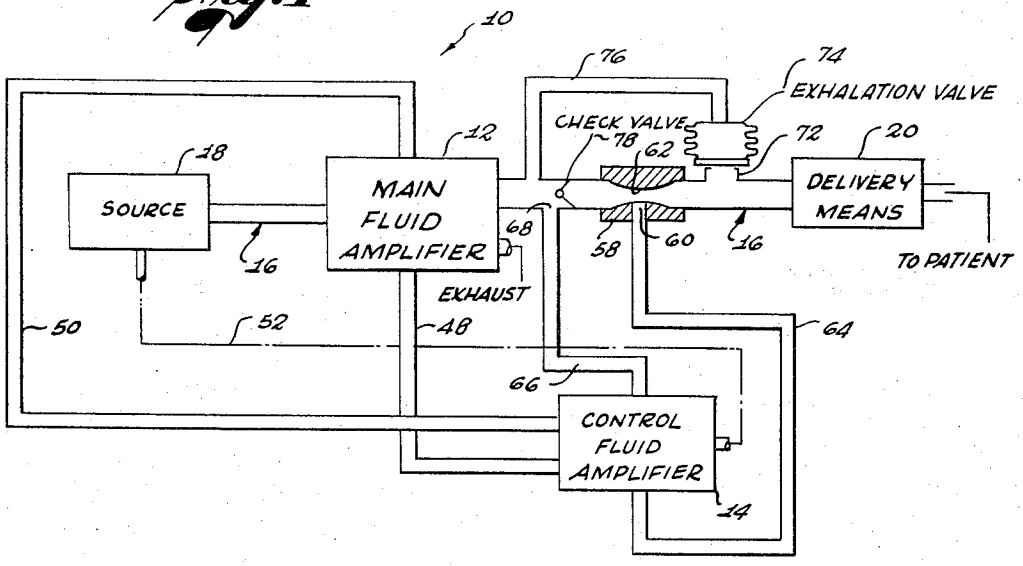
Feb. 13, 1968 N. F. BEASLEY 3,368,555

RESPIRATION APPARATUS WITH FLUID AMPLIFIER

Filed Dec. 2, 1965 2 Sheets-Sheet 1

Fig. 1



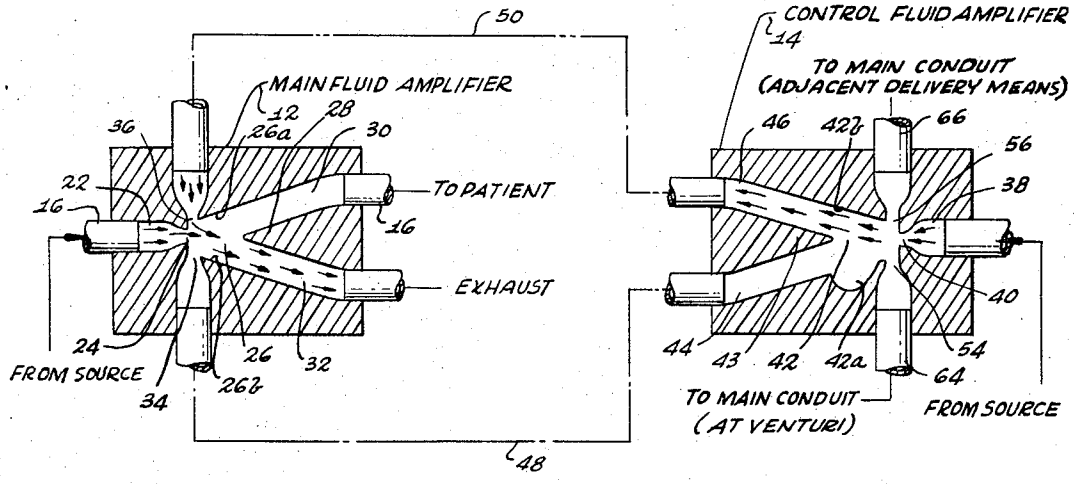


Fig. 2

INVENTOR.
NOEL F. BEASLEY
BY Fulwider, Patton, Rieber, Lee, and Utecht
ATTORNEYS

Feb. 13, 1968 N. F. BEASLEY 3,368,555

RESPIRATION APPARATUS WITH FLUID AMPLIFIER

Filed Dec. 2, 1965 2 Sheets-Sheet 2

Fig. 3

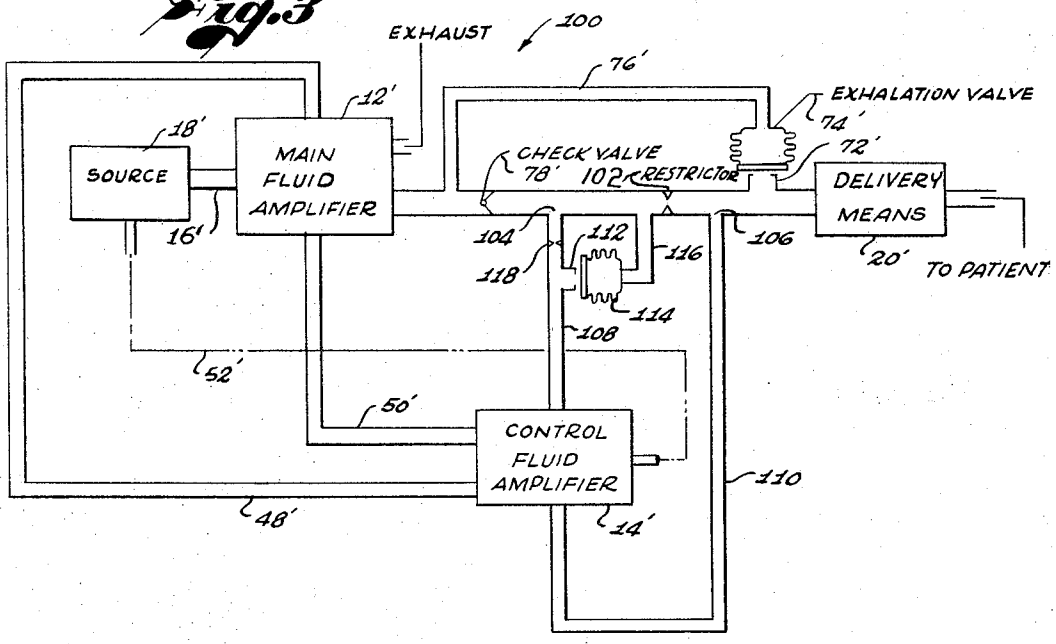
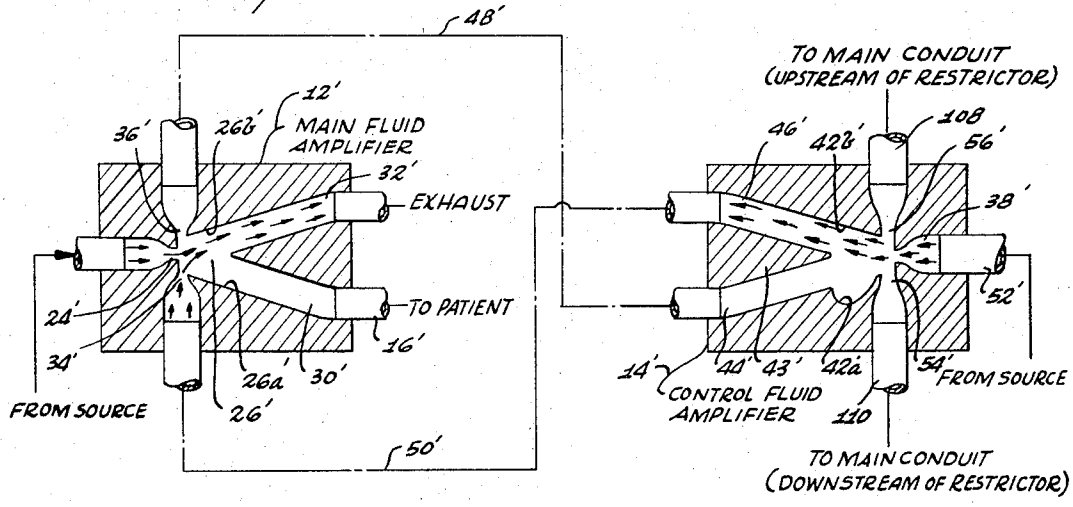


Fig. 4



INVENTOR.
NOEL F. BEASLEY
BY Fulwider, Patton, Rieber Lee, and Utecht
ATTORNEYS

United States Patent Office 3,368,555 Patented Feb. 13, 1968

3,368,555

RESPIRATION APPARATUS WITH FLUID AMPLIFIER

Noel F. Beasley, Santa Monica, Calif., assignor to Puritan Compressed Gas Corporation, Kansas City, Mo., a corporation of Missouri

Filed Dec. 2, 1965, Ser. No. 511,588
9 Claims. (Cl. 128—145.8)

This application relates to respiration apparatus for use in administering intermittent positive pressure breathing therapy, and more particularly to improve apparatus of this type embodying fluid amplifiers.

Intermittent positive pressure breathing, commonly known as IPPB, is a type of assisted breathing for patients who are breathing spontaneously at a self-controlled rate and rhythm. Such therapy has wide-spread acceptance as an effective means for relieving and treating many respiratory disorders.

In IPPB therapy, the patient initiates the inspiratory phase of the breathing cycle by making a slight inspiratory effort as in normal breathing. Gas comprising air or air enriched with oxygen, or in some cases an admixture of such gas and vaporized or nebulized medication is then supplied to the lungs under a mild pressure to achieve