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THERAPEUTIC INTERMITTENT POSITIVE PRESSURE RESPIRATOR

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5 Claims

ABSTRACT OF THE DISCLOSURE

An intermittent positive pressure respirator including an automatic control for providing constant volume pulses of air or other breathable fluid to a user at predetermined intervals and providing an override responsive to the user's demands to provide a shorter interval. The automatic control includes a control chamber having a diaphragm which is coupled to the main supply valve to close off the passage of breathable fluid to the user, said diaphragm moving in response to a controlled pressure change within said chamber. A humidifier, heat exchanger and temperature control means are included for delivering air to the user at substantially 100 percent relative humidity and body temperature.

This invention relates to a breathing apparatus and more particularly to a respirator which supplies pulses of air substantially independently of the patient, thereby forcing him to breathe, but which is automatically responsive to a patient's requiring additional air to reduce the interval between pulses and thereby supply such additional air.

Many persons who suffer from respiratory defects or illnesses require assistance in breathing. Respirators generally supply air, oxygen, and medicated fluids to a face mask worn by the patient or the air, oxygen, and medicated fluids may be fed directly into the trachea. In many instances it is desirable that the respirator supply a fixed quantity of air in each pulse or breath substantially independently of the resistance of the respiratory system or the lung compliance. With this constant volume type of machine, the patient is in effect forced to breathe.

One difficulty with a typical constant volume machine is that the patient may suddenly demand additional air. In other instances, it may generally be difficult for the patient to synchronize his breathing efforts with the output of the respirator. Thus, it would be desirable to have a respirator which would normally deliver a constant volume of air in each breath and at constant intervals, but which is also responsive to peculiar demands of the patient for additional air to reduce the interval between the constant volume pulses of air. Prior art machines are not this flexible.

Another difficulty with some prior art machines is that they have failed to provide an alternate supply of air in case of failure or air stoppage. In addition, many of the prior art respirators supply air which is much too dry for use by certain patients.

Accordingly, a primary object of this invention is to provide a respirator which normally provides constant volume pulses of air at constant intervals, but which will automatically vary the interval between breaths in response to unusual breathing requirements of the patient.

A further object of this invention is to provide a constant volume respirator which is adjustable to vary the volume and the timing, and one which utilizes a pneumatic timing control system.

A further object of this invention is to provide a humidifier for a respirator that will deliver air at substantially

100% relative humidity at body temperature to the patient.

The objects of this invention may be accomplished by providing passage means connectible to a source of breathable fluid for conducting the latter to the patient and valve means for controlling the flow of the fluid through the passage means. A valve operator controls the opening and closing of the valve substantially independently of the patient thereby establishing an automatic program for the valve. Override means responsive to the patient's beginning inspiration prior to the time established therefor by the automatic program opens the valve thereby reducing the normal interval between breaths. An exhaust passage through which the patient may exhale may also be provided. A relief valve blocks this expiration passage during inspiration and permits its opening during expiration.

It is also desirable to provide a humidifier that will supply air to the patient at substantially 100% relative humidity at body temperature. The humidifier is particularly useful when a tracheotomy is being performed because in its absence the relatively dry air, which is supplied directly to the trachea, would dry the latter thereby irritating the trachea membranes. The humidifier is constructed so that it can be positioned close to the patient to prevent substantial change of condition of the air supplied thereby. The system provides for controlled overheating of the air, addition of water vapor, cooling and condensing, and delivery to the patient at the desired temperature and humidity.

The invention, both as to its organization and method of operation, together with further objects and advantages thereof may thus be understood by reference to the following description taken in connection with the accompanying drawing in which:

FIG. 1 is a semidiagrammatic view of a respirator with the automatic valve therefor being shown in longitudinal section;

FIG. 2 illustrates a humidifier and several safety devices adapted for use with the respirator of FIG. 1; and
FIGURE 3 is a circuit diagram of a temperature control circuit for the humidifier of FIGURE 2.

Referring to the drawing, a fluid which may be made up of air, oxygen, and a medicinal agent is supplied to a bistable regulator 11 by supply lines 13, 15, and 17, respectively, and an inlet manifold 19. These fluids pass through flow meters 21, check valves 23, and flow control valves 25 to the supply manifold 19.

The fluid passes through a passage 27 within the regulator 11, a conduit 29, a reservoir 31, a flow control valve 33 in the conduit 29, a humidifier 35 (FIG. 2), and a conduit 37 to an outlet 39 which may be directly connected into the respiratory system of the patient.

