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Weigl

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[54] **FLOW RESPONSIVE RESPIRATION APPARATUS**

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[52] **U.S. Cl.** **128/145.8,** 137/842

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

[58] **Field of Search** 128/145.8, 145.6, 145.7, 128/145.5, 145; 137/842

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[57] **ABSTRACT**

Respiration apparatus for IPPB therapy in which the inspiratory effort of the patient to initiate an inspiration phase is sensed by a flow sensor which operates by directing a laminar jet of gas across a conduit of the apparatus toward a receiver, to produce a normal pressure in the receiver when there is no flow in the conduit. A second receiver establishes a reference pressure, and the change in the pressure relationship between the receivers, resulting when the patient creates a cross-flow across the jet, is used as a pilot signal to operate an actuator for opening a flow control valve. Similarly, as the flow rate is reduced near the end of the inspiration phase, the pressure relationship is restored and the actuator closes the control valve. One embodiment uses a laminar jet that is directed into an aligned receiver to raise the pressure therein relative to a receiver spaced from the jet, and referenced to actual patient delivery pressure, until a cross-flow disturbance changes the jet to turbulent, thereby reducing the pressure in the aligned receiver. Another embodiment uses a turbulent jet directed between two longitudinally spaced receivers, disposed in close proximity to one another, to establish equal pressures therein until the jet is deflected longitudinally toward one of the receivers and away from the other in response to a cross-flow.

13 Claims, 6 Drawing Figures

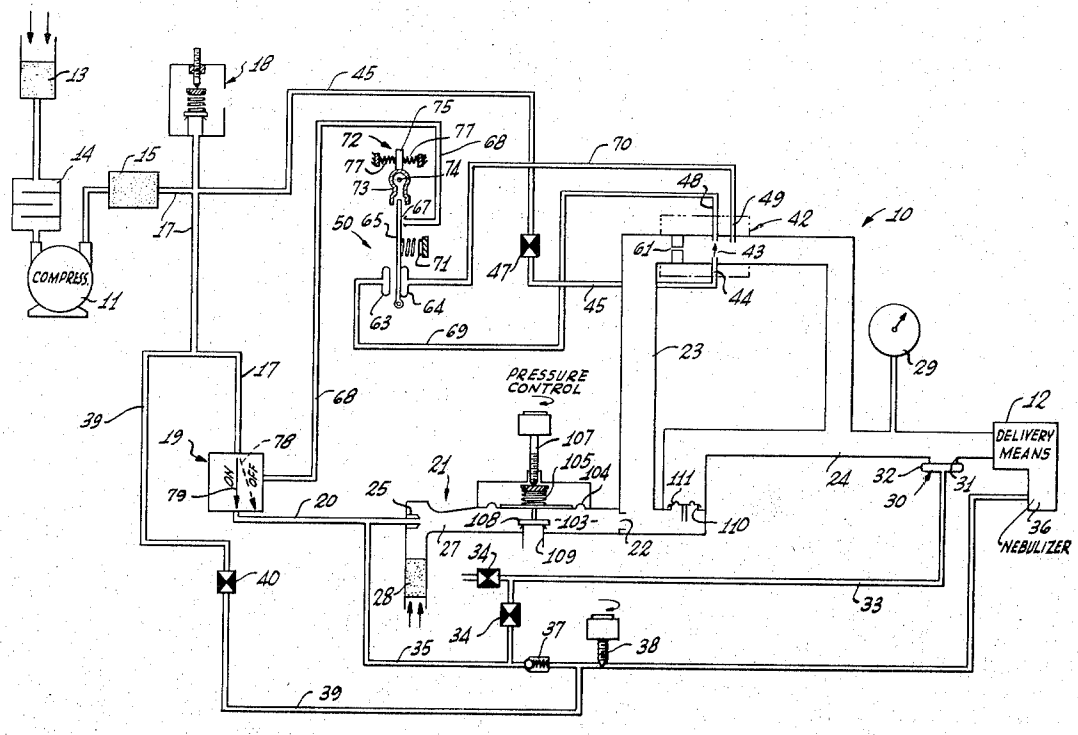
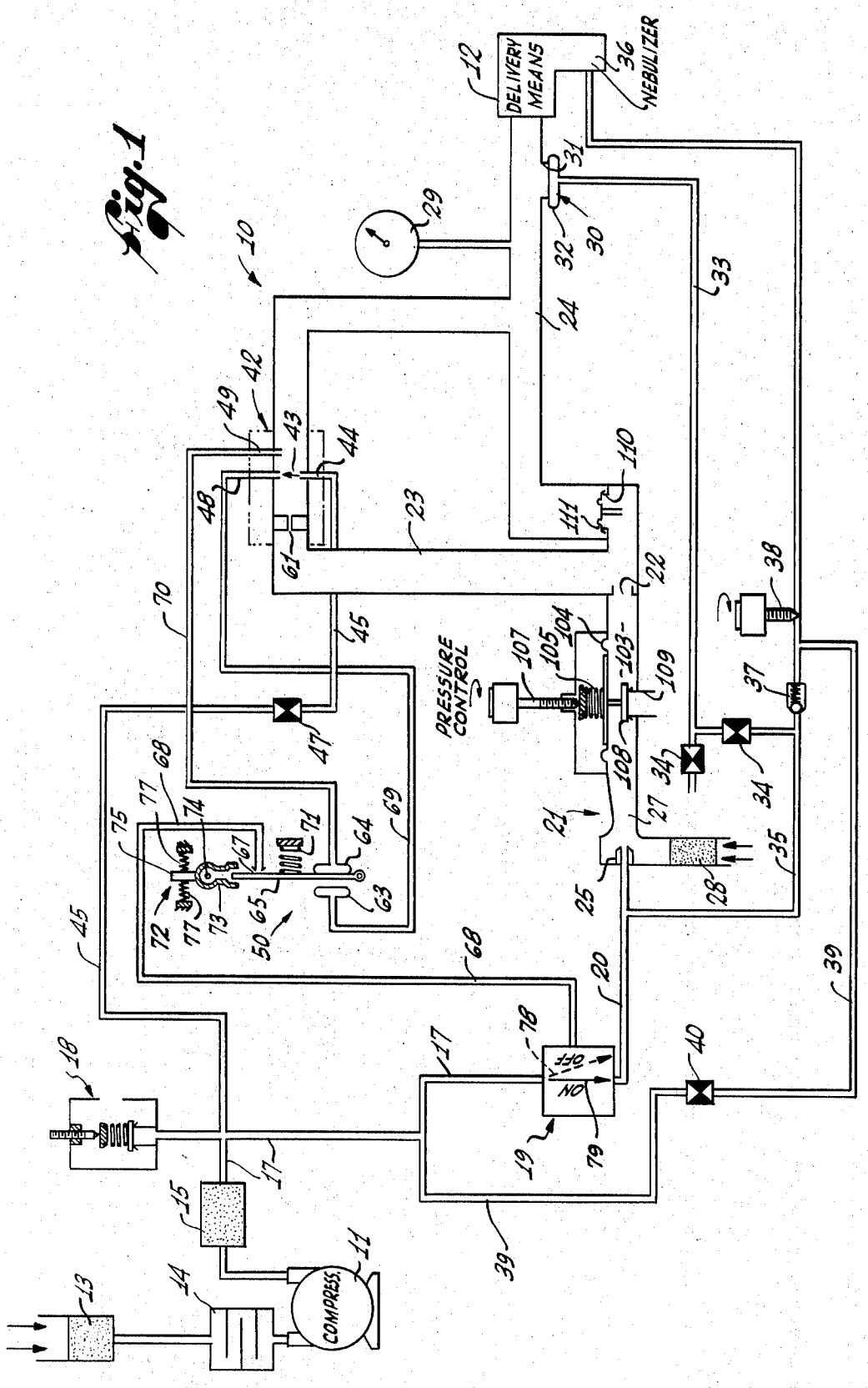


