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[54] **RESPIRATOR**

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[52] **U.S. Cl.** ..... **128/145.8**, 137/63 R

[51] **Int. Cl.** **A61m 16/00**

[58] **Field of Search** ..... 128/145.5, 145.6, 145.7, 128/145.8, 156, 145; 137/63 R

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[57] **ABSTRACT**

A volume-limited general medical respirator is controlled by an integrated fluidic circuit. The respirator includes various alarm systems, control valving and main exhalation and inhalation phases operated entirely through gas means. A collapsible bellows is utilized to inspire the patient and is powered by an operative gas such as oxygen. The same operative gas not only powers the bellows during inspiration of the patient but is then recycled during the exhalation phase and thereafter used in the system for introduction to the patient during the subsequent inspiration phase.

16 Claims, 4 Drawing Figures

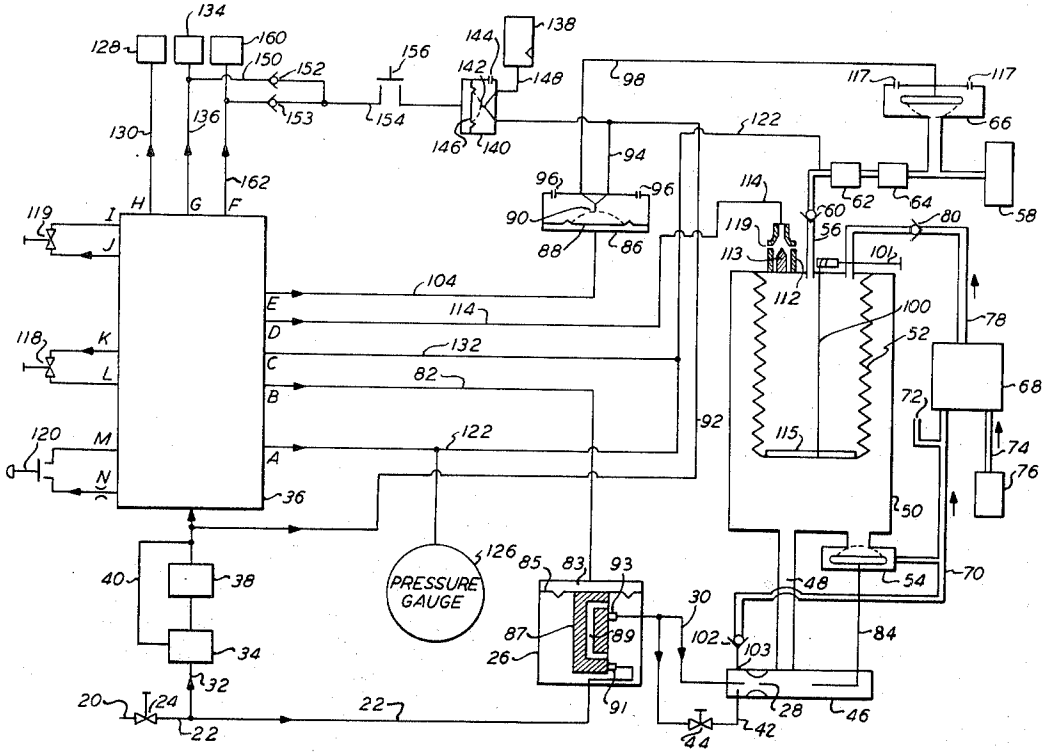


FIG. 1

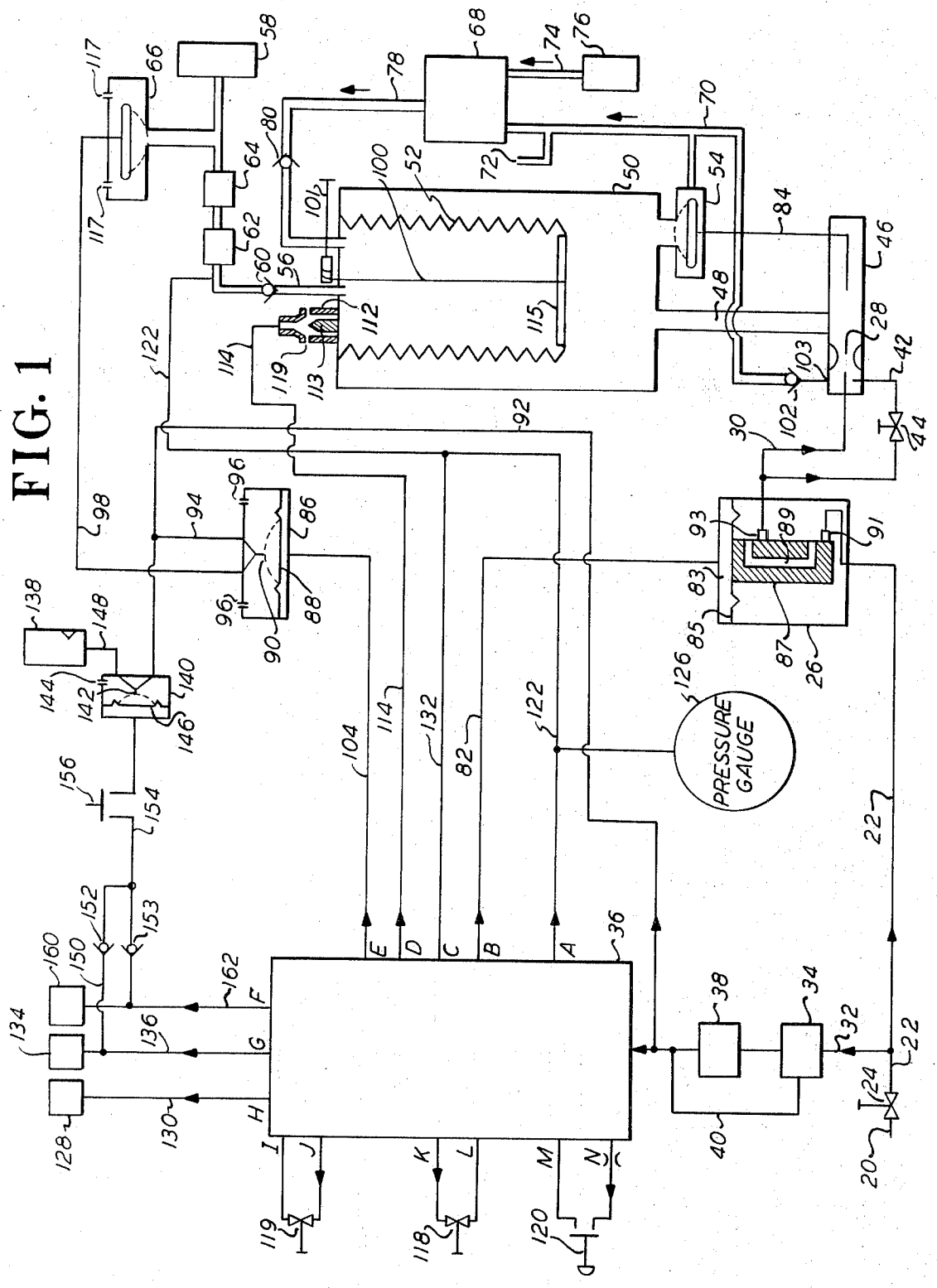


FIG. 3

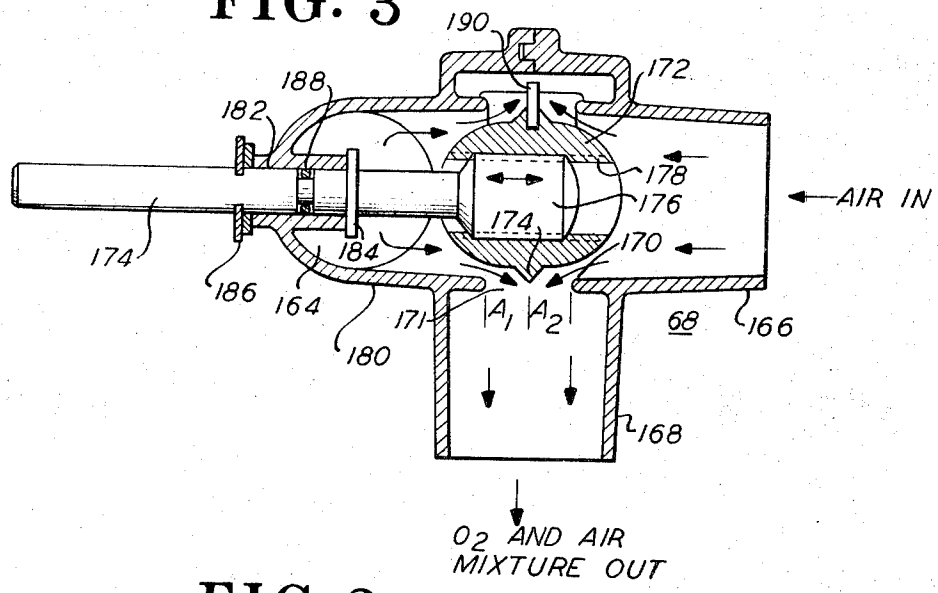


FIG. 2

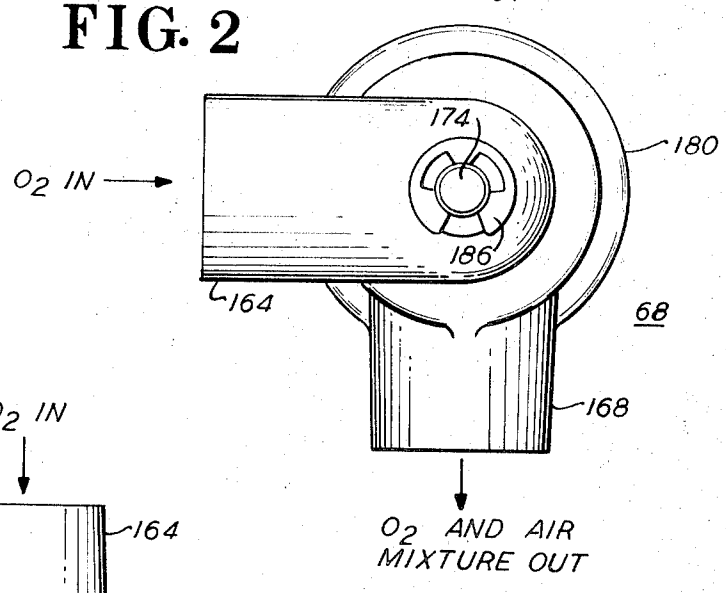
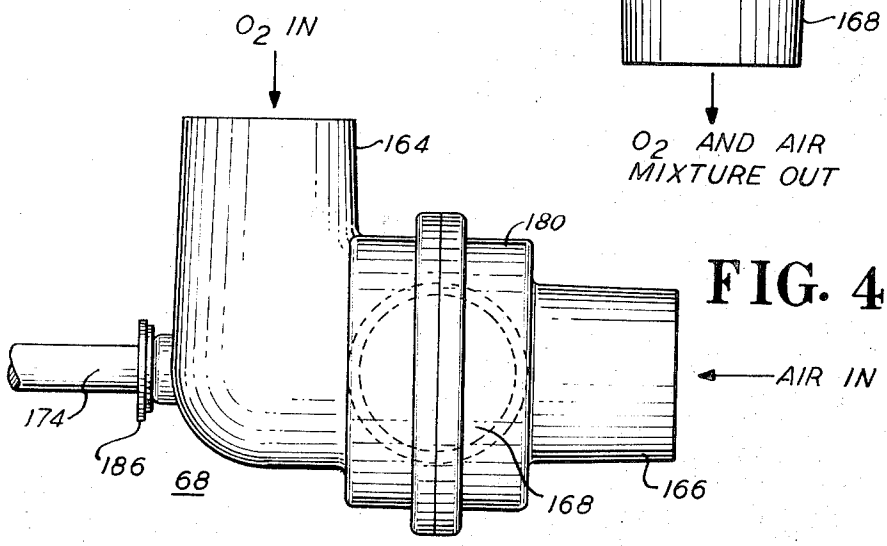


FIG. 4



RESPIRATOR

BACKGROUND OF THE INVENTION

This invention relates to patient breathing equipment and more particularly to a volume limited respirator for assisting in the breathing or respiration of a patient.

