** and chamber **54,** and out through vents **66, 68** and the vents not shown in the drawings. After active expiration ends, there is a pause before the next breath and renewed operation of the breath assist apparatus, during which time gas leaks may continue to drain gas from the conduit network. During this period, the chamber **54** is maintained as a substantially constant pressure plenum by the gas jet mechanism **60** acting through venturi **64.** The gas leaks are made up by a compensating, substantially unrestricted gas flow through the bleeder line **70** from chamber **54** to chamber **56,** thus maintaining the latter chamber also as a substantially constant pressure plenum. Since chamber **56** communicates openly with the conduit network through outlet port **34,** the pressure in that network may be kept at or above a minimum desired lung pressure so long as the pressure in chamber **54** is maintained.

When the patient attempts to draw breath, a sudden inflow of gas to the tap **36** is created which, due to the restriction of needle valve **72,** cannot be fully met by a compensating flow through bleeder line **70.** As a result, the pressure within the conduit network drops momentarily, creating a pressure differential between the plenums of chambers **54** and **56** that exceeds the threshold of transducer **74,** which instrument thereupon produces appropriate signals to start another respirator cycle.

The above-described embodiment is highly sensitive to gas flows, and is therefore particularly useful for patients such as infants who process a relatively small amount of gas with each breath. Another embodiment of the invention shown in FIG. **6** that is intended to be used with adults. This embodiment employs a simplified apparatus to achieve a somewhat lesser degree of sensitivity that nonetheless is sensitive enough for older patients. Several elements of this embodiment are carried over from the embodiment of FIG. **1**, and the same numerals have been used to indicate elements common to both.

Gas is cyclically charged into the conduit network, as in the previous embodiment, by breath assist apparatus which includes a piston **12** slidably lodged in cylinder **14**, a gas mix chamber **10**, and a manifold **16** which is connected by pipes or tubes to the last two elements. Check valve **46** prevents any reverse gas flow out of the conduit inlet port **30**, while an expandable balloon or bladder **136** is positioned adjacent to outlet port **34** to block that port during inhalation by expanding under the influence of air pumped in through a balloon stem **138**.

Instead of sensing a patient's attempt to breathe by measuring pressure differentials at the expiration end of the conduit network, a gas flow sensing mechanism **140** is interposed directly in line with the patient tap **36**. Gas flow sensor **140** may be of any convenient type, for example an ultrasonic device such as the sensor described in U.S. Pat. NO. **3,680,375** to Joy et al., so long as it is able to detect gas flows caused by a patient's attempt to inhale. A pressure regulator **142** is tapped into the inlet conduit branch **28** through a bleeder arrangement such as check valve **144** that permits gas to flow only into the conduit, the pressure regulator **142** comprising essentially a constant pressure plenum which is maintained at the minimum desired expiratory pressure.

Gas flow sensor **140** is connected in a control circuit with the breath assist control **24** through a switch **146**, and also to the balloon **136**, switch **146** being closed during expiration but open during inhalation to prevent the breath assist apparatus from being triggered. In operation, gas is charged into the conduit network to the patient for the patient to inhale, with balloon **136** expanded to block outlet port **30**. After the patient has received a full breath, balloon **136** is permitted to go flacid and the patient expires through outlet branch **32** and outlet port **34**. Should the pressure in the conduit network begin to fall below the level necessary to keep the alveolar sacs expanded, for instance because of gas leakage from tracheal tube **38**, a gas flow commences from the pressure regulator **142** into the conduit system that holds the pressure therein at an acceptable level. When the patient again attempts to inhale, the large inrush of gas exceeds the setting of flow sensor **140**, which thereupon initiates a control signal to trigger the breath assist control **24** and the input mechanism for balloon **136**, beginning a new breath cycle.

It is obvious that many modifications may be made to the subject invention which come within its true scope and spirit. Thus, the scope of the subject invention is considered to be limited only by the appended claims.

What is desired to be secured by Letters Patent of the United States is:

1. A respirator system for assisting a patient's breathing during alternate inhalation and expiration phases, said system including gas conduit means having an inlet port, an outlet port, and a patient supply tap intermediate said inlet and outlet ports, recyclable means for charging gas into said inlet port during inhalation phases for delivery to a patient, a control means for actuating said charging means, first valve means adapted to block an outward flow of gas through said inlet port during expiration phases, and second valve means adapted to block an inward flow of gas through said outlet port during inhalation phases, wherein the improvement comprises the provision of:

a pressure plenum,

means for positively maintaining said plenum at a predetermined pressure level,

bleeder means adapted to conduct gas from said plenum into said gas conduit means, and

a gas flow sensing means adapted to sense a flow of gas through said conduit means towards the patient during expiration phases and to produce a control signal in response to said flow exceeding a predetermined threshold flow rate,

said control means being connected to said sensing means for actuation by said control signal, and said bleeder means providing a gas flow path of sufficient conductance to enable a substantially unrestricted inflow of gas into said conduit means from said plenum at a maximum rate approximately equal to said threshold flow rate, whereby gas leaks from the patient supply tap at leak rates not exceeding the said threshold flow rate are replenished by a compensating gas flow into the conduit means from the pressure plenum without producing a control signal for actuating the gas charging means, and the pressure in said conduit means is maintained at a level substantially at least equal to said predetermined plenum level despite said gas leaks.

2. The respirator system of claim **1**, wherein said bleeder means provides a gas flow path from said plenum to the outlet port of said conduit means, and said gas flow sensing means comprises a pressure differential sensor means operably connected to sense pressure differences between said plenum and said outlet port, said bleeder means including flow restriction means adapted to produce a predetermined pressure differential across said bleeder means when the gas flow rate therethrough to said outlet port equals said threshold flow rate, said pressure differential sensor means being adapted to produce a control signal in response to the sensed pressure differential exceeding said predetermined amount.

3. The respirator system of claim **2**, said flow restriction means including adjustment means for adjusting the maximum gas flow rate through said bleeder means within a range corresponding to the expected range of voluntary inhalation flow rates produced by a patient.

4. The respirator system of claim **1**, wherein said gas flow sensing means is interposed in line with said patient supply tap.

5. A respirator system for assisting a patient's breathing during alternate inhalation and expiration phases, said system including gas conduit means having an inlet port, an outlet port, and a patient supply tap intermediate said inlet and outlet ports, recyclable means for charging gas into said inlet port during inhalation phases for delivery to a patient, a control means for actuating said charging means, first valve means adapted to block an outward flow of gas through said inlet port during expiration phases, and second valve means adapted to block an inward flow of gas through said outlet port during inhalation phases, wherein the improvement comprises the provision of:

first and second pressure plenums, means for positively maintaining the pressure in said first plenum at a predetermined level, adjustable bleeder means adapted to conduct gas from said first plenum to said second plenum to provide a pressure therein, said second plenum communicating with said conduit means during the expiration phases of said respirator so as to maintain said conduit means at a pressure substantially equal to the pressure of the second plenum during such expiration phases, and a pressure differential sensor means operably connected to sense pressure differences between said first and second plenums and to produce a control signal for actuation of the control means in response to the sensed pressure differential exceeding a predetermined amount.

6. The respirator system of claim **5**, wherein said second plenum communicates with said conduit means through the outlet port thereof, said bleeder means providing a gas flow path from said first plenum to said second plenum and thereby to said conduit means during expiration phases when said second valve means is open, and further including vent means communicating with said first plenum to vent expired air from the system.

7. The respirator system of claim **6**, and further including a passageway between said first and second plenums, said passageway including a check valve enabling a unidirectional gas flow from the second plenum to the first plenum in response to a pressure differential therebetween of appropriate polarity.

8. A respirator system for assisting a patient's breathing during alternate inhalation and expiration phases, said system including gas conduit means having an inlet port, an outlet port, and a patient supply tap intermediate said inlet and outlet ports, recyclable means for charging gas into said inlet port during inhalation phases for delivery to a patient, a control means for actuating said charging means, first valve means adapted to block an outward flow of gas through said inlet port during expiration phases, and second valve means adapted to block an inward flow of gas through said outlet port during inhalation phases, wherein the improvement comprises the provision of:

means responsive to a predetermined flow rate of gas through said conduit means to said patient supply tap during an expiration phase for producing a control signal to actuate said control means, and

pressure maintenance apparatus for said conduit means, said apparatus comprising a first plenum maintained at a predetermined pressure level, a second plenum in gas flow communication with said conduit means through said outlet port, check valve means enabling a unidirectional gas flow from the second plenum to the first plenum, and a bleeder conduit connected in parallel with said check valve means between said first and second plenums, said second plenum having a pressure during expiration phases determined by the pressure in said conduit means, said bleeder conduit including a gas flow restriction valve capable of being set to restrict the flow of gas between said plenums to a level no greater than the expected voluntary inhalation flow rate produced by a patient.

9. A respirator system for assisting a patient's breathing during alternate inhalation and expiration phases, said system including gas conduit means having an inlet port, an outlet port, and a patient supply tap intermediate said inlet and outlet ports, recyclable means for charging gas into said inlet port during inhalation phases for delivery to a patient, a control means for actuating said charging means, first valve means adapted to block an outward flow of gas through said inlet port during expiration phases, and second valve means adapted to block an inward flow of gas through said outlet port during inhalation phases, wherein the improvement comprises the provision of:

a first chamber, a second chamber surrounding said conduit means outlet port and communicating therethrough with said conduit means when said second valve means is open, a check valve means enabling a unidirectional gas flow from the second to the first chamber, a bleeder conduit connected in parallel with said check valve means between said first and second chambers, said bleeder conduit including an adjustable gas flow restriction valve for controlling the gas flow rate therethrough, vent means communicating with said first chamber for venting expired air from the system, a venturi in gas flow communication with said first chamber, and jet means adapted to direct a substantially constant velocity gas jet through said venturi to said first chamber, thereby maintaining the pressure in said first chamber at a substantially constant level.

10. The respirator system of claim **9**, and further including a pressure differential sensor means operably connected to sense pressure differences between said first and second plenums and to produce a control signal for actuation of the control means in response to the sensed pressure differential exceeding a predetermined amount.

11. The respirator system of claim **9**, and further including a third chamber interposed between said jet means and said venturi, said third chamber including longitudinally opposed walls having ports therein enabling the gas jet to pass through the chamber, and at least one outlet orifice in a transverse wall of said third chamber providing a vent for expired gas transmitted through said check valve means.

12. The respirator of claim **9**, wherein said second valve means comprises the combination of a diaphragm and means for releasably closing said diaphragm over said conduit means outlet port, said diaphragm forming a wall of said second chamber.

13. A method of operating a respirator system of the type which includes gas conduit means having an inlet port, an outlet port, and a patient supply tap intermediate said inlet and outlet ports, recyclable means for charging gas inwardly into said inlet port during inhalation phases for delivery to a patient, a control means for actuating said charging means, first valve means adapted to block an outflow of gas through said inlet port during expiration phases, and second valve means adapted to block an inward flow of gas through said outlet port during inhalation phases, said method comprising:

sensing the flow rate of gas toward a patient through said conduit means during expiratory phases when the inlet port is blocked by said first valve means,

supplying gas to said conduit means during expiratory phases to compensate for gas leaks from the patient supply tap,

limiting the compensating gas flow to a rate no greater than the patient's expected voluntary inhalation flow rate, and actuating the control means to operate the charging means when the sensed gas flow rate exceeds a predetermined threshold level which is no greater than the patient's expected voluntary inhalation flow rate.

14. The method of claim 13, and further including the step of maintaining a plenum at a substantially constant pressure, wherein said compensating gas flow is supplied from said plenum to said conduit means through the outlet port thereof, and the gas flow rate to the patient is sensed by sensing the gas flow rate from the plenum to the conduit means.

15. The method of claim 14, wherein said compensating gas flow is limited by restricting the gas flow from the plenum to the conduit means, and the rate of said restricted gas flow is sensed by sensing the pressure differential between said plenum and conduit means.

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