Fig. 1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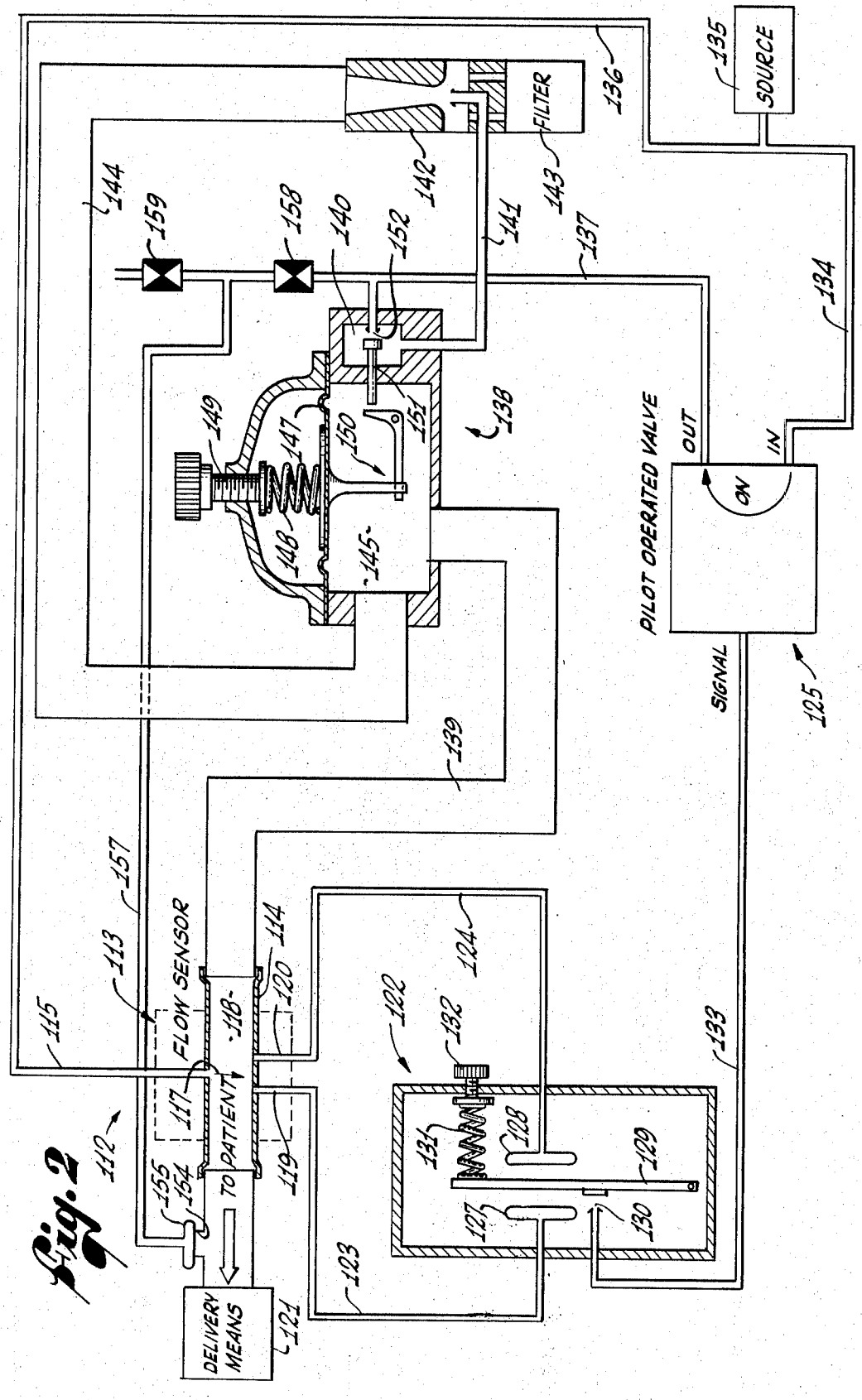
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DELIVERY MEANS
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Fig. 2