ventilation. The inspiratory phase continues, preferably until full and even ventilation has occurred. As this condition is approached, the flow of gas to the patient drops off rapidly to a low level and eventually to a so-called terminal flow. This terminal flow is the flow taking place just at the end of the inspiration.

Following the inspiratory phase is an expiratory phase. This is a passive phase in which the pressure is rapidly reduced, preferably to ambient pressure, and the lungs are vented to the atmosphere. Expiration then occurs spontaneously, as in normal breathing, because of the elasticity of the lung-thorax system. Completion of expiration normally ends a given breathing cycle.

It is desired that apparatus for administering such IPPB therapy have certain operational characteristics. One such characteristic is that the patient-effort required to initiate inspiration be no greater than that exerted in normal breathing. It is also desirable that the peak flow capacity of the apparatus be relatively high. This stems from the fact that the average patient has a high flow requirement near the start of inspiration. His requirement thereafter progressively decreases and, therefore, flow likewise decreases as pressure increases to the terminal flow which, as noted above, exists at the end of inspiration.

Another desirable operational characteristic is that the apparatus have a very low terminal flow. This enables full and even ventilation of the alveoli to be achieved. By way of explanation, the lungs comprise a network of small passages of varying resistance leading to the alveoli. With a low terminal flow, pressure is maintained on these passages for a sufficient time to insure that the desired ventilation is achieved.