Basically there are two types of medical respirators presently in use, one of which is a pressure limited respirator wherein the inspiration cycle is terminated when a predetermined pressure is sensed in the patient circuit. The predetermined sensed pressure indicates when the lungs are inflated at or near full capacity. A pressure limited respirator has a disadvantage in that the specific volume of gas delivered to the patient is generally uncertain and may vary during use of the respirator since the specific delivered volume is dependent upon the compliance of the patient's lungs.

A volume-limited respirator on the other hand provides a given predetermined volume of gas to the patient and continues to provide this predetermined volume during the respirator use. The volume-limited respirator does not depend upon patient lung compliance but operates to deliver a specific known volume of gas to the patient during each inhalation cycle. A volume-limited respirator may also include a pressure relief means which is responsive to a predetermined pressure sensed in the patient circuit in order to activate an alarm or otherwise terminate the inhalation phase in case of a pressure build-up in the patient airways caused by a flow stoppage such as an obstruction in the patient circuit.

In the field of medical respirators it is an advantage to power the apparatus entirely from a gas source and thus eliminate any electrical components or electrical connections which can be hazardous in the presence of oxygen which readily supports combustion. In this manner only a single source of power is necessary for operating the entire apparatus and electrical hazards are eliminated.

In hospitals a convenient source of pressurized supply is oxygen which is generally piped into various treatment or care rooms for easy access at many locations, however, the present respirator is operative with other gases under pressure, including air.

A medical respirator, in addition to other functions, must provide a varied range of oxygen concentrations to the patient and, preferably, an infinite range beginning at about 21 percent oxygen up to and including 100 percent oxygen. Any setting within this range must remain stable throughout the respirator operation. such oxygen ranges are normally provided on present respirators through a plurality of orifices which are changed to alter the oxygen concentration and, generally, the mixing between oxygen and air to vary oxygen concentrations occurs at relatively elevated pressures above atmospheric pressure.

SUMMARY OF THE INVENTION

In the present invention there is provided a fluidically controlled respirator for general medical use which is powered entirely by a source of pressurized oxygen and which includes various alarm circuits, fluid amplifiers, valves and control of inhalation and exhalation phases without the use of any other source of power.

An integrated fluidic circuit controls the various functions, however, the fluidic control itself does not form the essence of this invention. Such fluidic circuits

or controls are commercially available and may be devised by suppliers to meet whatever necessary design parameters are determined for the respirator.

An oxygen mixing system is used in the present respirator and includes a variable area relationship between incoming oxygen at approximately atmospheric pressure and make-up air at atmospheric pressure, which allows an infinite control through the entire selectable range and provides a stable oxygen/air volume output throughout the use of the respirator.

The oxygen source powers a collapsible bellows for inhalation of the patient with gas contained within the bellows. The same operative gas used to power the bellows is thereafter channeled through an oxygen mixing system and delivered to the interior of the bellows in a predetermined oxygen concentration to be supplied to the patient during the next inhalation phase. In this manner the most advantageous use is made of the pressurized oxygen since it is not only used to power or collapse the bellows but is therafter cycled, proportioned with air and introduced to the patient.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic illustration of the respirator circuitry used with the present invention.

FIG. **2** is a side elevational view of an oxygen mixing valve used on the respirator of this invention.

FIG. **3** is a cross-sectional view of the oxygen mixing valve taken along the line **3—3** of FIG. **2.**

FIG. **4** is a plan view of the oxygen mixing valve.

DESCRIPTION OF THE INVENTION

A. Basic Flow Circuit

Referring to FIG. **1,** there is shown a schematic of the overall respirator system having a main conduit means **22** which is adapted to be connected at **20** to a source of oxygen under a pressure of about 50 p.s.i. A main control valve **24** in the conduit **22** controls the supply of oxygen to the respirator. A normally closed interface valve **26** is also interposed in main supply conduit **22** and operates to control the supply oxygen to a venturi **28** through duct **30.** The operation of the interface valve **26** alternates between an opened and a closed position under certain conditions which will be later explained.

A portion of the supply oxygen is bled from main conduit **22** intermediate the main control valve **24** and interface valve **26,** through bleed duct **32** into a regulator **34.** The regulator **34** serves to reduce the supply oxygen pressure to approximately 3 p.s.i. for operation of the integrated fluidic circuit, shown as block diagram **36.** A filter **38** removes any impurities in bleed duct **32** to insure that the gas reaching the fluidic circuit **36** is free from harmful particles which might adversely affect its control characteristics. In the event an undue quantity of particles is built up within the filter **38,** causing the output pressure from the filter **38** to be reduced a predetermined amount, a feed-back line **40** senses a predetermined reduction in pressure and signals the regulator **34** to open a corresponding amount to offset the decreased sensed pressure. In this manner, even though filter **38** becomes partially clogged or otherwise obstructed, a relatively constant signal pressure is assured for operating the fluidic circuit **36.**

The oxygen supply from interface valve **26,** when open, enters venturi **28** and its flow through the venturi **28** is controlled by a control duct **42** having a venturi

flow control valve 44 in the flow stream. The control duct 42 communicates with the throat of the venturi and by controlling the flow in control duct 42, the flow through the venturi 28 can be correspondingly controlled.