Fig. 3

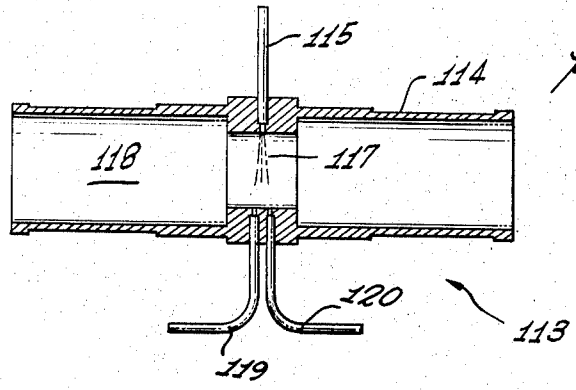


Fig. 4

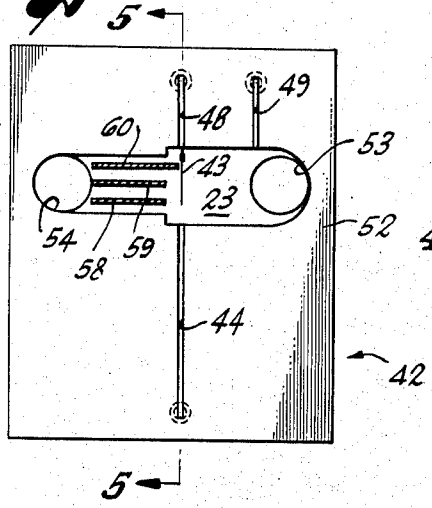


Fig. 5

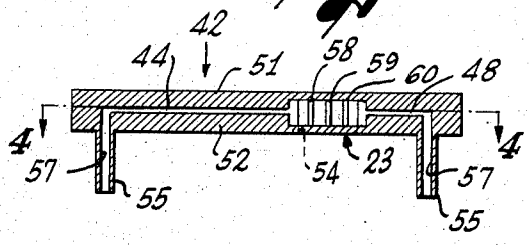
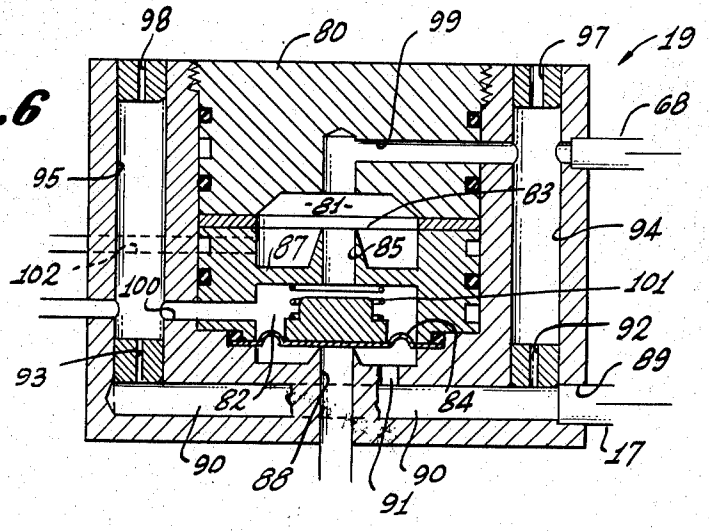


Fig. 6



FLOW RESPONSIVE RESPIRATION APPARATUS

BACKGROUND OF THE INVENTION

This invention relates to respiration apparatus, and more particularly to apparatus for administering intermittent positive pressure breathing (IPPB) therapy to a patient.

In such therapy, air, oxygen or oxygen-enriched air under pressure is supplied to a patient cyclically through delivery means such as a face mask or the like. Each inspiration phase is initiated in response to a slight inspiratory effort by the patient, and begins with a peak flow rate which inflates the patient's lungs, the flow rate then being reduced to a relatively low level at which all flow is terminated. Following the inspiration phase, the lungs are vented to atmosphere during an expiration phase, which terminates when the next inspiratory effort by the patient initiates the next cycle.

Examples of prior IPPB apparatus are shown in U.S. Pat. No. 3,362,404 and No. 3,368,555, illustrating two different approaches to the manner in which inspiration may be initiated and terminated. In U.S. Pat. No. 3,362,404, the patient draws air through the delivery means to create a pressure drop in the diaphragm chamber of a triggering valve, and this pressure drop is used to open a flow responsive valve which initiates the inspiration phase and eventually terminates inspiration in response to a selected low terminal flow level. In U.S. Pat. No. 3,368,555, a similar inspiratory effort by the patient is applied as a biasing signal to a control fluid amplifier of the monostable, lock-on type to switch a fluid flow therein from a preferred channel to another channel, thereby switching the flow through a main fluid amplifier of the bistable, lock-on type to initiate an inspiration cycle. The flow in the control amplifier switches back to the preferred channel automatically when the biasing signal is removed, and this switches the main amplifier to terminate inspiration at a selected low terminal flow rate.

Both of these approaches are effective to initiate inspiration in response to slight inspiratory efforts, but both utilize the actual reduction of pressure caused by the patient's inspiratory effort as the source of an actuating pressure signal, with the result that there is a perceptible resistance to inspiratory effort at the beginning of inspiration until the machine overcomes its internal delays and begins to flow gas through the delivery means. A primary object and advantage of the present invention is the reduction of this resistance to an almost imperceptible level, to increase the comfort of the patient during IPPB therapy, in a novel manner that does not detract in any way from other performance characteristics of the apparatus.

SUMMARY OF THE INVENTION

The present invention resides in a respiration apparatus of the foregoing general character in which the inspiratory phase of each respiration cycle is initiated by a flow-sensing device that does not require the patient to create a pressure drop any greater than that required to produce a slight flow of air within the conduits of the apparatus. In other words, the sensing device of the present invention is capable of initiating the inspiration phase in response to an inspiratory effort by the patient that is virtually the same as the normal effort during involuntary breathing, and is effective to initiate the inspiration phase with an open air circuit through the apparatus, preferably through a filter for mixing air with the primary flow of gas from the source.

This is accomplished by incorporating a fluidic flow sensor in one of the conduits of the apparatus, including means on one side of one of the conduits for directing a jet of gas under pressure across the conduit and receiver means in the path of the jet reference pressure relationship between two receivers of the receiver means, in the absence of any flow in the conduit. When a very low threshold flow is created in the conduit by the inspiratory effort of the patient, for example, a flow as low as 2 to 4 liters per minute, or even less, this cross-flow disturbs the air jet, changes the reference pressure relationship between the receivers, and produces a pressure signal that is used to initiate the inspiration phase of the apparatus. A pressure-actuated control valve responds to the signals of the flow sensor to initiate the supply of respiration gas, and a conventional regulator controls the flow rate to the patient.

As long as there is flow through the flow sensor, the changed pressure relationship is maintained to maintain the apparatus in the inspiration phase. As flow rate is reduced during inflation of the patient's lungs, however, the cross-flow through the jet is reduced to a low rate which falls below the threshold level for the flow sensor, the reference pressure signal is restored to the reference relationship, and the inspiratory phase is terminated by the control valve.

In one form of flow sensor disclosed, a turbulent jet is directed between two receivers disposed in close proximity to each other, to establish equal pressures therein until the jet is deflected longitudinally by a cross-flow, and all flow passes through the sensor, which may have a relatively high flow area capable of handling the peak flow rate of the apparatus. In another, more sensitive form, a normally laminar jet is directed into an aligned receiver, and a reference receiver is spaced from the jet to establish a reference pressure, the jet being converted to turbulent by a cross-flow, thereby dropping the pressure in the aligned receiver sharply. The flow area in this form is restricted, and a by-pass is provided around the sensor, for carrying peak flow rates to the patient.

Other aspects and advantages of the invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of one embodiment of a respiration apparatus constructed in accordance with the present invention;

FIG. 2 is a similar schematic view of an alternative embodiment of the invention;

FIG. 3 is an enlarged longitudinal cross-sectional view of a flow sensor incorporated in the apparatus of FIG. 2;

FIG. 4 is an enlarged cross-sectional view of a flow sensor incorporated in the apparatus of FIG. 1, the view being taken in a plane indicated by line 4—4 of FIG. 5;

FIG.5 is a cross-sectional view taken along line 5—5 of FIG. 4; and

FIG. 6 is an enlarged cross-sectional view of a pilot-operated flow control valve suitable for use in both embodiments of the invention.