Besides these operational characteristics, there are many other important considerations to be borne in mind in the design and manufacture of respiration apparatus. In view of the nature of such apparatus, it is apparent that reliability is a highly important feature. Experience has shown that reliability is difficult as well as costly to obtain with respiration apparatus embodying conventional valving mechanisms with numerous moving parts. Manufacture to close tolerances, closely controlled inspection and testing and the like, are all required in order to achieve the desired end with many types of apparatus heretofore available. Often costs are prohibitive and even assuming they are not, there is still the problem of potential abuse during use, resulting in malfunction. Thus, it

will be readily appreciated that it is highly desirable from a reliability standpoint to eliminate moving parts.

In view of the foregoing, it is a primary object of this invention to provide respiration apparatus which is highly reliable in operation.

A further, more specific object is to provide such respiration apparatus which has virtually no moving parts.

Another object of the invention is to provide respiration apparatus of the subject type further characterized in that a slight patient-effort is ample to initiate the inspiratory phase of the breathing cycle and in that it has a high peak flow capacity and a low terminal flow.

It is another object to provide respiration apparatus of the type described which is readily adapted to be thoroughly cleaned following use.

A still further object is to provide respiration apparatus capable of accomplishing all of the foregoing objects, yet which is simple in construction and may be mass produced at an extremely low cost.

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

FIGURE 1 is a semi-schematic view of the presently preferred embodiment of the invention, with the certain elements being shown in the positions occupied during the expiratory phase of the breathing cycle;

FIGURE 2 is a sectional view of suitable fluid amplifiers for use in the apparatus of FIGURE 1, with the amplifiers being shown schematically as connected to one another and with gas flow taking place as during the expiratory phase of the breathing cycle;

FIGURE 3 is a semi-schematic view, similar to FIGURE 1, of a modified version of the apparatus of the invention; and

FIGURE 4 is a sectional view, similar to FIGURE 2, of suitable fluid amplifiers for use in the apparatus of FIGURE 3.

Referring to the drawings, and in particular to FIGURE 1, the presently preferred apparatus of the invention, designated by the reference numeral **10**, includes a main fluid amplifier **12** and a control fluid amplifier **14**. These amplifiers **12** and **14** are, in turn, connected to one another and to main conduit means **16** leading from a source **18** of pressurized gas to delivery means **20**. The amplifiers are operable in such a manner that pressurized gas flows from the source **18** through the main conduit means **16** and amplifier **12** to the atmosphere during expiration and through these same elements to the patient during inspiration.

The source **18** of pressurized gas may, by way of example, comprise a tank of compressed gas, such as air or oxygen, or a pump for compressing ambient air. In applications where it is desirable to supply ambient air enriched with oxygen, the source then may comprise both a pump and a tank of compressed oxygen. As is conventional, the source **18** embodies suitable regulation apparatus for insuring that the gas supplied to the patient is at a mild pressure no greater than a preset maximum. Preferably, for flexibility of use, the regulation apparatus is adjustable to enable the maximum pressure to be preset within a safe range, e.g., 10 to 40 centimeters of water.

The delivery means **20** serves to establish communication between the respiration apparatus and the patient's respiratory system. Such means may comprise any of the many known types of devices adapted for this purpose, including face masks and mouth pieces.

Preferably, the main amplifier **12** is a pure fluid amplifier, that is, it has no moving parts. It is formed in accordance with known procedures, having a plurality of shallow, inner-connected channels and associated nozzles, as illus-

trated in FIGURE 2. These include an inlet channel 22 connected by an upstream section of the conduit means 16 to the source 18, and a main nozzle 24. A main stream of pressurized gas from the source issues from the main nozzle 24 into a receiving cavity 26 separated by a splitter 28, which is spaced away from the nozzle 24, into a patient channel 30 and an exhaust channel 32. As may be seen in FIGURES 1 and 2, the patient channel 30 is connected by a downstream section of the main conduit means 16 to the delivery means 20 and the exhaust channel 32 is vented to atmosphere. Therefore, as is apparent, gas flowing through the patient channel 30 is delivered to the patient, while gas flowing through the exhaust channel 32 is exhausted into the atmosphere.

The illustrative amplifier 12 is constructed so that without external influence, the main stream of gas issuing from nozzle 24 would divide substantially equally between the patient channel 30 and exhaust channel 32. In other words, the stream has no preferred position. For the purpose of directing the main stream initially toward one or the other of the channels 30 and 32 and directing or switching it therebetween, control means are provided. Such means here comprise inspiration and expiration control nozzles 34 and 36 arranged so that positive pressure signals issuing from them direct the main stream toward the patient and exhaust channels 30 and 32, respectively.

It is also preferred, though not essential, that the amplifier 12 be bistable in nature and of the boundary layer, lock-on type. As is well known, this may be achieved by suitably configurating the side walls 26*a* and 26*b* of the receiving cavity 26. With such a wall configuration, once the stream is directed by pressure signals from the control nozzles 32 and 34 toward one or the other of the channels 30 and 32, the main stream locks to the adjacent wall in a self-reinforcing action, and the entire stream will then flow down that channel. When a pressure signal of sufficient amplitude to overcome the lock-on phenomenon issues from the control nozzles then adjacent the stream, the stream is directed toward the other of the channels. It is to be noted that in the present case, as will be explained more fully below, positive pressure signals issue from the inspiration and expiration control nozzles 34 and 36 throughout the respective phases of a given cycle, thus serving independently of the lock-on effects to maintain the stream in a given one of the channels 30 and 32.