The fluid can only flow through the path outlined above as permitted by the regulator 11. The regulator 11 includes a housing 41 connected to the supply manifold 19 and the conduit 29 as illustrated. A normally open supply valve 43 mounted in the housing 41 controls the flow of fluid through the passage 27 to the patient. The valve 43 is maintained in the normally open position by a spring (not shown) or a bellows 45 which is sealed to the housing 41 and which communicates with the passage 27 through a plurality of inlet ports 47. The bellows 45 extends into a recess 49 in the housing 41, which is vented to the atmosphere through an aperture 51.

A diaphragm 53 and a wall 55 of the housing 41 form an operating or timing chamber 57 which receives fluid from the supply lines 13, 15, and 17 through the conduit 29, a lateral passage 59, a needle valve 61, a check valve 63, and an inlet port 65. The rate of fluid flow into the operating chamber 57 is controlled by the needle valve 61. When the pressure within the operating cham-

ber 57 reaches a predetermined value, which is a pressure sufficient to overcome the opposing pressure in the bellows 45 plus the small bellows spring force, the diaphragm 53 is forced outwardly to rapidly and tightly close the normally open valve 43. Thus, the diaphragm 53 acts as a valve closure means for closing the normally open valve in response to a predetermined increase in pressure in the operating chamber 57. Once the valve 43 is closed, the pressure in the bellows 45 reduces to atmospheric. Then the pressure in the operating chamber 57 must drop almost to atmospheric before the valve 43 can reopen. Thus the valve 43 functions in the nature of a bistable or on-off device.

During normal operation of the respirator, the fluid will exhaust from the operating chamber 57 through an exhaust port 67, a conduit 69, a check valve 71, and a needle valve 73. The needle valve 73 can be adjusted so that any desired predetermined amount of time will be required for the fluid to drain out of the operating chamber. During the time when the valve 43 is open and fluid is flowing through the conduit 29, none of the fluid will drain from the operating chamber 57 through the conduit 69 because the pressure in the conduit 29 will be at least as great as that in the operating chamber. However, when the valve 43 closes and the patient has drawn much of the fluid from the conduit 29 into his respiratory system, a pressure differential exists which permits exhausting of the operating chamber 57 through the conduit 69.

It is apparent that the exhausting of the operating chamber 57 will reduce the pressure on the diaphragm 53 and allow the normally open valve 43 to open. During normal operation of the respirator, the valve 43 will open and close at fixed intervals to supply equal volumes of air in the pulses or breaths. Likewise, the intervals between breaths will be constant. Thus, the valves 61 and 73 provide an automatic program for the valve 43.

The amount of air supplied by the respirator in each pulse can be adjusted by adjusting the needle valve 61. Thus, if the needle valve 61 is open a large amount, the operating chamber 57 fills more rapidly to cause the valve 43 to close more rapidly. This results in a lesser quantity of air being supplied by the respirator in each pulse. Conversely, partially closing the needle valve 61 results in a larger amount of air being supplied in each pulse.

The interval between pulses of air can be similarly varied. Thus, the larger the opening provided by the needle valve 73, the sooner the pressure in the operating chamber 57 will decrease to the point at which the normally open valve 43 can return to its normally open position. Conversely, the greater the impedance to flow through the conduit 69 provided by the needle valve 73, the greater the interval between pulses of air.

Sometimes a patient will be unable to synchronize his breathing with the output from the respirator. This will occur, for example, when the patient feels a need for an increased amount of air. Accordingly, one of the features of this invention is to provide override means which are responsive to the patient's beginning inspiration prior to the termination of the interval between breaths which has been established by the needle valve 73 for prematurely opening the valve 43. This override function is accomplished by rapidly venting the operating chamber 57 in response to the patient's attempts to inspire prior to the time the operating chamber pressure has been reduced sufficiently to allow the valve 43 to open. The wall 55 and a second diaphragm 75 define an exhaust manifold 77, and the housing 41 and the diaphragm 75 form a demand cavity 79. Air can be exhausted from the operating chamber 57 through an outlet 81 formed in the wall 55, the exhaust manifold 77, and an exhaust port 83 in the outer wall of the housing 41 to the atmosphere. A valve 85, which is seated in the outlet 81 controls the exhausting of air from the operating chamber 57.