DETAILED DESCRIPTION

As shown in the drawings for purposes of illustration, and with particular reference to FIG. 1, the invention is embodied in an IPPB respiration apparatus **10** for delivering an intermittent flow of air under pressure to a patient from a compressor **11**, through the various conduits and control components of the apparatus and delivery means **12** such as a face mask adapted to be worn over the patient's mouth and nose. The compressor draws outside air in through a filter **13** and a silencer **14**, and pumps the air through a second filter **15** into a main flow conduit **17** in which the pressure is controlled by a regulator **18**.

From this conduit **17**, the air is passed intermittently through a selectively operable control valve **19** and through a conduit **20** to a conventional pressure-responsive relief valve **21** for reducing the flow rate to the patient as back pressure in the system indicates that the patient's lungs are approaching full inflation. The outlet **22** of this relief valve is connected through two conduits **23** and **24** to the delivery means **12**. The entrance into the relief valve **21** is shown as a jet **25** for directing the gas into a venturi section **27**, thus creating a pressure drop for drawing outside air through a filter **28** and entraining this air with the primary air flow from the valve **21**.

Thus, the opening and closing of the control valve **19** initiates and terminates the inspiration phases of successive respiratory cycles of the apparatus **10**, and the relief valve **21** controls the flow rate during each such phase. The relief valve initially passes a relatively high peak flow, and then reduces this flow to a relatively low terminal flow rate before the valve **19** is closed to terminate inspiration. A gauge **29** preferably is provided to indicate system pressure.

After termination of inspiration, the patient is permitted to exhale naturally through the delivery means **12** and an exhalation valve **30** in the conduit **24** adjacent the delivery means, this valve comprising an exhalation port **31** which is closed during inspiration by a pressure-actuated closure **32**, herein an inflatable "mushroom" or "balloon" closure connected through a conduit **33** and a pressure divider formed by two restrictors **34**, to the conduit **35** that is pressurized during inspiration. When air is being supplied to the patient, the closure is inflated and the exhalation valve is closed. During exhalation, the pressure in the closure is relieved, and the valve opens to allow exhaled gas to escape.

If medication is to be administered to the patient as an incident to the IPPB therapy, a conventional nebulizer **36** may be included with the delivery means and supplied with nebulizing air under pressure through the conduit **35**, a one-way check valve **37**, and a needle valve **38**. Nebulizing air also may be supplied during the expiration phase by means of a conduit **39** connected to the conduit **17** ahead of the control valve **19** and having a flow restrictor **40** therein, this conduit being connected to the conduit **35** between the check valve **37** and the needle valve **38**.

In accordance with the present invention, the inspiration phases are initiated and terminated by a fluidic flow sensor **42** in which a jet **43** is directed across one of the conduits of the apparatus, herein the conduit **23**, toward receiver means which establish a reference pressure relationship and maintain that relationship as long as there is no disturbance in the conduit. When a disturbance occurs, as a result of inspiration by the patient through the delivery means **12** and the conduits of the apparatus, the pressure relationship departs from the reference, and this change is used to open the control valve **19** and initiate an inspiration phase of the apparatus. Similarly, when the flow rate is reduced to the low terminal flow rate, the pressure relationship is restored to the reference level, and this change is used to close the control valve and terminate the inspiration phase of the apparatus.

More specifically, as shown schematically in FIG. **1** and in detail in FIGS. **4** and **5**, the flow sensor **42** comprises a jet tube **44** opening into one side of the conduit **23** and shaped and positioned to direct a controlled laminar jet of gas (herein air from a conduit **45** connected through a restrictor **47** to the conduit **17**) across the conduit **23** and across the path of air drawn through the conduit when the patient begins to breathe through the respiration apparatus.

Directly across the conduit and aligned with the jet tube **44** to receive the air jet **43** is a first receiver tube **48**, the pressure in which is a function of the laminarity (as opposed to turbulence) of the air jet. Such a jet remains laminar for a considerably distance downstream from the orifice of the jet tube, and then breaks up into turbulence. The receiver tube is positioned closer to the jet orifice than the distance to the point of turbulence, and thus normally receives a laminar flow.

Spaced along the conduit from the first receiver tube **44** is a second receiver tube **49**, or reference tube, in which the pressure is essentially unaffected by the jet flow. Thus, a predetermined pressure differential normally exists between the two receiver tubes **48** and **49**, the difference being the pressure increase in the tube **48** produced by the jet **43**, as long as it remains laminar in character at the entrance to the tube.

When a patient begins to breathe through the apparatus, the external influence on the pressures at the two receiver tubes **48** and **49** is the same, but the disturbance of the air jet by the cross-flow of air in the conduit substantially reduces the distance to the point of turbulence. The receiver tube **48** is farther from the jet orifice than the reduced distance to the point of turbulence, and thus receives turbulent, rather than laminar, flow. The result is a marked decrease in the pressure in the receiver tube **48**, relative to original pressure. This decrease serves as a pilot pressure signal to actuate the control valve **19** and initiate the inspiration phase, herein through a pressure-operated actuator **50**.

Similarly, as the flow to the patient is reduced by the relief valve **21** near the end of the inspiration phase and the rate of flow through the conduit **23** declines, the disturbance of the air jet **43** is terminated, and the flow again becomes laminar at the entrance to the receiver tube **48**. When this occurs, the pressure in the tube increases markedly, and this increase serves as a pilot-pressure signal which acts through the actuator **50** to close the valve **19**.

Shown in FIGS. **4** and **5** is a specific embodiment of a suitable flow sensor **42**, in a form which may be injection molded as a small and inexpensive part, in two pieces, with the jet tube **44**, the receiver tubes **48** and **49**, and the conduit **23**. Basically, the sensor comprises two flat plates **51** and **52** fitted together as shown in FIG. **5** and having adjacent recessed sides defining the tubes and the conduit.

The patient end of the conduit **23** is a port **53** in the plate **52**, and the inlet end is a similar port **54** in the same plate. The air jet tube **44** is formed by an elongated channel in the plate **52**, which channel may be rectangular in transverse cross-sectional shape for convenience of manufacture. The two receiver tubes **48** and **49** may be similar channels, permissibly of shorter length. When the upper plate **51** is clamped over the lower plate, the recesses, which may be in one or both plates, define the various ports.