The amplifier 12 is operable so that even if back pressure in the outlet channel 30 substantially increases, as flow takes place through it, the established flow through that channel will continue. In practice, back pressure does in fact substantially increase in the patient channel 30 near the end of the inspiratory phase. For the desired full and even ventilation to be achieved, it is desired that flow through the patient channel continue, even when pressure in the conduit means 16 adjacent the delivery means 20 approaches the preset maximum pressure delivered by the source 18. Here flow continues notwithstanding the back pressure by virtue of the signal issuing continuously from nozzle 34 throughout inspiration and, also, by virtue of the main stream locking onto the wall 26*a* adjacent the patient channel 30. It is noted in passing that the channel 30 is never completely blocked. While the terminal flow preferably is low, as noted above, some flow takes place even at the very end of inspiration.

Pressurized gas is supplied to the nozzles 34 and 36 for directing the main stream toward the patient and exhaust channels 30 and 32, respectively, and maintaining it there by the control fluid amplifier 14. The latter amplifier is similar to the amplifier 12 in many respects, having an inlet channel 38 and an associated power nozzle 40. A control stream of gas issuing from the nozzle 40 enters a receiving cavity 42 with side walls 42*a* and 42*b* and separated by a splitter 43 into an inspiration outlet channel 44 and an expiration outlet channel 46. The channel 44, in turn, is coupled to the inspiration control nozzle 34 of the main amplifier 12 by a conduit 48, and the channel 46 is likewise coupled to the expiration control nozzle 36 by a conduit 50.

The control amplifier 14 is furnished with pressurized gas through a conduit 52 which, in the present case, is connected to the source 18. Such gas may be a relatively small stream and at relatively reduced pressure, since it need only have ample energy to overcome the lock-on phenomenon of the main amplifier 12 and direct the main stream of gas in the manner described above. The source 18 serves as a convenient and entirely satisfactory supply of gas for the control amplifier.

The control amplifier 14, like amplifier 12, preferably is of the boundary layer, lock-on type. However, it differs from amplifier 12 to the extent that it is monostable in nature, with its stable position being that in which the control stream flows through the expiration outlet channel 46. In addition, the amplifier 14 has a preferred position corresponding to channel 46, so that, without external influence, the control stream will still lock onto the side wall 42*b* of the cavity 42 adjacent the expiration channel 46. By way of further explanation, when the control stream initially issues from a nozzle 40 on start-up, lock-on will immediately take place, so that flow is entirely through channel 46. Moreover, if flow is occurring through the inspiration channel 44 under external influence or bias and such influence or bias is removed, the control stream will immediately switch back to its preferred position in the channel 46.

In order to achieve such operation of the control amplifier 14, it will be appreciated that it is necessary to prevent the control stream from locking onto the wall 42*a* of the cavity 42 adjacent the inspiration channel 44. As is known in the fluid amplifier field, this can be accomplished in several ways. One way is to space the side wall 42*a* away from the flow path by making it semi heart-shaped, as in FIGURE 2.

For the purpose of directing or switching the control stream to the inspiration outlet channel 44 and maintaining it there throughout inspiration, control nozzle means are provided. In the illustrative embodiment, such means comprise first and second control nozzles 54 and 56. The first control nozzle 54 is arranged to issue initially, in a given breathing cycle, a negative pressure signal to direct the control stream to the inspiration outlet channel 44. At a later stage of the cycle, a positive pressure signal issues from the nozzle 54. The second control nozzle 56, on the other hand, is arranged to issue a positive pressure signal for maintaining the control stream in the inspiration outlet channel 44.

Pressure signals are supplied to the control nozzles 54 and 56 in accordance with the pressure then existing at the location of the sensing elements in the conduit means 16 downstream of the amplifier 12. In this connection, a venturi 58 in the conduit means 16 is connected by a passageway 60 opening at its throat 62 to the nozzle 54 by an auxiliary conduit 64. Flow through the venturi 58 produces a velocity increase and pressure drop at the throat 62, which is transmitted as a pressure signal, either positive or negative with respect to atmospheric pressure, through the conduit 64 to the nozzle 54. The second control nozzle 56 is coupled by an auxiliary conduit 66 to a sensing port 68 in the conduit means 16. The port 68 is spaced from the venturi 58 on the upstream side thereof.

To enable the patient to expire to the atmosphere, an expiration passage 72 is provided in the conduit means 16 between the main amplifier 12 and the delivery means 20. Closure of the passage 72 during the inspiratory phase of the breathing cycle is by a diaphragm-type exhalation valve 74. The lower end of the valve 74 is positioned in close proximity to the opening in the passage 72. Thus, when a slight negative pressure is drawn in the adjacent portion of the conduit means 16, the valve 74 is pulled down to close the passage 72.

Positive pressure is supplied to the valve 74 to maintain it securely closed throughout inspiration through a conduit 76 connected to the conduit means 16. Connection is at location between the main amplifier 12 and the venturi 58. It will be observed in FIGURE 1 that the cross-sectional area of the valve 74 is greater than the area of the opening in the passage 72. Thus, even though the pressure within the valve 74 is equal to, or even slightly greater than, that in the passage, i.e., the pressure acting on the underside of the valve, the latter will remain closed.