The venturi 28, itself, is disposed within the entrance to a venturi chamber 46. An open passageway 48 provides communication between the venturi chamber 46 and the interior of a bellows container 50. A bellows 52 is freely suspended within the bellows container 50 and is circumferentially sealed to the upper surface of container 50. A further opening in the bellows container 50 is formed in the bottom thereof and is controlled by an inflatable mushroom valve 54. The interior of bellows 52 is isolated from the remaining interior of the bellows container 50, such that an inhalation of the patient, the pressure in the bellows container 50 is raised in order to collapse the bellows 52, thereby expelling any gas within the bellows 52 through patient conduit 56 to the patient, shown as 58. Within the patient conduit 56, there is also located a check valve 60 to prevent the patient's exhaled breath from being reintroduced into the bellows. A filter 62 removes any impurities in the form of pathogens which might be present within the gas from the bellows 52, and a humidifier 64 may be provided to add moisture to the gas to be inhaled by the patient. A patient exhaust valve 66 is teed from patient conduit 56 and opens the patient conduit 56 to the surrounding atmosphere during the exhalation phase, thereby forming a short path for the patient's exhalation.

During the inhalation and exhalation cycles, which will be later explained, the bellows 52, after reaching its uppermost position, is allowed to drop by means of gravity. A weight is normally located in the bottom of the bellows 52 to hasten its downward travel. As the bellows 52 drops, the gas which had filled the bellows container 50, exterior of bellows 52, is exhausted through mushroom valve 54 and enters an oxygen mixer 68 through conduit 70. A further flow of gas from the bellows container 50 is caused to pass downwardly through passageway 48 and into the venturi chamber 46. A pop-off valve 102 is in communication with the interior of the venturi chamber 46 at a point 103 upstream of the venturi 28. This valve 102 is held closed whenever gas from duct 30 is flowing through the venturi 28, since a slight vacuum is drawn at 103. When gas is exhausted from bellows 52 as described, however, the venturi 28 is not being used, therefore, the increase in pressure in venturi chamber 46 caused by the exhausted gas, opens pop-off valve 102 and allows the gas to combine, in conduit 70, with that gas which has exhausted through the mushroom valve 54. A standpipe conduit 72 connects the conduit 70 to atmosphere and serves to reduce the pressure of gas entering the oxygen mixer 68 from conduit 70 to at or slightly above atmospheric pressure. The gas passing through conduit 70 is preferably oxygen which previously had been used to collapse bellows 52. In the oxygen mixer, the oxygen from conduit 70 is mixed with room air which enters the mixer 68 from conduit 74 and an external filter 76. The oxygen mixer 68 will be fully explained further, however, it mixes the oxygen and air to a predetermined proportion and the mixed gas exits from the oxygen mixer 68 through conduit 78, check valve 80 and is introduced to the interior of the bellows 52 as the bellows descends downwardly in bellows container 50. In this manner the driving gas, oxygen, which forces the bellows to collapse on one phase of the cycle, is, on the very next cycle, exhausted, mixed to a predetermined proportion with room air and is introduced to the interior of the bellows 52, thereby utilizing a portion of the same oxygen for a powering gas and for the source of oxygen for introduction into the patient. When the respirator is set to operate on 21 percent oxygen, as will be later explained, all of the oxygen from the bellows container 50 is dumped to atmosphere through the standpipe conduit 72, and only room air is drawn into the bellows 52 through the oxygen mixer 68 as the bellows 52 descends downwardly. As it may be seen, and will be more fully explained in dealing with the control elements of this respirator, the oxygen/air mixture which enters the interior of bellows 52 from the oxygen mixer 68, is, on the succeeding phase, forced out of the bellows 52 as it is collapsed and thereafter enters the patient conduit 56 into the patient.

B. Inhalation Phase Control

To better understand the various fluidic controls, the operation of the respirator is presented by referring to the two main phases of operation, the inhalation phase where gas is forcibly caused to enter the patient, and the exhalation phase where the patient is allowed to exhale gases from his lungs to the surrounding atmosphere.

The integrated fluidic circuit 36, used with the present respirator, is preferably a commercially designed unit employing fluidic amplifiers. Such fluidic circuits are generally analagous to present electrical components and can be designed fairly readily to perform almost any functions or provide any signals that heretofore have relied upon electrical devices. As such, therefore, the assembly or internal operation of the fluidic circuit itself does not form a part of the present invention but it is only shown and described in block form using its output and input ports as a black box type of operation. The fluidic circuit, therefore, will be explained in terms of the outputs and inputs utilized to control the various features which make up the present invention. The fluidic circuit itself is designed commercially to operate in the disclosed manner based on the desired parameters required by the particular respirator functions.

The respirator is operated by turning the main control valve 24 to the on position, thus allowing oxygen at about 50 p.s.i. from the supply 20 to be supplied to interface valve 26 and also to provide the powering gas to integrated fluidic circuit 36, the latter gas being reduced to a pressure of about 3 p.s.i. through regulator 34. When the respirator initiates its inhalation phase, either manually, automatically, or by patient triggering as will be later explained, a control signal appears at both Port B and Port E of fluidic circuit 36. These signals are indicated by the directional arrows appearing adjacent these control ports on FIG. 1.

The presence of a control signal at Port B is transmitted through control flow line 82 to interface valve 26, causing it to open. The interface valve 26 is shown as a typical commercially available pneumatic valve, however, a fluidic amplifier may be suitably operable by a control pressure. The interface valve 26 has an enclosed chamber 83 and a flexible diaphragm 85 which is displaced when a pressure signal is received within

the enclosed chamber **83.** A sufficient displacement of the flexible diaphragm **85** causes the valve operator **87** to move from the normally closed position as shown in FIG. **1,** to an open position where a fluid passageway **89** within operator **87** is aligned with input port **91** and output port **93,** thus allowing the 50 p.s.i. supply oxygen to pass through the interface valve **26** into the venturi chamber **46.** As previously explained, the flow into venturi chamber **46** is controlled by the flow control valve **44** which affects the flow through the venturi **28.**

The increased pressure in the venturi chamber **46** is directly transmitted to the bellows container **50** through open passageway **48** and also serves to inflate, or close, the mushroom valve **54** through duct **84.** The closed position of mushroom valve **54** is shown in the dotted line position in FIG. **1.** The mushroom valve **54,** when closed, prevents the flow of gas from the bellows container **50,** thus allowing an immediate buildup of pressure within bellows container **50.**

The increased pressure within bellows container **50** causes the bellows **52** to collapse, forcing the gas contained therein out through the patient conduit **56,** check valve **60,** patient filter **62,** humidifier **64** and to the patient **58** through a mask, tracheal or endotracheal tube. The gas from the bellows **52** is prevented from being exhausted through conduit **78** by means of the check valve **80.**

The exhaust valve **66** is closed, as indicated in the dotted line position on FIG. **1,** so that the gas from bellows **52** is not exhausted to the surrounding room. Closing of exhaust valve **66** during the inhalation cycle is caused by the control signal appearing at Port E during the inhalation phase and which is transmitted via conduit **104** to a diaphragm control amplifier **86.** A stretched diaphragm **88** within control amplifier **86** is displaced by the signal pressure to close a bleed opening **90** which, when open, normally allows the 3 p.s.i. control oxygen signal from bleed conduit **92** and conduit **94,** to be vented through openings **96** to the atmosphere. By closing the bleed opening **90,** approximately 1.5 p.s.i. oxygen enters conduit **98** to the exhaust valve **66** and fills an expansible mushroom chamber to close exhaust valve **66.** Again, although a diaphragm activated valve is shown schematically in FIG. **1,** the diaphragm control amplifier **86** may be of comparable fluidic amplifier devices without departing from the spirit of this invention.

C. Exhalation Cycle

Under normal operating conditions the shift from the inhalation phase to exhalation phases occurs when a predetermined volume of gas has been expelled from the bellows **52** to the patient, thus, the volume-limited respirator delivers a constant gas volume during each inhalation phase. The volume of gas admitted to the patient is determined by adjusting the stroke of the bellows **52** to a preset point by means such as a cord **100** extending down into the interior of the bellows fastened to the bottom thereof and having a windable spool **101** to adjust the length of cord **100.** The cord **100** terminates the downward travel of the bellows when its extended length has been reached. Once the length of the cord is set in accordance with the tidal volume desired for the patient, the respirator will continue to provide that volume throughout its normal operation each time the bellows is collapsed. At the uppermost point of the bellows stroke, a bellows switch **112** is closed. The bellows switch **112** comprises a magnet **113** having its poles coaxially positioned with respect to the movement of bellows **52** and vent holes **119.** At the lower extremity of the bellows **52** is a magnet **115** having a predetermined pole position such that as the bellows reaches its uppermost position, a like pole of magnet **113** reacts with a like pole of magnet **115,** causing the magnet **113** to be repelled upwardly, closing normally open duct **114** which, in the normally open position, vents through holes **119.** This causes a signal to traverse through duct **114** to Port D of the fluidic circuit **36.** When Port D receives a signal of at least a predetermined strength, it changes the mode of the fluidic circuit **36** from its inhalation phase to its exhalation phase, and both Port B and Port E lose their control signals.

As Port B loses its signal, the interface valve **26** closes, thus shutting off the supply of oxygen to the venturi chamber **46** and the bellows container **50.** As the pressure drops in venturi chamber **46,** the inflated mushroom valve **54** becomes deflated and opens, as shown in the solid line position of FIG. **1,** to allow gas within the bellows container **50** to pass into conduit **70.** The pressure within the bellows container **50** is thereby depleted, allowing the bellows **52** to fall due to the force of gravity. As the bellows **52** drops, the oxygen within the surrounding bellows container is forced through the mushroom valve **54** into conduit **70** and also through passageway **48,** venturi chamber **46** and through pop-off valve **102** into conduit **70** for introduction into the oxygen mixer **68.** The stand pipe conduit **72** lowers the pressure of this oxygen to, at or slightly above atmospheric pressure as it enters oxygen mixer **68.** Also, since the stand pipe conduit **72** becomes filled with oxygen which is heavier than air, outside air does not enter the stand pipe conduit **72** to the oxygen mixer **68.** In the alternative, a check valve may be located within stand pipe conduit **72** to prevent the entrance of outside air. Room air, at atmospheric pressure, is drawn into the oxygen mixer **68** through external filter **76** and conduit **74.**

In FIGS. **2–4** there is shown an oxygen mixer which can be used in the present respirator and which proportions the air and oxygen by varying the area of the inlet openings for oxygen and air, however, the total opening, i.e. the total area of both openings remains constant, thus the total flow is constant despite a relative change in the air/oxygen concentration.

The principle of operation of the oxygen mixer **68,** that of mixing the gases in proportion to the area of their respective inlets, while maintaining the total area of both inlets constant, may be physically accomplished in many devices, however, in FIGS. **2–4** the device therein shown has been found to produce good reliable mixing results in an economically attractive unit.

The oxygen mixer **68** comprises an oxygen inlet port **164** and an air inlet port **166** adapted to be connected, respectively, to conduits **70** and **74** shown in FIG. **1.** The oxygen and air streams which enter their respective ports are at approximately atmospheric pressure and meet intermediate their inlet ports as will be described. The mixed stream of air/oxygen leaves the oxygen mixer **68** through discharge port **168** into conduit **78.** An inwardly directed projection **170** within the discharge port **168** serves to provide a fixed, reproducible orifice or circular area **171** through which the total

flow of air/oxygen passes. A movable baffle **172** proportions the respective areas through which the air and oxygen streams pass through opening **171.** A shown, the movable baffle **172** has a projection **174** which directs the respective air and oxygen streams into the discharge port **168.** The projection **174** divides the area within the discharge opening **171** into two separate definable areas, indicated in FIG. **3** as areas A_1 and A_2. Oxygen which enters the oxygen mixer **68** through inlet port **164** is channeled through the area designated as A_1, while the room air entering through inlet port **166** is channeled through the area designated as A_2. It may be seen, therefore, that by varying the proportions of A_1 and A_2 while maintaining the total of A_1 plus A_2 constant, the relative mixture of air and oxygen can be controlled while the total flow remains constant. A change in the A_1/A_2 areas proportions is accomplished by moving baffle **172,** thereby increasing or decreasing, simultaneously, the individual areas A_1 and A_2 while maintaining the overall discharge opening **171** constant. A control shaft **174** is engaged with the movable baffle **172** by means of a threaded enlarged end **176** coacting with internally threaded bore **178** within movabe baffle **172.** The shaft **174** is affixed to the oxygen mixer housing **180** through housing bore **182** and shaft retainers **184** and **186.** The shaft retainer **184** and **186** prevent axial movement of the shaft **174** with respect to housing **180** while allowing rotational movement therebetween. A shaft seal **188** prevents the leakage of gas along the shaft **174.** As the shaft **174** is rotated, therefore, the movable baffle **172,** constrained against rotational movement by means such as a pin **190** retained within an elongated slot in the housing **180,** is caused to move axially with respect to shaft **174,** thereby adjusting the relative areas A_1 and A_2.

As an example of the operation of the oxygen mixer **68,** in FIG. **3,** the movable baffle **172** is shown in a position such that A_1 is about equal to A_2, therefore, 50 percent air and 50 percent oxygen will be drawn through the oxygen mixer **68** and be discharged through port **168.** If the movable baffle **172** is adjusted such that A_2 is zero, i.e., at the extreme right position of FIG. **3,** no air will be admitted and 100 percent oxygen will be discharged through port **168.** Similarly, if A_1 is zero, then all of the oxygen from the bellows container **50** is discharged through standpipe conduit **72** to room atmosphere, and only air (21 percent oxygen) is drawn through the oxygen mixer **68** to the interior of bellows **52.** As it may readily be seen, the movable baffle **172** may be set at any desired intermediate position to provide between 21 percent oxygen and 100 percent oxygen. The mixing occurs at low pressure, at or near atmospheric, so that a predictable, fairly non-critical setting will retain the desired concentration with great stability.

Returning to FIG. **1,** the oxygen/air mixture leaves the oxygen mixer **68** through conduit **78,** check valve **80** and enters the interior of bellows **52** as the bellows **52** travels downward. The oxygen mixing is effected both by a slight position pressure in conduit **70** as a result of the belows **52** pushing oxygen from the bellows container **50,** and also through a slight negative pressure in conduit **78** caused by the expansion of the interior of bellows **52** as it falls downwardly.

The oxygen mixing system conserves the use of oxygen since, during inhalation, the oxygen is the propelling force to collapse the bellows and the same propelling oxygen is then mixed with room air and used to fill the expanding bellows **52** during the exhalation cycle.

As the bellows **52** drops, the patient exhales through exhaust valve **66** to the outside atmosphere. Since, at the commencement of this exhalation phase, the signal at Port E has been lost by activation of bellows switch **112,** the diaphragm **88** of control amplifier **86** returns to the position shown by solid lines in FIG. **1,** thereby opening bleed passage **90** to atmosphere through opening **96.** This allows a rapid deflation of the exhaust valve **66** to the position shown by solid line representation in FIG. **1,** so that the patient may exhale to the room through the exhaust valve **66** via openings **117.**

The bellows **52,** on exhalation, reaches the lowermost point of its stroke fairly rapidly and is unaffected by the time period of the patient's exhalation. The time of the exhalation phase, i.e., the period from the end of any one inhalation phase to the start of the next inhalation phase, is controlled by an adjustable orifice valve **118** which joins Ports K and L of the fluidic circuit **36.** The adjustable orifice valve **118** essentially controls the period of the exhalation phase by varying the time in which a contained volume is filled within fluidic circuit **36.** When the contained volume reaches a specified pressure, the fluidic circuit **36** changes to the inhalation phase. Therefore, by controlling the rate at which the contained volume is filled, the switchover time from the exhalation phase to the inhalation phase may be accurately adjusted.

A manual switchover from exhalation phase to inhalation phase is provided by pushbutton valve **120.** The valve **120,** when depressed, automatically switches the respirator into the inhalation phase no matter what phase the respirator is in at that time. The valve **120,** if held depressed, will retain the respirator in the inhalation phase, thereby holding a full breath within the patient for the taking of X-rays or other tests. In this manner the attending hospital personnel can manually operate the respirator.

When switchover from exhalation to inhalation occurs, whether manually or by the expiration timing circuit, the fluidic circuit **36** again provides a signal at each of Ports B and E, thereby beginning the inhalation phase again.

The inhalation phase may also be initiated through an effort by the patient to inhale. A patient triggering bleed duct **122** extends from the patient conduit **56** to Port A of the fluidic circuit **36.** A negative pressure of at least a predetermined threshold amount, such as occasioned by the patient attempting to inhale, signals Port A and causes the fluidic circuit **36** to switch over to the inhalation phase. In this manner, when the patient triggering feature is being used, the patient may operate the switchover from exhalation to inhalation, however, should the patient not signal the fluidic circuit **36,** normal phase switchover will occur due to the timing circuit. The amount of negative pressure required by the patient to trigger the fluidic circuit **36** is adjustable by means of valve **119.**

A pressure gauge **126** may be provided in communication with bleed duct **122** for a visual monitor of the inhalation pressure being applied to the patient, and also to provide a visual indication in the event a high pressure is built up in the patient conduit **56** as would

be experienced in case of an obstruction in the path to the patient's lungs.

A further visual monitor of the respirator is a patient trigger indicator **128** which is connected to Port H via duct **130.** When Port A receives a negative signal sufficient to cause a switchover from exhalation to inhalation, a visual signal appears at the patient trigger indicator **128** so that hospital personnel can easily determine when the respirator is being cycled through patient effort. The patient trigger indicator **128** is a pressure operated device, commercially available, and receives a pressure signal to move a disc to a position where a bright color appears in a transparent window.

D. Alarm Circuits

1. Low Pressure Alarm

An alarm is provided to sense a low pressure, or lack of pressure build-up in the patient conduit **56.** This low pressure might occur if the patient breathing mask, tracheal or endotracheal tube, becomes dislodged from the patient so that the back pressure normally provided by the patient's lungs during inhalation is not present.

This alarm is activated through Port C of the fluidic circuit **36,** that Port being connected to the patient bleed duct **122** through duct **132** and senses the pressure which is provided to the patient. Port C is adapted, through the fluidic circuit **36,** to require a signal of a predetermined pressure within a predetermined time interval or it will signal Port G that a low pressure or loss of pressure has occurred. In the preferred embodiment, Port C must receive a signal of about 8 cm. water at least every 15 seconds or it will cause a signal to appear at Port G. By this, the patient must be receiving gas at the rate of approximately four breaths per minute for which a predetermined back pressure is sensed at therefore, C. If, therefire, the connection means becomes dislodged from the patient, such that no back pressure is built up in patient conduit **56,** a maximum of 15 seconds will pass before a signal will appear at Port G.

A signal appearing at Port G immediately activates the low pressure alarm indicator **134** through duct **136.** The low pressure alarm indicator **134** is similar to the patient trigger indicator **128** and flashes a visual indication which is pressure activated.

In addition to this visual indicator **134,** an audible alarm **138** may give a further alarm to attending personnel. The audible alarm **138** is operated by oxygen via conduit **92** at control pressure through diaphragm amplifier **140.** Under normal conditions, the oxygen supply enters diaphragm amplifier **140** from conduit **92** and is vented to atmosphere through a bleed opening **142** and further openings **144.** The bleed opening **142** may be closed by diaphragm **146** as shown in the dotted line position of FIG. 1 when an alarm condition is in effect, thereby channeling the oxygen directly through duct **148** to sound the audible alarm **138.**

Movement of diaphragm **146** to close bleed opening **142** is effected by the signal which appears at Port G through duct **150** having a check valve **152** therein, and through duct **154.** A toggle valve **156** in duct **154** allows the attending personnel to connect or disconnect the operation of the audible alarm **138.**

Once the low pressure condition has been rectified, Port C will again receive a signal to indicate that back pressure in the patient circuit **56** has been restored. Port C will then disconnect the signal at Port G and will return to its normal function of determining that a signal in the patient conduit **56** is sensed every 15 seconds.

As the signal at Port G is removed, the low pressure alarm indicator **134** will return to its normal non-alarm status and the signal pressure in ducts **152** and **154** is removed, whereby diaphragm **146** is moved away from bleed opening **142,** allowing the pressure within duct **148** and the audible alarm to be dumped to the atmosphere through openings **144** in diaphragm amplifier **140,** silencing the audible alarm.

2. Failure to Cycle Alarm

An alarm is provided in the event the respirator fails to operate during inhalation or during exhalation cycles.

a. Failure to Cycle — Inhalation

During the inhalation cycle, there is always a signal present at Port B since it controls the interface valve **26** which allows the oxygen to collapse bellows **52.** Since inhalation can only occur when Port B is on, a timing device in the form of a contained volume within the fluidic circuit **36** is caused to fill. This volume is set to cause a signal to appear at Port F in the event that the signal at Port B is present beyond a predetermined time. As an example, if a signal is present at Port B for five seconds, or longer the contained volume reaches its predetermined pressure and a signal will appear at Port F. This would occur in the event an excessive pressure is built up within the patient such that the bellows would fail to collapse, thus the inhalation phase would, unless otherwise controlled, be continued indefinitely.

As the 5 second time interval is exceeded, a signal appears at Port F and also, the signal which would normally be present at Port E during inhalation is removed, thus the quick diaphragm valve **86** opens to relieve the pressure in the exhuast valve **66,** thereby opening the patient circuit **56** to atmosphere. In this manner, the excess pressure which has been built up within the patient is allowed to vent to the room atmosphere.

The alarm signal that appears at Port F causes a recognition color to flash in the failure to cycle alarm indicator **160** through duct **162.** In addition, the audible alarm **138** is signalled in the same manner as described in connection with the low pressure alarm indicator **134.** A check valve **153** is included in duct **154.**

b. Failure to Cycle — Exhalation

This alarm operates from Port D since this Port is signalled whenever the bellows **52** reaches the top of its stroke to activate bellows switch **112** to change the fluidic circuit **36** from an inhalation phase to exhalation phase. If Port D does not receive a signal in a predetermined interval, such as **15** seconds, a signal is caused to appear at Port F.

In addition to causing a signal to appear at Port F, this alarm circuit also insures that the signal at Port E is off, thus insuring that diaphragm valve **86** is open to allow the patient to freely exhale to atmosphere through patient exhaust valve **66.**

Therefore, in the event of any of the abnormal conditions under which an alarm might be triggered, i.e., low pressure, failure to cycle — inhalation, or failure to cycle — exhalation, the patient is immediately vented

to the atmosphere through the exhaust valve 66, insuring patient safety.

We claim:

1. A respirator adapted to be connected to a source of first gas under pressure, said respirator comprising a bellows container and an expandable, collapsible bellows operatively positioned within said bellows container, valve means for introducing the first gas into said bellows container to collapse said bellows, an inhalation conduit for receiving gas from said bellows whereby said bellows delivers a predetermined volume of a portion of the first gas to patient, means to remove the first gas from said bellows container during expansion of said bellows, means for reducing the pressure of said removed gas to substantially atmospheric pressure, mixing means for combining at least a portion of the first gas removed from said bellows container with a second gas at substantially atmospheric pressure and means to introduce the mixed first and second gases into said bellows during expansion of said bellows for delivery to said inhalation conduit during subsequent collapse of said bellows.

2. A respirator as defined in claim 1 wherein said first gas is oxygen and the second gas is air.

3. A respirator as defined in claim 1 wherein said mixing means comprises a chamber at about atmospheric pressure.

4. A respirator as defined in claim 3 wherein said chamber has a first and second valve means for introducing said first and second gases to said chamber, said first and second valve means having variable size openings wherein the total opening area of said first and second valve means is constant.

5. A respirator in accordance with claim 1, wherein said valve means for introducing said first gas into said bellows container includes a venturi chamber having an outlet to said bellows container, a first inlet branch for delivering said gas to said venturi chamber upstream of a ventui formed therein, and a second adjustably valved inlet branch in parallel with said first branch and delivering gas to the reduced pressure zone at said venturi in accordance with the preset adjustment of said valve; said adjustment by regulating the flow of said first gas into said container varying the rate of collapse of said bellows.

6. A respirator system comprising in combination:

a bellows container having an inlet and a valved outlet port;

a bellows mounted in said container, said bellows having an inlet and an outlet, and being expandable to a predetermined volume;

gas conduit means communicating said container outlet port to said bellows inlet;

a breathing circuit connected to said bellows outlet;

a source of first gas under pressure;

first control means operable to connect said first gas to said container inlet while closing said container outlet port to pressurize said container, thereby collapsing said bellows and delivering the predetermined volume of gas to said bellows outlet;

second control means operable upon said bellows reaching its collapsed condition to open said container outlet port to remove the first gas from said bellows container;

means for reducing the pressure of said removed gas to substantially atmospheric pressure;

mixing means for combining at least a portion of the first gas removed from said bellows container with a second gas at substantially atmospheric pressure; and

means to introduce the mixed gases into said bellows during expansion of said bellows for delivery to said breathing circuit during subsequent collapse of said bellows.

7. Apparatus according to claim 6 wherein said second control means includes a gas pressure switch mounted externally to said container; said switch comprising a normally-bled orifice and a valve body displaceable into said orifice to close said orifice; said valve body carrying a first magnetic pole; the extensible end of said bellows carrying a second magnetic pole of the same polarity as said first pole; said first magnetic pole being responsive to the repellent force with said second magnetic pole when said bellows moves to its collapsed condition to drive said valve body into said orifice to close said orifice, the closing of said orifice providing a pressure signal for actuating said second control means.

8. A medical respirator system, comprising in combination:

a. a source of gas pressure;

b. a bellows container having an inlet and a valved outlet controlled by a pressure chamber;

c. a bellows having an inlet and an outlet mounted within said container, said bellows being expandable and collapsible between end positions;

d. said source of fluid pressure being connected to said container through an interface valve and said pressure chamber;

e. a breathing circuit for a patient serviced by said system being connected to the outlet of said bellows volume, said breathing circuit including exhaust valve means for venting said breathing circuit;

f. control means for said breathing circuit exhaust valve;

g. said valved outlet of said bellows container being connected to the inlet of said bellows; and

h. fluid logic circuit means connected to said pressure source, to said control means for said breathing circuit exhaust valve, and to said interface valve; said circuit means being adapted to: (1) provide a first enabling signal for opening said interface valve to pressurize said chamber, thereby closing said container outlet valve and pressurizing said container to collapse said bellows forcing gas into said breathing circuit; (2) provide to said breathing circuit exhaust valve control means a second enabling signal simultaneous with said first enabling signal, for maintaining said breathing circuit exhaust valve closed; (3) terminate said first and second enabling signals to close said interface valve upon said bellows reaching its collapsed end condition, thereby removing pressure from said chamber and opening said outlet valve of said container enabling flow of gas from said container to said bellows inlet to expand said bellows, while opening said breathing circuit exhaust valve to relieve said breathing circuit pressure.

9. A system in accordance with claim 8, including fluid switch means connected to said fluid logic circuit means, said switch means being operable upon said bellows reaching its collapsed end condition to provide a

signal to said logic circuit for terminating said first and second enabling signals to said interface valve and breathing circuit exhaust valve control means.

10. A system in accordance with claim **9,** wherein said switch means includes a normally bled orifice, and a valve body displaceable to close said orifice, both said elements being mounted external to said container; said valve body including at least a first magnetic pole adjacent said container; and wherein the movable end of said bellows carries magnet means having a second pole opposite to the polarity of said first pole, movement of said bellows to said second position bringing said second pole toward said first pole to drive said valve body toward said orifice, thereby closing said orifice and providing said signal to said logic circuit.

11. A system in accordance with claim **10,** further including means coupling the pressure in said breathing circuit to an alarm input port at said fluid logic circuit, said logic circuit being adapted to provide at a first alarm output a first alarm signal upon the pressure at said breathing circuit dropping below a first predetermined level; and visual alarm indicator means connected to said first alarm signal to provide visual indication means connected to said first alarm signal to provide visual indication of said alarm condition.

12. A system in accordance with claim **11,** further including audible alarm indicator means coupled to said pressure source through a control valve means; said first alarm signal being coupled to said control valve whereby occurrence of said signal activates said control valve to enable said audible alarm.

13. A system in accordance with claim **11,** wherein said fluid logic circuit includes a second alarm output, timing means at said fluid logic circuit being adapted to provide a second alarm signal at said second output when the first enabling signal to said interface valve is present beyond a predetermined time period, said second signal being coupled to alarm indicators thereby signalling failure of cycling in said respirator system.

14. A system according to claim **13,** wherein said first and second alarm signals are both connected to a common alarm indicator.

15. A system in accordance with claim **11,** wherein the said fluid logic circuit is further adapted to terminate said first and second enabling signals upon the pressure from the said breathing circuit dropping below a second predetermined level, whereby said system is triggered between inhalation and exhalation phases in consequence of patient breathing effort.

16. A system in accordance with claim **15,** wherein said fluid logic circuit is adapted to provide a patient trigger signal upon said system being switched between said inhalation and exhalation phases by said patient effort, said signal being coupled to an observable alarm indicator means to indicate said patient triggered condition.

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