It should be evident that it is very important for the jet tube **44** to be smooth-walled, to avoid premature transition to turbulent flow. Suitable connectors **55** are formed on the plate **52** with passages **57** to carry the jet flow into the jet channel **44** and for connection of signal lines to the receiver channels **48** and **49**.

It will be seen in FIG. **4** that a plurality of elongated parallel fins **58, 59** and **60** are formed in the left-hand portion of the conduit **23**, perpendicular to the path of the jet **43** across the conduit. These fins serve as flow straighteners, and also reduce the cross-sectional flow area of the conduit, to concentrate the cross-flow on the air jet. The flow area in the opposite end portion is greater by an amount equal to that occupied by the fins, and also is increased by widening of the conduit **23**, the resulting restriction being indicated schematically at **61** in FIG. **1**.

In addition, it will be seen in FIG. **4** that the upper fin **60**, farthest from the orifice of the jet tube **44**, has a downstream end **62** which is closely adjacent the normal path of the jet **43** when the flow is laminar. This fin is intended to intercept and amplify the eddy currents along the edge of the jet that are created by cross-flow, and thus to promote crisp switching of the sensor.

The sensitivity of the flow sensor **42** may be adjusted to different threshold flow rates by moving the disturbing cross-flow either closer to or farther from the jet orifice along the axis of jet flow. Accordingly, the inspiration phase can be initiated and terminated at different flow rates through the conduit **23**. For example, for high sensitivity, at a threshold flow rate on the order of 1 to 2 liters per minute, the cross-flow is directed at the jet at a location relatively close to the supply jet orifice. For a lower degree of sensitivity, at a threshold rate of 2 to 4 liters per minute, the cross-flow is directed at the jet at a location farther away from the jet orifice and closer to the receiver orifice.

While high sensitivity is desirable for ease in initiation of inspiration, lower sensitivity can be desirable for termination at a somewhat higher terminal flow rate. Thus, a comprise may be made between these two considerations, or a by-pass may be provided so that only a portion of the flow is passed through the flow sensor **42**.

The illustrative pressure-operated actuator **50**, shown in FIG. **1**, includes two inflatable members **63** and **64**, which may be of the "mushroom" type comprising freely flexible, hollow plastic bodies. These members are disposed on opposite sides of a lever **65** to urge the lever back and forth relative to an orifice **67** through which air under pressure from a conduit **68** escapes when the lever is spaced from the orifice. The member **63** on the left-hand side is connected by a conduit **69** to the receiver tube **48**, and thus will be inflated when there is no flow through the conduit **23**, to urge the lever **65** toward the orifice **67** into a blocking position. The member **64** on the right-hand side of the lever is connected by a conduit **70** to the receiver tube **49**, to be subjected to the lower patient delivery pressure, and tending to swing the lever to an open position. A light spring **71** is positioned to exert an opening force on the lever, and to cooperate with the member **64** in developing an opening force moment that is less than the closing moment when jet flow is undisturbed, but greater than the closing moment when the jet flow is disturbed.

A manual control **72** is shown in FIG. **1** for shifting the lever **65** into and out of its blocking position, independently of the forces exerted by the members **63** and **64**. This is simply a yoke **73** that is pivotally mounted on a pin **74** above the free end of the lever, with the legs of the yoke straddling the lever and a knob **75** projecting upwardly therefrom and normally held in the centered position shown, by two springs **77**. The knob can be shifted in either direction to cause the yoke to pick up the lever and shift it into a selected position.

Air under pressure is continuously supplied to the signal conduit **68** through the control valve **19** to escape through the orifice **67** when it is unblocked by the lever **65**, and to build up an actuating back-pressure signal in the conduit when the orifice is blocked. This back-pressure signal from the normally blocked orifice holds the control valve in a closed condition, indicated by the dotted-line arrow **78** in FIG. **1**, and permits the valve to open when the orifice is unblocked, as indicated by the arrow **79**.

Various control valves are available to serve this function, one suitable valve construction being shown in detail in FIG. **6**. This valve has a body **80** formed with two internal diaphragm chambers **81** and **82** with diaphragms **83** and **84** therein, the upper diaphragm **83** serving normally to close a passage **85** through a partition **87** between the chambers, and the diaphragm **84** serving normally to close a passage **88** extending out through the lower end of the body and connected to the conduit **20** leading to the relief valve **21**.

The conduit **17** from the compressor **11** is connected to a port **89** on one side of the body, and delivers compressed air through this port to a cross-passage **90** in the body, feeding the air into the lower chamber **82** beneath the diaphragm **84**, through a passage **91**, and also through restrictors **92** and **93** into two vertical passages **94** and **95**. The upper ends of these passages have venting restrictors **97** and **98** therein, which cooperate with the restrictors **92** and **93** in maintaining selected reduced pressures in the vertical passages **94** and **95**. For example, when 10 psi air is supplied to the cross-passage **90**, the restrictors **93** and **98** may be equal in size to maintain 5 psi in the passage **95**, while the vent restrictor **97** is sufficiently larger than the restrictor **92** to maintain about one-third of 1 psi in the passage **94**.

It will be seen in FIG. **6** that a conduit **99** leads from the passage **94** to the upper diaphragm chamber **81**, above the diaphragm **83**, to hold this diaphragm down to close the upper central passage **85** when the signal conduit **68** is blocked at the orifice **67**. At the same time, 5 psi pressure from the vertical passage **95** is applied to the lower diaphragm chamber **82**, above the diaphragm **84**, through a passage **100**. The resulting force, plus a light spring **101** above the diaphragm, holds the latter down to close the lower passage **88**. This is the closed, or "off," condition of the valve **19**

in which no flow is delivered from the "in" port 89 to the "out" passage 88.

When the orifice 67 is unblocked by the lever 65 in response to disturbance of the air jet 43 by the patient's breathing through the conduit 23, pressure above the upper diaphragm 83 is relieved, and the higher pressure from the chamber 82 below, acting through the central passage 85, lifts the diaphragm and is vented through a conduit 102. This relieves the pressure above the lower diaphragm 84, so that the lifting force of the pressure beneath it overcomes the spring 101 to raise the diaphragm and open the "out" passage 88, connecting this passage to the supply conduit 17 through the lower chamber 82, beneath the diaphragm 84, and through the cross-passage 90 and the "in" port 89.

Accordingly, air flows through the valve 19 to the relief valve 21, and thus to the patient, as long as the orifice 67 is unblocked by the lever 65. When the lever is returned to the blocking position, pressure is restored above the upper diaphragm 83, closing the central passage 85 and thereby restoring the pressure above the lower diaphragm 84 to close the "out" passage 88. This shuts off the flow out of the valve 19.