A check valve 78 biased slightly to a closed position is provided in the conduit means 16 at a location downstream of the junctions of the part 68 and the junction of the conduit 76 and upstream of the venturi 58. The valve 78 operates to block back flow from the delivery means 20 during expiration so as to insure that the valve 74 remains open during that phase. Biasing the valve 74 slightly to a closed position is desired in order to inhibit the negative pressure drawn in the conduit means 16 adjacent the delivery means 20 upon the patient exerting an inspiratory effort from acting through the conduits 66 and 76.

The apparatus 10 of the invention is readied for use by simply activating the source 18, assuming the maximum pressure has been preset at the desired level, to deliver gas to the main amplifier 12 through the conduit means 16 and to the control amplifier 14 through the conduit 52. A main stream of gas issues from the nozzle 24 of amplifier 12 and a control stream issues from the nozzle 40 of amplifier 14. The control stream immediately seeks its preferred position and locks onto the wall 42*b* of the receiving cavity 42 adjacent the expiration outlet channel 46, and flow takes place through that channel.

This output of the control amplifier 14 is delivered to the expiration control nozzle 36 of the main amplifier by the conduit 50. A positive pressure signal is caused to issue from the nozzle 36 to direct the main stream toward the exhaust channel 32. Lock-on quickly occurs and flow of the main stream is entirely through the exhaust channel 32. As brought out above, the signal issues continuously through the expiration nozzle 36, and such signal and, in the illustrative case, the lock-on phenomenon independently serve to maintain the stream in the channel 32. The gas issuing from nozzle 36 is entrained by the main stream and the composite stream is delivered to the atmosphere.

A stable operative condition exists at this stage, such condition corresponding to the expiratory mode of operation of the apparatus 10. The flow paths through the amplifiers 12 and 14 in this stable condition are shown by the arrowed lines in FIGURE 2. It will be appreciated that this mode of operation would continue indefinitely, absent a negative pressure in the conduit means downstream of amplifier 12.

Assuming the delivery means 20 is suitably connected to the patient's respiratory system, a slight inspiratory effort on his part, as in normal breathing, serves to initiate the inspiratory phase. Such an effort produces a slight negative pressure in the conduit means 16 adjacent the delivery means 20. This first has the effect of pulling the valve 74 closed. Negative pressure then acts through the venturi 58 and conduit 64, resulting in a negative pressure signal being issued by the inspiration control nozzle 54. This negative pressure signal, in turn, acts on the control stream with sufficient influence to break the lock-on phenomenon and move the stream toward the inspiration outlet channel 44. In this manner, the control stream is directed or switched to the channel 44 in opposition to the biasing force inherent in the structure of the amplifier 14 and normally causing that stream to seek its preferred, stable condition. The valve 78, being slightly biased to a closed position, insures that negative pressure is inhibited from simultaneously acting through the conduits 66 and 76 in such a manner as to adversely affect the switching operation.

Switching of the control amplifier in the manner described above has the effect of switching the main amplifier 12. Referring to FIGURE 2, the pressure signal issued by the nozzle 36 terminates and a similar signal, supplied by amplifier 14 through the conduit 48, issues from inspiration control nozzle 34. The main stream is thereby directed toward the patient channel 30, whereupon lock-on takes place, and the stream is maintained in that channel by both the continuously-issuing signal and the lock-on phenomenon. The composite stream, including gas from the control amplifier 14 entrained by the main stream, then flows through the downstream section of the conduit means 16 to the patient. Once main stream flow occurs through the conduit means 16 to the patient, a positive pressure is applied to the valve 74 to forcefully maintain it seated, and this condition exists throughout the remainder of inspiration.

Characteristic of the inspiratory phase of a normal breathing cycle is a high flow requirement near the start of the phase. Accordingly, flow through the conduit means 16 and the venturi 58 installed therein is initially at a relatively high rate, while pressure is relatively low. In this connection, it is to be observed that the venturi 58 serves advantageously as a sensing element without appreciably restricting flow. In other words, system pressure in the conduit means 16 on opposite sides of the venturi 58 is substantially the same.

At relatively high flow rates, as near the start of inspiration, a substantial pressure drop is produced at the throat 62 of the venturi 58. It may even serve at this stage to produce a negative pressure (with respect to ambient pressure) in the conduit 64 leading to the nozzle 54. In any event, a relatively low pressure signal issues from the nozzle 54 by virtue of the action of the venturi 58. On the other hand, higher pressure is sensed by the port 68 in the conduit means 16 downstream of the venturi 58. The latter pressure is, in turn, transmitted through the conduit 66 and issues as a positive pressure signal from the nozzle 56. It will, therefore, be appreciated that at this stage of inspiration, counteracting pressure signals of different amplitudes act on the control stream, which is then flowing through the inspiration outlet channel 44. Since the amplitude of the signal issuing from the nozzle 54 is substantially greater than that issuing from the nozzle 56, the control stream is maintained in the channel 44 in opposition to its "memory" or tendency to move back to its preferred position in channel 46.

As inspiration progresses, the flow rate through the main conduit means 16 decreases, while system pressure correspondingly increases. Some spill over of the main stream from the patient channel 30 to the exhaust channel 32 may even occur near the end of inspiration when the back pressure is substantial. With such decreasing flow through the main conduit means 16, the pressure drop produced at the throat 62 of the venturi 58 likewise decreases. Therefore, the difference in amplitudes of the pressure signals issuing from the nozzles 54 and 56 diminishes. It will be noted that the venturi 58 with the passage 60 is at its throat 62 and the port 68 cooperate during the latter part of inspiration to sense flow through the conduit means independently of absolute pressures. It is the difference in pressures transmitted through the conduits 64 and 66 and issuing from the nozzles 54 and 56 that maintains the apparatus in its inspiratory mode of operation, and such difference varies in accordance with flow through the conduit means. Eventually, when the flow through the main conduit means 16 drops to the terminal flow, the difference in amplitudes of these pressure signals is insufficient to overcome the tendency of the control stream to return to its preferred position, and the stream switches back to the expiration outlet channel 46.