A spring 87 normally biases the valve 85 to the closed position. The pressure in the demand cavity 79 and the spring 87 control the movements of the valve 85 and hence the exhausting of air from the operating chamber 57 through the outlet 81. A conduit 89 interconnects the demand cavity 79 and the conduit 29 downstream of the valve 43 thereby causing the pressure in the demand cavity to be substantially the same as the pressure in the conduit 29 downstream of the valve 43. A pressure gage 90 may be installed on the conduit 89.

The operation of the portion of the respirator illustrated in FIG. 1 is as follows. Fluid is supplied through the supply manifold 19, the regulator 11, the reservoir 31 and the conduit 29 to the patient. The end of the conduit 29 shown in FIG. 1 may be connected to a face mask or other devices for transmitting the fluid into the nose or mouth of the patient. The purpose of the reservoir 31 is to reduce the rate of change of fluid flow from the respirator to the patient. Initially, fluid will flow through the normally open valve 43 and the inlet ports 47 to the bellows 45 to expand the latter and open the valve 43 a greater amount. Fluid will also flow through the lateral passage 59 as permitted by the needle valve 61 into the operating chamber 57. When the pressure in the operating chamber 57 is sufficient to overcome the force tending to hold the valve 43 in the open position, the diaphragm 53 will rapidly force the valve 43 to a closed position. During the time the valve 43 is open, the user is receiving air and, accordingly, the closure of this valve marks the end of inspiration. When the valve 43 closes, the patient will utilize enough of the air in the conduit 29 to reduce the pressure therein to about atmospheric. This pressure reduction in the conduit 29 allows the fluid in the operating chamber 57 to flow through the conduit 69 into the conduit 29, and when the pressure in the operating chamber is sufficiently low, the normally open valve 43 will return to its normally open position and the cycle will be repeated.

During the time the valve 43 is closed, the patient will be exhaling. If the patient begins inspiration prior to the time that the valve 43 has returned to its normally open position, the pressure in the conduit 29 will drop below atmospheric. The pressure in the demand cavity 79 will drop accordingly, and the diaphragm 75 will cause the valve 85 to open the outlet 81 to exhaust the operating chamber through the exhaust manifold 77 and the exhaust port 83. This causes the valve 43 to open immediately and supply air to the patient. In actual practice it has been determined that the valve 85 will operate reliably in response to a negative pressure of only one centimeter of water. Thus, the regulator 11 responds immediately to the demands of the patient for an additional breath of air. As soon as the valve 43 opens, the pressure in the conduits 29 and 89 and hence the demand cavity 79 rapidly becomes sufficient to close the valve 85.

Referring to FIG. 2, the fluid passes from the conduit 29 into the humidifier 35. The humidifier is usually used when a tracheotomy is being performed, in which case the outlet 39 may deliver air directly into the trachea. Bypassing of the nose and mouth results in a drying of the trachea with resulting crustations and other irritations to the trachea membranes. Bacterial growths and heavy secretions in the respiratory system frequently result. These undesirable conditions exist even where the incoming air is delivered at 100% relative humidity at room temperature. It has been found that the incoming air should be at 100% relative humidity at body temperature, which calls for considerably higher water content of the air. At the same time, the temperature of the air must be closely controlled as the delivery of air at 100% relative humidity at a temperature in excess of body temperature would result in condensation within the respiratory system of the user. The humidifier and associated elements of FIG. 2 provides this desired operation in a respirator. The humidifier is quite small and may be positioned close to

the patient thereby reducing the dead space in the conduits and eliminating excessive cooling of the gases, resulting in a closely controlled air supply system.

The humidifier 35 includes a container 91 for holding a quantity of water 93. A first heat exchanger 95 is mounted in the container 93 and extends vertically thereabove to a location at which it is connected to the conduit 29. Typically the heat exchanger 95 is a block of metal and includes an elongated shell 97 having an aperture 99 formed therein just above the water level within the container 91 and an electrical heater 101 preferably disposed below the water level in the container 91 and supplied with electrical power through a connector 103. The heater 101 heats the incoming fluid from the conduit 29 and also heats the water 93. The container 91 is closed by a cover 105 and the heated water forms a vapor in a head space 106 of the container 91 between the top of the water 93 and the cover.

The breathable fluid from the conduit 29 passes through the heat exchanger 97 where it is heated to a temperature above body temperature, typically 50°–60° C., and passes out through the aperture 99 and into the head space 106 where it becomes saturated with water vapor. The moisture-laden fluid will then pass out of the container 91 through another heat exchanger 107, the conduit 37, and the outlet 39 to the respiratory system of the patient. The air is cooled somewhat in passing through the heat exchanger 107 and some of the moisture therein condenses, assuring 100% relative humidity at the exit temperature. Both heat exchangers 97 and 107 may incorporate a metal sponge or similar material in the air flow passages for improving the heat transfer characteristics.

The temperature of the air at the inlet to the patient is controlled by sensing the air temperature and varying the output of the heater 101. This form of temperature control is highly desirable, since the volume of air intake varies over wide ranges and fixed temperature systems do not provide satisfactory results. In the embodiment illustrated, a temperature sensing element, such as a thermistor 109, is positioned at the outlet 39, as close as practical to the inlet to the patient. The thermistor 109 is connected into a control circuit, as shown in FIG. 3, for varying the power supply to the heater 101. The heater 101 is energized from an A.C. source through a silicon controlled rectifier 102. The thermistor 109 is connected in series with a resistor 110 across a D.C. source so that variations in resistance of the thermistor will produce corresponding variations in the control voltage applied to the silicon controlled rectifier 102. The resistor 110 preferably is a variable resistor to permit initial adjustment of the system. An A.C. modulation may be coupled into the resistor circuit via a transformer 112, if desired. Under steady state conditions, the resistor 110 is adjusted to deliver air to the patient at the desired body temperature. This means that air leaving the humidifier will be saturated at a higher temperature, will be cooled in the second heat exchanger with the absolute humidity being reduced and will be delivered at the patient's inlet at the desired temperature and humidity. If the rate of air intake increases, the control system will provide for additional heat from the heater to maintain the desired temperature. Similarly, if the rate of air intake decreases, the control circuit will reduce the heat input to maintain the desired temperature.

A relief valve is provided adjacent the heat exchanger 107 and includes an annular valve seat 113 having a pressure-responsive valve member or counterweight 115 slidably mounted thereon. The pressure within the system acts on the lower side of the valve member 115 through openings 111 and, if such pressure becomes excessive, the valve member or counterweight 115 will be forced upwardly off the seat 113 to exhaust the system to atmosphere. This counterweight type of relief valve is preferred because of its simplicity.

An expiration passage is provided through which the

patient may exhale. In the specific embodiment illustrated, the conduit 37 and a relief or exhaust valve 117 form the expiration passage. The valve 117 is normally closed and is connected to the conduit 37 through the heat exchanger 107, which also functions as a manifold. The valve 117 includes a valve housing 119 defining an outlet 121, a movable valve member 123, and a valve seat 125. A spring 127 normally urges the valve member 123 toward the valve seat 125.

Means are provided to close the valve 117 when the valve 43 is opened so that the valve 117 will be locked in the closed position during inspiration. Such means includes a bellows 129 mounted in the valve housing 119 and defining therewith a valve operating chamber 131. A conduit 133 connects the conduit 29 to the operating chamber 131 so that the pressure in the operating chamber 131 will be substantially the same as the pressure in the conduit 29 downstream of the reservoir 31.

When the valve 43 is open, fluid under pressure is supplied through the conduit 133 to the operating chamber 131. This fluid under pressure extends the bellows 129 to cause the valve member 123 to seat and close the valve 117. Thus, the valve 117 is always closed during inspiration. When the valve 43 closes, the pressure in the conduits 29 and 133 decreases and the bellows retracts, with the spring 127 holding the valve closed.

The respirator described herein provides constant volumes of air to a patient at fixed predetermined intervals substantially independently of the lung compliance of the patient. The patient is therefore forced to breathe at the machine rate. However, the amount of air supplied by the machine in each pulse and the interval between pulses are variable over a wide range by making the appropriate adjustments of the needle valves 61 and 73. If the patient should unexpectedly require additional air, the respirator will supply it automatically in response to his efforts to obtain breaths more rapidly. The humidifier and associated equipment will produce air at substantially 100% relative humidity at body temperature. The counterweight type relief valve 107 guards against overpressures in the system.

Many changes, modifications, and substitutions may be made by one having ordinary skill in the art without necessarily departing from the spirit and scope of this invention.

What is claimed is:

1. In a respirator for supplying a breathable fluid to a user, the combination of:

a source for providing the breathable fluid under pressure;

inlet means for delivering the breathable fluid to the user;

a humidifier for supplying water vapor to the breathable fluid and including a heater for heating the incoming breathable fluid to a temperature above body temperature;

a heat exchanger for cooling the breathable fluid passing therethrough;

valve means between said source and said inlet means to control the flow of fluid from said source to said inlet means;

conduit means coupling said source, valve means, humidifier, heat exchanger and inlet means for flow of the breathable fluid from the source the valve means, humidifier, heat exchanger and inlet means to the user;

temperature sensing means positioned at said inlet means for sensing the temperature of the breathable fluid adjacent the point of delivery to the user; and

control means having said temperature sensing means as an input for controlling said heater to vary the temperature of the breathable fluid leaving said humidifier to maintain the temperature of the breathable fluid at said inlet means substantially at body temperature.

2. In a respirator for supplying a breathable fluid from a source to the inlet means of a user, the combination of: passage means for connecting the source of the breathable fluid to the inlet means of the user; valve means for controlling the flow of the fluid through said passage means; valve operator means for automatically opening and closing said valve means substantially independently of the user at predetermined intervals thereby causing constant volume pulses of the breathable fluid to be supplied to the user at predetermined intervals, said valve operator means thereby establishing an automatic program for said valve means; override means responsive to the user's beginning inspiration prior to the termination of said interval between pulses for overriding said automatic program and opening said valve means for shortening the interval between pulses; a humidifier for supplying water vapor to the breathable fluid and including a heater for heating the incoming breathable fluid to a temperature above body temperature; a heat exchanger for cooling the breathable fluid passing therethrough, said humidifier and heat exchanger being connected in said passage means between said valve means and the user; temperature sensing means positioned in said passage means adjacent the user for sensing the temperature of the breathable fluid adjacent the point of delivery to the user; and control means having said temperature sensing means as an input for controlling said heater to vary the temperature of the breathable fluid leaving said humidifier to maintain the temperature of the fluid in the passage means adjacent the user substantially at body temperature.

3. In a respirator for supplying a breathable fluid from a source to the inlet means of a user, the combination of: passage means for connecting the source of the breathable fluid to the inlet means of the user; normally open valve means disposed in said passage means for controlling the flow of the fluid through said passage means and valve means; valve operator means for automatically opening and closing said valve means substantially independently of the user at predetermined intervals thereby causing constant volume pulses of the breathable fluid to be supplied to the user at predetermined intervals, said valve operator means thereby establishing an automatic program for said valve means, said valve operator means including an operating chamber, means for conducting the breathable fluid at a first predetermined rate from a location in said passage means downstream of said normally open valve means to said operating chamber to increase the pressure therein, means for returning the fluid at a second predetermined rate from said operating chamber to said passage means downstream of said normally open valve means to decrease the pressure in said operating chamber, and means for closing said normally open valve means in response to a predetermined increase in pressure in

said operating chamber, said normally open valve means returning to its normally open position in response to a predetermined decrease in pressure in said operating chamber; and override means responsive to the user's beginning inspiration prior to the termination of said interval between pulses for overriding said automatic program and opening said valve means for shortening the interval between pulses, said override means including means for prematurely causing said predetermined decrease in pressure in said operating chamber thereby causing opening of said valve means prior to the time established therefor by said automatic program comprising a demand chamber, means connecting said demand chamber to said passage means downstream of said valve means, the pressure in said demand chamber being reduced at least to a third predetermined amount when the user begins inspiration, and means responsive to the reduction of the pressure in said demand chamber to said third predetermined amount for rapidly venting said operating chamber to allow said normally open valve means to open.

4. A combination as defined in claim 3 including exhaust valve means in said passage means for venting said passage means to the atmosphere during expiration and including a first pressure responsive valve operating means responsive to the pressure in said passage means downstream of said normally open valve means for closing said exhaust valve means during inspiration and a second pressure responsive valve operating means responsive to the pressure in said passage means for opening said exhaust valve means during expiration, with said first operating means overriding said second operating means during inspiration.

5. A combination as defined in claim 4 including: a humidifier in said passage means downstream of said normally open valve means; a heat exchanger in said humidifier for heating the fluid passing therethrough; and control means adjacent the inlet means for controlling the temperature of fluid delivered to the user.

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