It has been stated that the pressure relief valve 21 may be of conventional construction, the valve illustrated being of the type sold by Bennett Respiration Products, Santa Monica, Calif., as the No. 1694 A Relief Valve. As will appear subsequently, the same function may be accomplished by a Bennett Respiration Products No. 0666 Diluter Regulator, which is preferred when the source supplies oxygen rather than air.

In general, the relief valve 21 defines a chamber 103 into which the primary flow of air is injected through a venturi device where room air is entrained past the outside-air filter 28, one side of this chamber being formed by a diaphragm 104 adjustably loaded by a spring 105 and adjusting screw 107 for setting the pressure control range. When ambient pressure exists in the chamber 103, a closure 108 carried by the diaphragm covers a "dump" port 109 opening out of the chamber, thus preventing escape of air except through the normal outlet 22 leading to the conduits 23 and 24.

As back pressure builds up in the chamber 103 as a result of inflation of the patient's lungs, the diaphragm 104 is raised away from the "dump" port 109, lifting the closure 108 to allow air to escape from the chamber. The action of the relief valve is progressive, and eventually results in dumping of almost all of the supply flow, and delivery of only a low terminal flow to the patient.

The entrance 110 of conduit 24 is closed during initiation and termination of the inspiration phase, by a flexible leaf-type check valve 111 which is closed initially to pass all of the flow from the patient's breathing to the sensor 42, and opens in response to delivery of the peak flow of air through the relief valve 21, thus increasing the flow capacity far beyond the practical flow through the restriction 61 in the flow sensor 42. This leaf valve closes again as the flow rate is reduced by the relief valve 21, for example, when the rate drops within the range of 10 to 20 liters per minute, and thereby routes all of the flow through the sensor as the inspiration phase nears completion.

Design criteria for the flow sensor 42 can be worked out in accordance with known principles in the art, examples of existing reference literature being the book "Fluidics--Components and Circuits," by Foster and Parker, published by Wiley-Interscience, and specifically pages 301–308 thereof. Other reference works are Siwoff, "Improve-of the Static and Dynamic Behaviour of the Turbulence Amplifier (etc.)," Third Cranfield Fluidics Conference (1968), Paper 2; Verhelst, "On the Design, Characteristics and Production of Turbulence Amplifiers," Second Cranfield Fluidics Conference (1967), Paper F2; Siwoff, "A Method for Dimensioning the Turbulence Amplifier," Fourth Cranfield Fluidics Conference (1970), Paper A5; and "The Turbulence Amplifier in Control Systems" by R. N. Auger of Fluid Logic Control Systems, New York, N.Y.

A flow sensor 42 specifically designed for the system shown in FIG. 1, and constructed in the manner shown in FIGS. 4 and 5, uses a jet tube 44 about 1 inch in length and about 0.018 of an inch square, with the receiver tube 48 spaced 0.31 of an inch from the jet orifice. The effective flow area of the wider end portion of the conduit 23 is about 0.5 of a square inch, and the effective flow area of the restricted end portion is about 0.02 of a square inch.

With this sensor, a jet flow rate of about 0.3 of a liter per minute, at a pressure of 0.5 of one psi, can be used, and a pressure drop on the order of 0.05 of one centimeter H_2O at the port 53 creates enough flow through the conduit to trigger the sensor. In contrast, prior turbulence amplifiers have required a relatively large triggering pressure drop on the order of 1 centimeter H_2O, utilizing substantially smaller passages.

It bears emphasis that the flow sensor 42 is a highly sensitive type which is simple and inexpensive, easy to maintain, and stable in operation, and can operate with a low-pressure jet of low flow rate, sensitive to low cross-flow disturbances. This sensor can be characterized as a switching type, in which the pressure drop in the receiver tube 48 is sharp, when the normal laminar flow at the entrance to the receiver is changed to a turbulent flow. Because its effective flow area is small, however, high peak flow rates are by-passed around the sensor through the conduit 24.

Shown in FIG. 2 is an alternative form of the respiration apparatus 112 with a flow sensor 113 of the fluid jet deflection type (FIGS. 2 and 3). In this case, all of the patient flow during the inspiration phase passes through the sensor, eliminating the need for a by-pass conduit such as the conduit 24 of FIG. 1. This type of sensor may be somewhat less sensitive and stable, however, than the type shown in FIGS. 1, 4 and 5, but is effective to control inspiration in substantially the same manner, while having the advantageous capability noted above.

In this case, the sensor 113 has a tubular body 114, and a jet tube 115 opens into the body on one side thereof to direct a jet 117 of air across the conduit 118 defined by the body. This jet may travel, for example, about 0.5 inches and is directed toward a receiver formed by two tubes 119 and 120 (e.g., about 0.020 inches in internal diameter) spaced a short distance apart (e.g., about 0.040 of an inch) on opposite sides of the jet's path, preferably equidistant therefrom so that the jet creates equal pressures into the two receiver tubes.

A relatively high-pressure jet is used, for example, at 10 psi, delivering about 3 liters per minute, and the reference pressure relationship established comprises

equal pressures in the two receiver (e.g. about 60 centimeters H_2O) rather than different pressures as in the first embodiment.

As the patient breaths air through the delivery means **121** and the sensor **113**, the flow of air deflects the jet **117** toward the receiver **119**, increasing the pressure linearly in this receiver, relative to the pressure in the receiver **120**, as the flow rate in conduit **118** increases. The pressure change is applied to an actuator **122**, through signal conduits **123** and **124**, to operate a control valve **125** that may be the same as the valve **19** in FIGS. 1 and **6**.

In this case, the actuator **122** is responsive to a preselected pressure differential, including an increase in the pressure at the receiver tube **119** produced by a given degree of deflection of the jet **117** toward the delivery means **121**. The change in the pressure differential is proportional to the deflection of the jet and therefore the cross-flow, and the actuator **122** can be set to operate the valve **125** at a selected level. For background information regarding a fluid jet deflection device of this general type, reference is made to a report of J. W. Tanney, "An Anemometer for Very Low Velocities," File M49—7—82, February, 1967, Low Speed Aerodynamics Section, National Aeronautical Establishment, National Research Council of Canada.

As before, the actuator **122** has two inflatable actuating members **127** and **128** that are pressurized through the conduits **123** and **124**, a lever **129** between these members, an orifice **130** positioned to be blocked and unblocked by the lever, and a spring **131** for assisting the member **128** in urging the lever toward the blocking position. An adjusting screw **132** is provided to vary the spring force, thereby to set the actuator for operation at a selected output pressure level of the signal produced by the sensor **113**.