By appropriately sizing and shaping the parts, particularly the control amplifier **12** and the venturi **58**, the terminal flow can be established at the desired level. In most operational situations, it is desired that such flow be less than 5 liters per minute and this can readily be accomplished with the apparatus of the invention. Moreover, it can be accomplished without impairing the capability of the apparatus to meet the patient's peak flow capacity.

Responsive to the control stream in the control amplifier **12** switching back to its preferred, stable position in the expiration outlet channel **46**, the main amplifier **12** switches to its expiratory mode of operation in the manner previously described. As set forth above, flow through this amplifier takes place as shown by the arrowed lines in FIGURE 2. Main stream flow is through the exhaust channel **32** to the atmosphere, and this serves immediately to relieve pressure in the downstream section of the conduit means **16**. The exhalation valve **74** opens passage **72** and the patient is free to expire to the atmosphere through the pasage **72**. It is to be noted that expired gas is prevented by the check valve **78** from flowing back through the conduit means **16** to the interior of the exhalation valve **74**.

The apparatus then remains in its expiratory mode, as in FIGURES 1 and 2, until expiration is completed. This constitutes one complete breathing cycle. It will be understood that the next, as well as all subsequent cycles, commence in the same manner as described above.

A slightly modified version of the apparatus of the invention, designated by the reference numeral **100**, is illustrated in FIGURES 3 and 4. Many of the elements of the apparatus **100** are identical to the elements of apparatus **10**. To simplify the description, like elements of the two embodiments have been identified with like numerals and are not again described. In the case of the latter apparatus **100**, the numerals carry a prime subscript. It is observed that in the case of the main amplifier **12'**, the patient and exhaust channels **30'** and **32'** have been reversed from top to bottom as compared to their orientation in amplifier **12** in FIGURE 2. However, this amplifier is symmetrical about a horizontal center line and, therefore, this presents no problem.

The principal difference between the present embodiment over the former is in the means for sensing negative pressure in the conduit means **16** to initiate inspiration and, thereafter, for sensing flow through the conduit means to continue inspiration until the flow drops to the terminal flow. In this instance a restrictor **102** is provided in the conduit means **16'** intermediate the main amplifier **12'** and the delivery means **20'**. Ports **104** and **106** are provided in the conduit means **16'** on the upstream and downstream sides, respectively, of the restrictor **102**, and connected by conduits **108** and **110** to the nozzles **54'** and **56'** of the control amplifier **14'**.

Inspiration is initiated in the case of the apparatus **100** by negative pressure acting through the conduit **110** and issuing as a negative presure signal from the nozzle **54'**. To prevent a like signal from issuing from the nozzle **56'** and counterbalancing the desired triggering signal, a vent passage **112** is provided in the conduit **108**. The passage **112** is adapted to be closed from the exterior by a diaphragm-type valve **114**, similar to the exhalation valve **74** of the apparatus **10**, disposed in close proximity to the opening of the pasage **112**. Pressure is supplied internally to the valve **114** for actuating it through a conduit **116** connected to the main conduit means **16'** between the port **104** and the restrictor **102**.

As in the case of the exhalation valve **74** of the prior embodiment, the effective cross-sectional area of the valve **114** is greater than the area of the opening to the associated passage **112**. Thus, the valve **116** will be open or closed, depending upon whether there is a positive or negative pressure existing in the main conduit means **16'** adjacent the junction with the conduit **116**. This is true notwithstanding the fact that an equal pressure exists in the auxiliary conduit **108** adjacent the vent passage **112**. Thus, the valve **114** will be drawn off its seat to open the passage **112** when the patient exerts a negative pressure to initiate inspiration and will be seated to close the passage during periods in which gas is being delivered to the patient through the main conduit means **16'**. To insure that the negative pressure acts in the desired manner through the conduit **110** when the valve **114** is open, a restrictor **118** is provided in the conduit **108**.

As is well known, the pressure drop across a restrictor in a gas flow path will vary in accordance with the flow rate. In the case of the present apparatus, it is the pressure differential produced by the restrictor **102** and transmitted to the amplifier **14'** that overcomes the tendency of the control stream to move to its stable preferred position, maintaining the apparatus in its inspiratory mode of operation. When flow through the conduit means **16'** exceeds the predetermined terminal flow, the pressure differential is sufficient to maintain the control stream in the inspiration outlet channel **44'**. On the other hand, when flow drops to the terminal flow, such differential is insufficient.

Briefly reviewing the operation of the apparatus **100**, upon the source **18'** being activated, the apparatus assumes its expiratory mode of operation. The flow paths through amplifiers **12'** and **14'** are as shown in FIGURE 4, with the gas from the source **18'** being vented to the atmosphere through the exhaust channel **32'** of the main amplifier **12'**. As slight inspiratory effort on the part of the patient produces a negative presure in the conduit means **16'** adjacent the delivery means **20'**. Such pressure acts through the passage **72'** to draw the exhalation valve **74'** closed, and through the conduit **116** to draw the valve **114** off its seat. Accordingly, an ambient pressure will exist in the conduit **108** adjacent the nozzle **56'**. On the other hand, a negative pressure will act through the conduit **110** and issue as a negative pressure signal from the nozzle **54'**. This signal then serves to break the lock-on phenomenon and draw the control stream from the expiration outlet channel **46'** toward the inspiration outlet channel **44'**.

Switching of the control amplifier **14'**, in turn, switches the main amplifier **12'**, so that main stream flow is supplied through the patient channel **30'** and conduit means **16'** to the patient. Positive pressure in the conduit means acts through the conduits **76'** and **116** to maintain the valves **74'** and **114** closed. Moreover, as flow takes place, pressures in the conduit means **16'** at the locations of the ports **104** and **106** on opposite sides of the restrictor **102** are sensed and supplied through the conduits **108** and **110** as positive pressure signals counterbalancing one another to the nozzles **56'** and **54'**. Provided the flow rate through the conduit means **16'** exceeds the terminal flow, the amplitude of the signal issuing from nozzle **56'** is sufficiently higher than that issuing from nozzle **54'** to maintain the control stream in the inspiration outlet channel **44'**.

As the patient becomes fully ventilated, the pressure differential across the restrictor **102** sensed at the parts **104** and **106** diminishes, and when the terminal flow is reached, such differential is insufficient to maintain the stream in the channel **44'**. Accordingly, it switches back to the expiration outlet channel **46'** to complete a breathing cycle.

In the case of apparatus **100** the desired terminal flow can be established by appropriately sizing the restrictor **102**, as well as by appropriately sizing and shaping the control amplifier **14'**. In this connection, it is noted that the restriction afforded by the restrictor **102** should not be such as to unduly restrict the peak flow capacity of the apparatus. In general, it is desired that at an average control pressure, the apparatus be capable of delivering up to 100 liters per minute of gas in order to meet the

patient's peak flow requirement. By appropriate sizing of the various parts, the apparatus can be made to satisfy this requirement, yet still have a relatively low terminal flow on the order of less than 5 liters per minute.

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

I claim:

1. In respiration apparatus including a source of pressurized gas and delivery means, the combination of:
main conduit means adapted to connect the source and the delivery means; a main fluid control means in said main conduit means having an inspiration state in which flow takes place from said source to said delivery means and an expiration state in which said flow is terminated, said control means being actuated by means applying pressure signals to move said control means between its inspiration and expiration states;
flow responsive means in said main conduit means intermediate said control means and said delivery means and having a pair of sensing ports at which pressures of different magnitudes are sensed during flow through said main conduit means; and
a control fluid amplifier coupled to said control means and having a power nozzle connected to said source, inspiration and expiration outlet channels for receiving, alternately, a control stream of gas issuing from said power nozzle and connected to said means for applying pressure signals whereby said control means is actuated to its inspiration state when said control stream is flowing through said inspiration outlet channel and being actuated to its expiration state when said control stream is flowing through said expiration outlet channel, and first and second control nozzles coupled to said first and second sensing ports, respectively and arranged to issue pressure signals to direct said control stream between said inspiration and expiration outlet channels.

2. In respiration apparatus including a source of pressurized gas and delivery means, the combination of:
main conduit means adapted to connect the source and the delivery means;
a main fluid amplifier in said conduit means having
a main nozzle connected to said conduit means on the upstream side of said amplifier,
an exhaust channel vented to the atmosphere,
a patient channel connected to said conduit means on the downstream side of said amplifier,
said exhaust and patient channels being arranged to receive, alternately, a main stream of gas issuing from said main nozzle,
and inspiration and expiration control nozzles arranged to issue pressure signals to direct said main stream toward said exhaust and patient channels, respectively; flow responsive means in said main conduit means intermediate said main fluid amplifier and said delivery means having a pair of sensing ports at which pressures of different magnitudes are sensed during flow through said main conduit means; and
a control fluid amplifier having
a power nozzle,
an inspiration outlet channel connected to said inspiration control nozzle,
an expiration outlet channel connected to said expiration control nozzle,
said inspiration and expiration outlet channels being arranged to receive, alternately, a control stream of gas issuing from said power nozzle,
and control nozzle means connected to said ports of said flow responsive means,
said control nozzle means being arranged to issue a pressure signal to direct said control stream to said inspiration outlet channel.

3. The subject matter of claim 2, wherein said control fluid amplifier is of the monostable type with a stable, preferred position in which said control stream is received by said expiration outlet channel.

4. The subject matter of claim 3, wherein said main fluid amplifier is of the bistable type.

5. In respiration apparatus including a source of pressurized gas and delivery means, the combination of:
main conduit means adapted to connect the source and the delivery means;
a main fluid amplifier in said conduit means having
a main nozzle connected to said conduit means on the upstream side of said amplifier,
an exhaust channel vented to the atmosphere,
a patient channel connected to said conduit means on the downstream side of said amplifier,
said exhaust and patient channels being arranged to receive a main stream of gas issuing from said main nozzle,
and first control nozzle means for issuing a positive pressure signal for directing said main stream from said exhaust channel toward said patient channel; flow-responsive means in said main conduit means intermediate said main fluid amplifier and said delivery means having first and second sensing ports at which pressured of different magnitudes are sensed during flow through said main conduit means; and
a control fluid amplifier having
a power nozzle connected to said source, inspiration and expiration outlet channels for receiving, alternately, a control stream of gas issuing from said power nozzle,
said outlet channels being connected to said first control nozzle means and arranged so that when said control stream is directed from said expiration outlet channel toward said inspiration outlet channel, a positive pressure signal is issued by said first control nozzle means to direct said main stream toward said patient channel,
first and second control nozzles coupled to said first and second sensing ports, respectively, and arranged to issue pressure signals to direct said control stream bewteen said inspiration and expiration outlet channels.

6. In respiration apparatus including a source of pressurized gas and delivery means, the combination of:
main conduit means adapted to connect the source and the delivery means;
a main fluid amplifier in said conduit means having
a main nozzle connected to said conduit means on the upstream side of said amplifier,
an exhaust channel vented to the atmosphere,
a patient channel connected to said conduit means on the downstream side of said amplifier,
said exhaust and patient channels being arranged to receive a main stream of gas issuing from said main nozzle,
and first control nozzle means for issuing a pressure signal for directing said main stream from said exhaust channel to said patient channel; flow-responsive means in said main conduit means intermediate said main fluid amplifier and said delivery means having a pair of sensing ports at which pressures of different magnitudes are sensed during flow through said main conduit means; and
a control fluid amplifier having

a power nozzle connected to said source,
inspiration and expiration outlet channels for receiving a control stream of gas issuing from said power nozzle,
said outlet channels being connected to said first control nozzle means and arranged so that when said control stream is directed from said expiration outlet channel to said inspiration outlet channel, a positive pressure signal is issued by said first control nozzle means to direct said main stream toward said patient channel, and so that when said control stream is directed from said inspiration outlet channel to said expiration outlet channel, a positive pressure signal is issued by said first control means to direct said main stream toward said exhaust channel,
and second control nozzle means having a pair of nozzles connected, one each, to said ports of said flow-responsive means, to
said second control nozzle means being responsive to a negative pressure in said conduit means adjacent the delivery means for issuing a pressure signal for directing said control stream from said expiration outlet channel to said inspiration outlet channel, and responsive to flow through said main conduit means at a rate greater than a predetermined terminal flow for issuing a pressure signal for maintaining said control stream in said inspiration outlet channel.

7. In respiration apparatus including a source of pressurized gas and delivery means, the combination of:
main conduit means adapted to connect the source and the delivery means;
a main fluid amplifier in said conduit means having
a main nozzle connected to said main conduit means on the upstream side of said amplifier,
an exhaust channel vented to the atmosphere,
a patient channel connected to said main conduit means on the downstream side of said amplifier,
said exhaust and patient channels being arranged to receive, alternately, a main stream of gas issuing from said main nozzle,
and inspiration and expiration control nozzles arranged to issue pressure signals to direct said main stream to said exhaust and patient channels, respectively;
a control fluid amplifier having
a power nozzle connected to said source,
an inspiration outlet channel connected to said inspiration control nozzle,
an expiration outlet channel connected to said expiration control nozzle,
said inspiration and expiration outlet channels being arranged to receive, alternately, a control stream of gas issuing from said power nozzle with said expiration outlet channel being the preferred position of said control stream,
first and second control nozzles arranged to issue pressure signals to direct said control stream between said inspiration and expiration outlet channels;
a venturi having a throat in said main conduit means intermediate said main fluid amplifier and the delivery means, there being a passageway in said venturi with an opening at said throat;
first auxiliary conduit means connecting said first control nozzle and said main conduit means at a location spaced from said venturi; and
second auxiliary conduit means connecting said second control nozzle and said passageway in said venturi.

8. The subject matter of claim 7, wherein said first auxiliary conduit means is connected to said main conduit means at a location upstream of said venturi, and including a main check valve in said main conduit means at a location between the connection of said first auxiliary conduit means to said main conduit means and said venturi, said main check valve being slightly biased to a closed position and arranged to block flow through said main conduit means from said delivery means toward said main amplifier, but to permit flow in the opposite direction.

9. In respiration apparatus including a source of pressurized gas and delivery means, the combination of:
main conduit means adapted to connect the source and the delivery means;
a main fluid amplifier in said conduit means having
a main nozzle connected to said conduit means on the upstream side of said amplifier,
an exhaust channel vented to the atmosphere,
a patient channel connected to said conduit means on the downstream side of said amplifier,
said exhaust and patient channels being arranged to receive, alternately, a main stream of gas issuing from said main nozzle,
and inspiration and expiration control nozzles arranged to issue pressure signals to direct said main stream to said exhaust and patient channels, respectively;
a control fluid amplifier having
a power nozzle connected to said source,
an inspiration outlet channel connected to said inspiration control nozzle,
an expiration outlet channel connected to said expiration control nozzle,
said inspiration and expiration outlet channels being arranged to receive, alternately, a control stream of gas issuing from said power nozzle with said expiration outlet channel being the preferred position of said control stream,
first and second control nozzles arranged to issue pressure signals to direct said control stream between said inspiration and expiration outlet channels;
means forming a restriction in said conduit means intermediate said main fluid amplifier and said delivery means;
first auxiliary conduit means connecting said first control nozzle and said main conduit means at a location downstream of said restriction;
second auxiliary conduit means connecting said second control nozzle and said main conduit means at a location upstream of said restriction;
means forming a vent passage in said second conduit means; and
valve means for closing said vent passage responsive to a positive pressure in said main conduit means.

References Cited

UNITED STATES PATENTS

3,223,101	12/1965	Bowles	137—81.5
3,244,189	4/1966	Bailey	137—81.5
3,280,832	10/1966	Burns	137—81.5 XR
3,292,623	12/1966	Warren	128—203

RICHARD A. GAUDET, *Primary Examiner.*
K. L. HOWELL, *Assistant Examiner.*