When the orifice **130** is blocked, a back-pressure signal is applied through a conduit **133** to the control valve **125** to maintain it in the closed condition, as described in connection with FIG. **6**, thereby preventing any flow of primary gas through the main flow conduits of the system. In this embodiment, a main flow conduit **134** connects a pressure-regulated source **135** to the valve **125**, which is connected through another main conduit **137** to a flow-rate regulating valve **138**, from which gas flows to the sensor **113** and the patient through a conduit **139**, the conduit **118** of the sensor being a section of this conduit. A conduit **136** connects the source to the jet tube **115**.

In this instance, the source **135** supplies oxygen, which may be diluted in the regulating valve **138**. For this purpose, the valve **138** is a diluter/regulator of the type sold by Bennett Respiration Products as No. 0666, previously mentioned.

When the patient starts to withdraw air from the apparatus **112**, the flow control valve **125** is opened in response to the increased pressure in the receiver tube **119**, resulting in the unblocking of the orifice **130**. Then oxygen flows through the valve from the conduit **134** to the conduit **137**, and thus to the diluter/regulator. Initially, the flow enters a control chamber **140**, from which it flows through a conduit **141** through a venturi device **142** where outside air is drawn in through a filter **143**. Then the mixture is delivered through a conduit **144** to a pressure chamber **145** in the diluter/regulator, and passes out through the conduit **139** leading to the sensor **113** and the delivery means **121**.

In the pressure chamber **145**, the back pressure in the system is sensed by a diaphragm **147** that is backed by a spring **148** adjusted by a screw **149** to set the pressure range of the device. As the back pressure increases during the inspiration phase, the diaphragm bulges upwardly, and acts through a linkage **150** to shift a flow-restricting plunger **151** towards an orifice **152** forming the inlet to the control chamber **140**. The plunger is moved progressively closer to the orifice, thereby progressively reducing the flow rate as the back pressure increases.

As the flow drops to a selected low flow rate, the jet **117** of the sensor **113** returns toward its normal position between the two receivers **119** and **120**, and the pressure differential declines to the threshold level, whereupon the lever **129** is returned to its blocking position to close the valve **125** and terminate inspiration. The expiration phase then occurs in the same manner as in the apparatus of FIG. **1**, the exhalation valve being formed by a port **154** adjacent the delivery means **121**, and an inflatable closure **155** pressurized during inspiration through a conduit **157** that communicates with the main flow conduit **137** through a restrictor **158**. A restricted bleed passage **159** relieves pressure in the closure **155** when the inspiration flow in the conduit **137** is terminated, so the patient can exhale through the port **154**.

From the foregoing, it will be evident that the present invention provides an improved respiration apparatus that is truly flow responsive, being operable in response to a flow on the order of 1 to 4 liters per minute that can be drawn through an open system of conduits, without need for a positively operated check valve for isolating the patient from the air supply openings in the relief valve **21** or the diluter/regulator **138**. The result in an apparatus that can be much more comfortable in use, since the resistance of the apparatus to the initial breath is almost imperceptible, and the opening of the control valve **19**, **125** supplies gas for pressure breathing as a smooth continuation of the patient's first slight effort.

Sensitivity is high, particularly in the apparatus **10**, and is easily varied, and low pressure, low quantity jet flows can be used, again particularly the form **10**, in which the flow sensor can be made as relatively inexpensive, easy-to-clean, molded plastic part.

It also will be evident that, while two specific embodiments have been illustrated and described, various modifications and changes may be made without departing from the spirit and scope of the invention.

I claim:

1. Flow responsive respiration apparatus for administering intermittent positive pressure breathing therapy to a patient from a source of gas under pressure and through delivery means into which the patient breaths to initiate an inspiration phase of a respiration cycle, said apparatus having, in combination:

conduit means connectible between said source and said delivery means for carrying gas intermittently therebetween;

a flow control valve in said conduit means having an inlet port connected to said source by said conduit means, an outlet port connected to said delivery means by said conduit means, a closure member movable between a first position establishing com-

munication between said ports and a second position disconnecting said ports, and pressure-responsive means for moving said closure member to said first positive in response to a first pressure signal, and to said second position in response to a second pressure signal;

a flow sensor in said conduit means adjacent said delivery means comprising means for directing a jet of gas across said conduit means, and a receiver spaced from said jet-directing means to be pressurized thereby in accordance with the condition of said jet, to a first pressure level when there is no cross-flow in said conduit means and to a second pressure level when there is a cross-flow resulting from breathing by the patient;

actuator means connected to said flow control valve and to said flow sensor and operable to produce said first pressure signal when said first pressure level exists in said receiver, and to produce said second pressure signal when said second pressure level exists in said receiver, thereby to open said flow control valve and initiate the inspiration phase in response to breathing by the patient through said flow sensor;

and means for reducing the rate of flow of gas through said apparatus to the patient in response to increasing back pressure therein as the lungs of the patient are inflated, and thereby to reduce the flow rate through said flow sensor during said inspiration phase until said first pressure level is restored, to close said flow control valve and terminate the inspiration phase.

2. Flow responsive respiration apparatus for administering intermittent positive pressure breathing therapy to a patient from a source of gas under pressure and through delivery means into which the patient breaths to initate an inspiration phase of a respiration cycle, said apparatus having, in combination:

conduit means connectible between said source and said delivery means for carrying gas intermittently therebetween;

a flow control valve in said conduit means having an inlet port connected to said source by said conduit means, an outlet port connected to said delivery

and means for reducing the rate of flow of gas through said apparatus to the patient in response to increasing back pressure therein as the lungs of the patient are inflated, and thereby to reduce the flow rate through said flow sensor during said inspiration phase until said first pressure level is restored, to close said flow control valve and terminate the inspiration phase;

and wherein

said flow sensor has a first receiver aligned with said jet,

said jet-directing means maintains laminar flow in said jet at said first receiver only until said cross-flow disturbs the jet,

and the resulting change to turbulent flow produces a marked pressure drop in said first receiver, said sensor also having a second receiver spaced from said first receiver to establish a reference pressure level with respect to which said first and second pressure levels are detectable in said actuator means.

3. Flow responsive respiration apparatus for administering intermittent positive pressure breathing thereapy to a patient from a source of gas under pressure and through delivery means into which the patient breathes to initiate an inspiration phase of a respiration cycle, said apparatus having, in combination:

conduit means connectible between said source and said delivery means for carrying gas intermittently therebetween;

a flow control valve in said conduit means having an inlet port connected to said source by said conduit means, an outlet port connected to said delivery means by said conduit means, a closure member movable between a first position establishing communication between said ports and a second position disconnecting said ports, and pressure-responsive means for moving said closure member to said first position in response to a first pressure signal, and to said second position in response to a second pressure signal;

a flow sensor in said conduit means adjacent said delivery means comprising means for directing a jet of gas across said conduit means, and a receiver spaced from said jet-directing means to be pressurized thereby in accordance with the condition of said jet, to a first pressure level when there is no cross-flow in said conduit means and to a second pressure level when there is a cross-flow resulting from breathing by the patient;

actuator means connected to said flow control valve and to said flow sensor and operable to produce said first pressure signal when said first pressure level exists in said receiver, and to produce said second pressure signal when said second pressure level exists in said receiver, thereby to open said flow control valve and initiate the inspiration phase in response to breathing by the patient through said flow sensor;

and means for reducing the rate of flow of gas through said apparatus to the patient in response to increasing back pressure therein as the lungs of the patient are inflated, and thereby to reduce the flow rate through said flow sensor during said inspiration phase until said first pressure level is restored, to close said flow control valve and terminate the inspiration phase;

and wherein said flow sensor has two receivers connected to said actuator means and longitudinally spaced apart on opposite sides of the path of said jet, to be equally pressurized by the jet while there is no cross-flow through said sensor, and to be pressurized unequally when the jet is deflected toward one of said receivers by a cross-flow.

4. Respiration apparatus for administering intermittent positive pressure breathing therapy to a patient from a source of gas under pressure and through delivery means into which the patient breathes to initiate a respiration cycle, said apparatus having, in combination;

conduit means connectible to said source for carrying gas therefrom intermittently to said delivery means;

a flow control valve in said conduit means operable to close the latter in a first condition of the valve and to open the same in a second condition;

a pressure-responsive flow regulator for reducing the flow rate through said conduit means to said delivery means as back pressure builds up in said conduit means during inflation of a patient's lungs;

and a flow sensor in said conduit means for actuating said flow control valve between the open and closed conditions in response to breathing-in by said patient through said conduit means, said flow sensor including means for directing a jet across said conduit means, first and second receivers opening into said conduit means, said first receiver being positioned across said conduit means from said jet-directing means to be pressurized by said jet, thereby to produce a first pressure relationship between said receivers when there is no flow through said conduit means and a second and different pressure relationship when there is a disturbance of said jet by a flow through said conduit means resulting from breathing by the patient;

and actuator means responsive to the change from said first pressure relationship to the second and operable to produce an amplified pressure signal and thereby to actuate said flow control valve and initiate an inspiration phase of said apparatus in response to said flow.

5. In a respiration apparatus for administering intermittent positive pressure breathing therapy to a patient from a source of gas under pressure through delivery means into which the patient breaths to initiate a respiratory cycle, the combination of:

conduit means connectible to said source for carrying gas therefrom to said delivery means;

a flow control valve for opening and closing said conduit means;

flow sensing means including means for directing a jet of gas across said conduit means, and receiver means positioned across said conduit means to receive gas from said jet-directing means and produce a pressure signal having one value when there is no flow transversely of said jet resulting from breathing of the patient through said conduit means;

and actuator means responsive to changes in said signal, for producing an amplified pressure signal to open and close said valve.

6. In a respiration apparatus for administering intermittent positive pressure breathing therapy to a patient, and including a source of gas under pressure, delivery means for administering the gas to the patient, conduit means connecting said source to the patient to carry the gas to the delivery means, and a selectively operable flow control valve for opening and closing said conduit means between said source and said delivery means, the combination of:

means for directing a jet of gas under pressure across a portion of said conduit means through which the patient breathes in drawing a breath through said delivery means;

receiver means positioned across said portion of said conduit to be pressurized by said jet to a first level when said jet is undisturbed, and to a second level when said jet is disturbed by cross-flow in said portion of said conduit means resulting from breathing by the patient;

and actuator means responsive to the change in the pressure in said receiver means from said first level to said second level for producing an amplified pressure signal to open said control valve.

7. A respiration apparatus as defined in claim **6**, in which said receiver means include a first receiver positioned across said portion of said conduit means in alignment with said jet, and in which said jet-directing means produces a jet which remains laminar at said first receiver as long as the jet is undisturbed, and changes to turbulent at said first receiver when disturbed by a cross-flow.

8. A respiration apparatus as defined in claim **7** further including a second receiver in said conduit means spaced from said first receiver to establish a reference pressure with respect to which said first and second levels are detectable in said means for opening said control valve.

9. A respiration apparatus as defined in claim **7** further including a disturbance amplifier in said portion of said conduit means, having an edge alongside the path of said jet, adjacent said first receiver.

10. A respiration apparatus as defined in claim **9** further including a plurality of flow-straightening vanes in said portion of said conduit means for directing the cross-flow perpendicular to said jet.

11. A respiration apparatus as defined in claim **6** in which said portion of said conduit is a first restricted conduit communicating with said delivery means, and further including a second, larger conduit also communicating with said delivery means around said first conduit, and having check means therein for directing said cross-flow through said first conduit and passing the flow of gas from said source to said delivery means.

12. A respiration apparatus as defined in claim **6** in which said receiver means comprise two receivers spaced apart on opposite sides of the path of said jet to be pressurized equally thereby when there is no cross-flow in said portion of said conduit means, one of said receivers being positioned to be pressurized to a higher level as said jet is deflected by said cross-flow.

13. A respiration apparatus as defined in claim **12** in which said portion of said conduit means is a tube adjacent said delivery means through which the patient breathes and through which all of the gas is supplied to the patient.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,817,246 Dated June 18, 1974

Inventor(s) JAMES WEIGL

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 10, line 38, "in" should be --is--.

Column 11, line 4, "positive" should be --position--.

Column 11, line 44, after "delivery" insert --means by said conduit means, a closure member movable between a first position establishing communication between said ports and a second position disconnecting said ports, and pressure-responsive means for moving said closure member to said first position in response to a first pressure signal, and to said second position in response to a second pressure signal;

a flow sensor in said conduit means adjacent said delivery means comprising means for directing a jet of gas across said conduit means, and a receiver spaced from said jet-directing means to be pressurized thereby in accordance with the condition of said jet, to a first pressure level when there is no cross-flow in said conduit means and to a second pressure level when there is a cross-flow resulting from breathing by the patient;

actuator means connected to said flow control valve and to said flow sensor and operable to produce said first pressure signal when said first pressure level exists in said receiver, and to produce said second pressure signal when said second pressure

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CERTIFICATE OF CORRECTION

Patent No. 3,817,246 Dated June 18, 1974

Inventor(s) JAMES WEIGL

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

level exists in said receiver, thereby to open said flow control valve and initiate the inspiration phase in response to breathing by the patient through said flow sensor;--

Column 12, line 57, delete "tion;" and insert therefor --tion:--.

Signed and sealed this 29th day of October 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents