April 1, 1969 H. ZIERMANN ET AL 3,435,822

BREATHING APPARATUS WITH FLUID DIODE VALVE

Filed June 29, 1965 Sheet 1 of 2

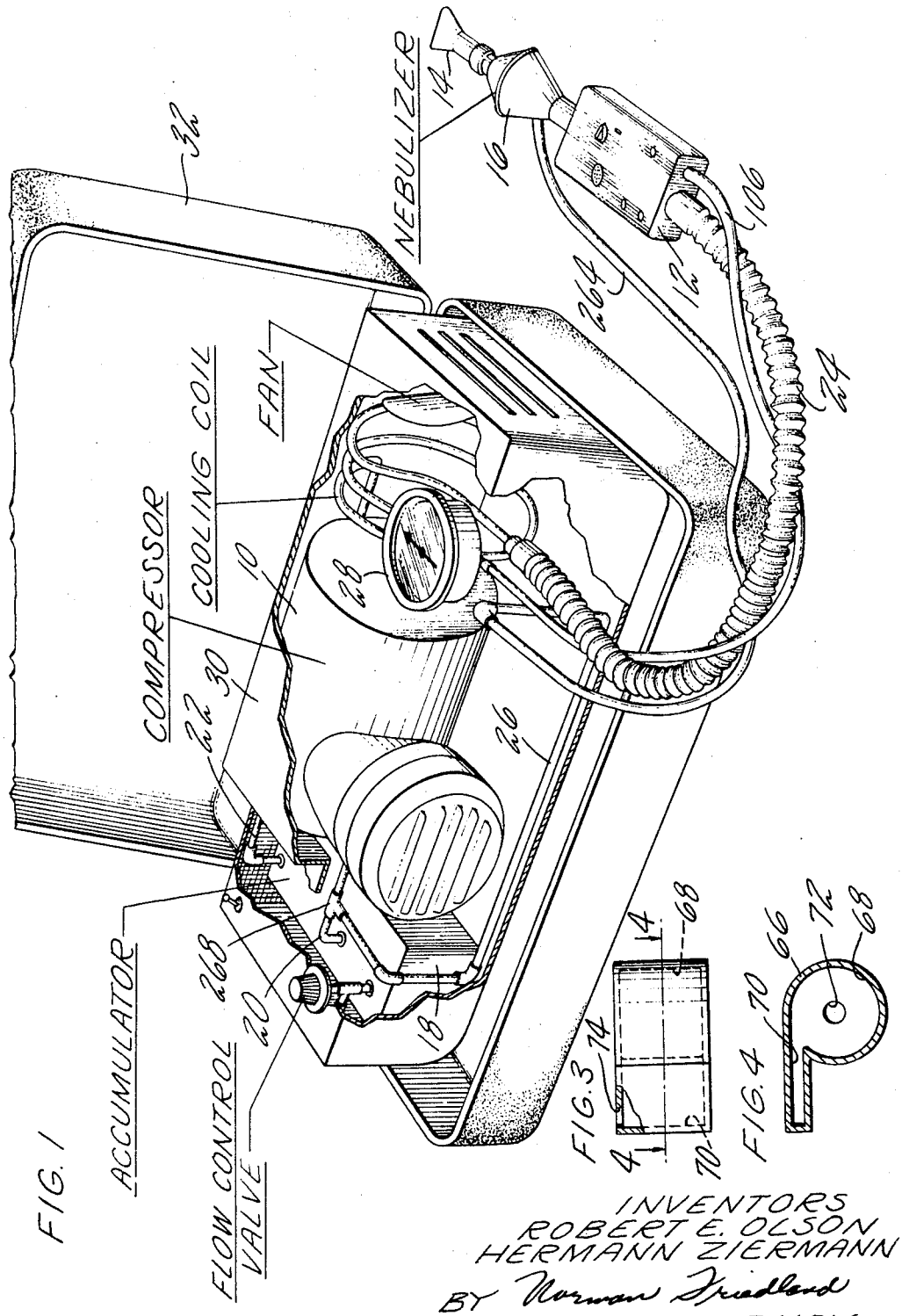


FIG. 1

FIG. 3

FIG. 4

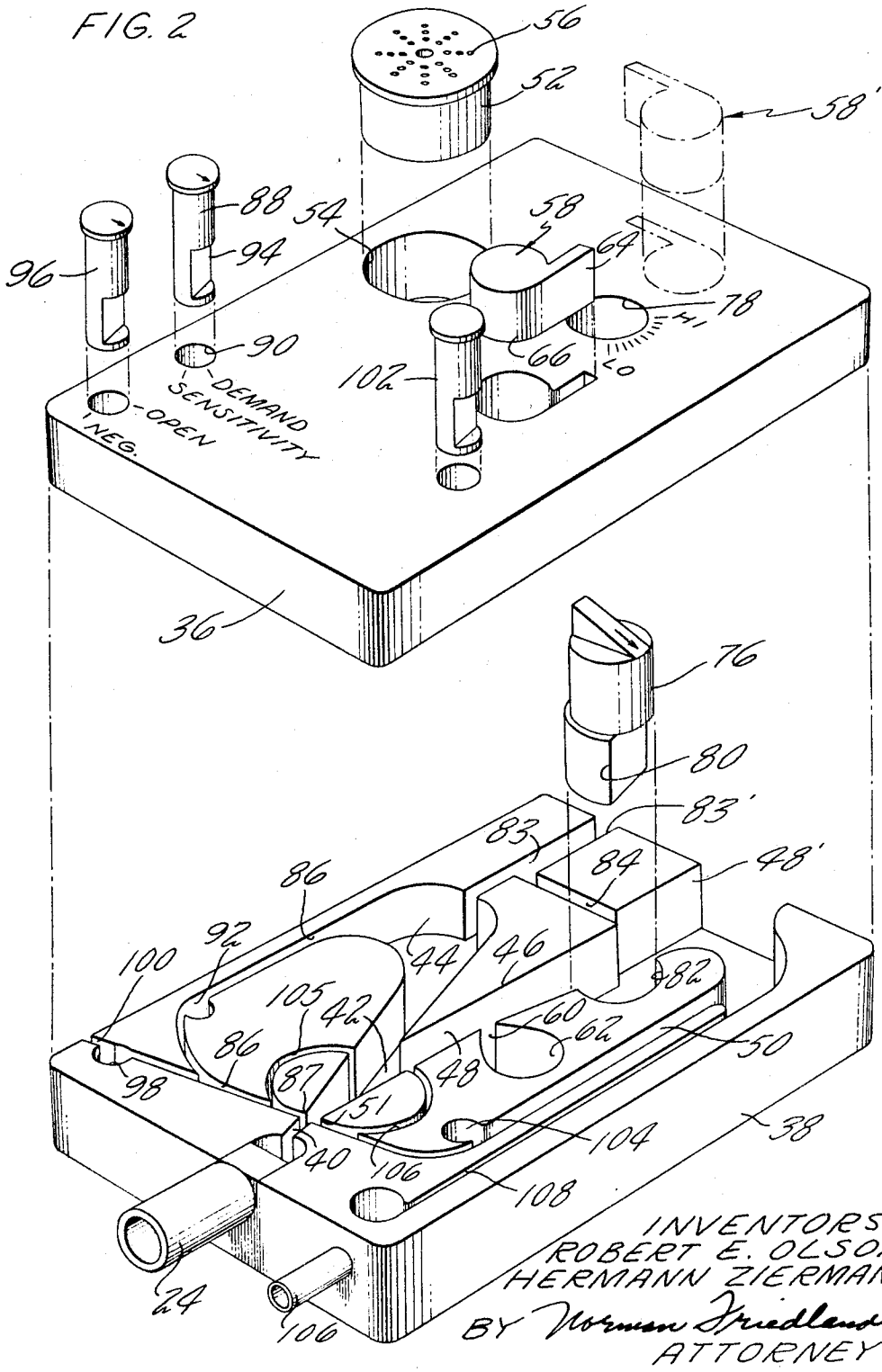
INVENTORS
ROBERT E. OLSON
HERMANN ZIERMANN
BY Norman Friedland
ATTORNEY

April 1, 1969 H. ZIERMANN ET AL 3,435,822

BREATHING APPARATUS WITH FLUID DIODE VALVE

Filed June 29, 1965 Sheet 2 of 2

FIG. 2



INVENTORS
ROBERT E. OLSON
HERMANN ZIERMANN
BY Norman Friedland
ATTORNEY

United States Patent Office 3,435,822 Patented Apr. 1, 1969

3,435,822

BREATHING APPARATUS WITH FLUID DIODE VALVE

Hermann Ziermann, Cheshire, and Robert E. Olson, Vernon, Conn., assignors to United Aircraft Corporation, East Hartford, Conn., a corporation of Delaware

Filed June 29, 1965, Ser. No. 467,842
Int. Cl. A62b 7/00
U.S. Cl. 128—145.6 5 Claims

ABSTRACT OF THE DISCLOSURE

A fluid diode in the inhalation channel of a pure fluid amplifier for a respirator decouples the channel from the inner action region in combination with a flow control valve in the same channel for permitting selection of flow without changing the switching pressure.

This invention relates to respirators of the types that can assist or control respiration utilizing pure fluid amplifiers.

As is generally well known in the art the respirator is a device intended to assist a patient, generally, one afflicted by certain pulmonary diseases, in breathing. In some applications this device may be employed as a respirator which provides an assist to the patient so that relatively little effort on the part of the patient is required to effectuate breathing, and in others it can be employed as a resuscitator to provide positive breathing. While there are presently a number of respiratory devices available, these devices are characterized as being very costly and/or operate by a very high pressure which are occasioned by the fact that they require a number of moving parts such as valves operated by diaphragms and bellows. The complexity of the respirator which obviously materially affects the cost thereof can be reduced by utilizing a pure fluid amplifier which switches without the use of any moving parts the fluid from a source of pressure to supply a certain predetermined volume of fluid during the inhalation cycle and then utilizing the pressure from the source to assist during the exhalation cycle. In such a device the patient's breathing effort is significantly reduced and hence, requires substantially little effort to provide the switching from the inhalation to the exhalation cycles. In this type of respirator it is possible to provide up to 90 liters per minute of air with as little as 2–4 p.s.i. at the power nozzle of the fluid amplifier.

As is generally well known in the art a fluid amplifier is basically a device in which an input or power fluid flow is modulated between two or more output channels by the application of a control fluid stream generally disposed at right angles to the power fluid flow at the inter-action section of the fluid amplifier. There are two basic types of fluid amplifiers, namely, proportional and digital. This application is directed to the utilization of the digital type of pure fluid amplifier, i.e., where the power stream adheres to one of the output channels until a control signal causes a switchover. For a general description of pure fluid amplifiers reference should be made to U.S. Patent No. 3,122,165 issued to B. M. Horton.

In the use of fluid amplifiers it is pointed out here that certain dimensions become critical so that the switching from one channel during inhalation to the other channel during exhalation takes place upon reaching a predescribed pressure in the mouthpiece and the transition from the inhalation to exhalation and back to inhalation must be smooth and gradual.

In addition to the requirements noted above, the respirator must, whether for home or clinical use, be able to supply variable volumes of air inasmuch as lung capacities of different patients vary. As noted above, the type of respirator constituting the present invention operates at a substantially low pressure in comparison to the prior art respirators. There are two ways in which the volume can be altered, one is by supplying more air to the input of the fluid amplifier by increasing the output of the compressor or source of pressurized air and second, to provide additional flow by controlling the output of the amplifier. In either situation care must be taken to assure that the pressure in the mouthpiece or that which enters into the lungs does not exceed an intolerable level which may result in injury to the patient. Two flow controls may be provided such that one of the controls has a varying pressure and the other varies the flow without a pressure change. By the use of one of the flow controls as long as the pressure is sufficient to switch from inhalation to exhalation and vice versa, the patient can vary the flow without a pressure change.

As was mentioned above the respirator must assure that the pressure in the mouthpiece or that which enters into the lungs does not suddenly increase or decrease but rather goes through a smooth transition change without imposing injury or uncomfort to the user. It has been found that this smooth transition can be accomplished by closely controlling the geometry of the inner action region and also by providing in the feedback loop of the fluid amplifier a positive pressure control and in another feedback loop a negative pressure control interconnecting an outlet passage communicating to ambient. These controls are manually adjusted to set an area in these feedback passages and serve to provide a smooth and gradual transition from inhalation to exhalation and vice versa.

A feedback loop is also provided in the exhalation passage and a manual control is inserted therein which serves to adjust the ratio of inhalation to exhalation cycles. As an assist type of respirator it is noted that the actual control of the inhalation and exhalation cycle is done by the patient by his own impetus in breathing. The respirator is set for a predetermined ratio of exhalation to inhalation. However, the impetus of the switching occurred by the breathing of the patient overrides this ratio but since the fluid amplifier is set for a natural or normal ratio, a little additional effort is required by the patient to overcome this natural setting. However, once the breather becomes accustomed to the respirator with the set inhalation to exhalation ratio he will eventually come into rhythm with this setting.

In the inner region of the fluid amplifier, a double feedback loop may be utilized to bias the control port with the flow in the inlet or outlet output channels for reducing the patient's effort necessary to effectuate switching from the inhalation to exhalation cycles.

The respirator must also assure that during the inhalation cycle the flow can be regulated without a pressure change and the pressure can be regulated without a flow change, and also during the exhalation cycle excessive ambient air must not be induced in the inhalation passage. This is accomplished by the particular flow control and fluid diode valve disclosed in this application. As will be described in more detail hereinbelow, the diode valve is judiciously inserted in the fluid amplifier and serves to decouple the output load (mouthpiece) and the inner action region of the amplifier during the inhalation cycle. In this manner the flow control valve inserted in the fluid amplifier is utilized to adjust the flow to the patient's lungs yet without changing the mouthpiece pressure at which the fluid amplifier switches from inhalation to exhalation. Also a manual positive pressure control in the

feedback loop can be utilized to adjust the switching pressure without affecting the flow.

It is therefore an object of this invention to provide in a respirator and/or intermittent breathing apparatus of the type employing a pure fluid amplifier, means for adjusting the flow into the patient's lungs without affecting the pressure.

A still further object of this invention is to provide means to decouple the load from the inner action region of the fluid amplifier.

A still further object of this invention is to utilize a fluid diode valve judiciously located in the fluid amplifier so as to assure that pressure switchover changes do not disturb the flow and that flow changes do not disturb pressure switchover level.

Other features and advantages will be apparent from the specification and claims and from the accompanying drawings which illustrate an embodiment of the invention.

FIGURE 1 is a perspective view of the entire respirator as packaged as a portable unit.

FIGURE 2 is an exploded perspective view of the amplifier and its various controls.

FIGURE 3 is an elevated view of the diode valve.

FIGURE 4 is a sectional view taken along lines 4—4 of FIG. 3.

Referring now more particularly to the details of this invention as is illustrated in FIG. 1, the respirator comprises basically a compressor generally illustrated by numeral **10**, the fluid amplifier generally illustrated by numeral **12**, mouthpiece **14** and a nebulizer **16** inserted between the mouthpiece and the amplifier **12**. Compressors that are currently available inherently produce a pressure pulsation in the discharge flow which may be eliminated by incorporating an accumulator which is illustrated by numeral **18**. The accumulator is merely a plenum chamber that is inserted between the fluid amplifier and the discharge end of the compressor. Suitable valving may be utilized to control the flow from the accumulator to the fluid amplifier. Fluid from the compressor is fed to the accumulator through line **20** and is directed to the fluid amplifier through piping **22** which is helically wound so as to reject the heat picked up as a result of compression. A flexible cable **24** may be utilized to interconnect line **20** to the fluid amplifier affording freedom of movement of the mouthpiece. A bleed line **26** is tapped into line **20** at the discharge end of the compressor for supplying a pressurized fluid to nebulizer **16**.

The unit may also contain a visual pressure gauge of any suitable type generally indicated by numeral **28** which is connected to fluid amplifier **12** in such a way as to allow the patient to visually inspect the pressure of the fluid entering into the mouthpiece **14**.

It will be appreciated that mouthpiece **14** is detachable from the unit so that a suitable face mask may be utilized in its place. The compressor and accumulator and cooling coils are encapsulated in a suitable housing **30** which, in turn, is mounted in a portable suitcase generally indicated by numeral **32**. This, of course, illustrates the simplicity of the unit while also pointing out that such a unit is portable.

Looking now at FIG. 2 the details of the fluid amplifier will next be described. The fluid amplifier may be formed into two plates which may be made from suitable plastic material. The cover plate **36** may be secured by any suitable well-known means to overlie the top surface of plate **38**. Fluid from the compressor **10** is admitted to the power nozzle **40** through line **24**. From there the flow enters the inner chamber **42** of fluid amplifier **12** where it can be directed to either the channel **44** formed on the left of splitter **46** or channel **48** formed on the right side of splitter **46**. The flow passing through channel **48** is eventually directed to the mouthpiece and for the purposes of this description will be hereinafter referred to as the inhalation channel. Looking for the moment at the operation during the inhalation cycle, the flow entering the inner chamber normally will adhere to the right wall of the inner chamber and flow onward through the inhalation channel to the mouthpiece. Channel **50** communicating at the upper end of channel **48** senses the pressure therein which is obviously at the same value as the pressure in the mouthpiece, where it is directed to discharge in the main stream of the inner chamber adjacent the power jet and serves to create a pressure differential thereacross. This is known in the art as the control channel and it may be located so that the flow from the control channel will be 90° relative to the flow in the inner chamber. When the pressure in the feedback channel **50** reaches a predetermined value, the flow in the inner chamber locked-on to the right-hand wall will be caused to switch to the left-hand wall to flow through the left-hand channel **44** hereinafter referred to as the exhalation channel. An enlarged chamber **44** is formed in the upper portion thereof and is adapted to communicate with bleed valve **52** secured in position in a recess **54** formed in the top plate. A plurality of holes **56** formed in the top cover of bleed valve **52** bleed air to ambient at a given back pressure level.

In order to control the flow in the inhalation channel without effecting a pressure change, diode valve **58** judiciously located adjacent the inhalation channel is mounted in the top plate and contains an opening located at the bottom end thereof which is in communication with the opening **60** adjacent the inhalation channel. A portion of the flow in the inhalation channel, therefore, will pass through opening **60** into chamber **62** into the inner cylindrical opening in fluid diode **58**, pass through the leg portion **64** of diode **58** and then out to ambient through the opening formed on the top of leg portion **64**.

For the moment referring now particularly to FIGS. 3 and 4 which show the details of the fluid diode (like reference numeral reference like parts). The fluid diode is substantially an enclosed cylinder having a leg depending tangential to the outer wall. The diode is enclosed by a suitable wall **66** defining a cylindrical cavity **68** and a rectangular cavity **70**. Opening **72** formed on the bottom wall communicates with the inner cylindrical cavity **68** which cavity in turn communicates with cavity **70** from where flow is directed to ambient through opening **74**. As will be apparent, fluid in the fluid diode valve flows in both directions, namely, into opening **74** through cavities **70** and **68** and then out through opening **72** and vice versa. Owing to the fact that the flow entering opening **74** is directed tangentially and then swirls to form a vortex in cavity **68** before discharging through aperture **72**, a greater resistance will be evidenced than when the flow enters **72** and passes through opening **74**. Hence, it is apparent from the foregoing that the flow entering through **72** and discharging through **74** under the same pressure conditions will afford less resistance than relative to the flow entering **74** and discharging through **72**. The fluid diode, thus, decouples the airstream just downstream thereof (inner action region) and the airstream just upstream thereof (mouthpiece) during the inhalation cycle. Fluid is bled to ambient through the fluid diode at a rate dependent on the setting of valve **76**. Low settings will provide high leak rates and high settings will provide low leak rates tending to maintain the pressure in the system at a constant value. The fluid diode during the exhalation cycle restricts the admittance of ambient air so that no interference with the switching will occur.

Referring back to FIG. 2 flow valve **76** inserted through opening **78** formed on the top plate contains a portion **80** partially circular in cross section which projects into recess **82** formed adjacent the inhalation channel **48**. Rotation of **76** serves to vary the area of the inhalation channel just upstream of the mouthpiece. Flow valve **76** working in conjunction with fluid diode **64** allows the patient to adjust the flow from say 50 liters per minute (l./m.)

to 90 l./m. and increments therebetween without changing the pressure necessary to effectuate switching.

Considering next the expiration cycle which occurs when the pressure in the mouthpiece, as will be evidenced in the inhalation channel **48** downstream of recess **82**, reaches a predetermined value. This pressure fed back through feedback channel **50** creates an unbalanced force across the main stream and causes it to switch from the inhalation channel to the exhalation channel. The flow, diverted to channel **42** passes into cavity **44** where it is bled to ambient through openings **56** in the bleed valve **52** and through passage **83**. As will be observed from FIG. 2, the flow adjacent the edge of the splitter **46** entering channel **42** effectively induces fluid out of channel **48** and the flow in channel **83** likewise induces fluid out of channel **48** through channel **84**, having the overall effect of inducing the flow at a quick and fast rate out of the lungs while the patient is exhaling without the necessity of providing a movable type of exhalation valve.

As noted, pressure in chamber **44** is fed to control port **87** via feedback channel **86** and when it reaches a predetermined value, an unbalance of force across the main stream is created causing the stream to switch back to the inhalation channel.

From the foregoing it is therefore apparent that the control feedback channels **50** and **86** effectively change the pressure differential across the main stream causing the stream to switch from the inhalation to the exhalation cycle and vice versa. The rate of change of the inhalation to exhalation ratio (*I/E*) is controlled by the proper sizing of openings **56** and the setting of the manual adjustable valve **88** which is rotatably supported in opening **90** formed in the cover plate **36** and the registering recess **92** formed in the bottom plate **38**. The slot **94** of valve stem **88** cooperates with feedback channel **86** to meter the flow to control port **87** and the rate of flow therethrough adjusts the *I/E* ratio. Adjustment of valve **88** also controls the sensitivity from a positive pressure level to a negative pressure level. By virtue of this control the unit can be utilized as an assist or control type of respirator and including the intermittent positive pressure breathing apparatus. That is to say, by changing the setting of valve **88**, the pressure in the mouthpiece can be adjusted to a peak pressure and any intermediate pressure for a given *I/E* cycle. Thus, for example, as an intermittent positive pressure type, the pressure in the mouthpiece will range between 10 and 30 centimeters of water. As an assist type of respirator, the pressure in the mouthpiece will normally range between 0 and 30 centimeters of water.

As can be seen from FIG. 2, feedback channel **86** is provided and connected to ambient for the purpose of controlling the sensitivity of the fluid amplifier. A manually adjustable valve **96**, similar to valve **88**, is inserted into recess **98** adjacent the line **100** for controlling the sensitivity of the fluid amplifier. Valve **96** can be adjusted to create a negative pressure in the face mask if so desired.

Valve **102**, similar to valve **88**, fits into recess **104** adjacent feedback line **50** for adjusting the flow to control port **51**. Proper balancing of the settings of valves **96** and **102** will assure a smooth and gradual transition in the switching from the inhalation to exhalation and exhalation back to inhalation cycles.

It is also possible to reduce the patient's efforts in switching from the inhalation-exhalation cycles by providing an additional pair of feedback channels **105** and **106**. Both feedback channels **105** and **106** communicate with the main flow in the inner chamber at a point approximately in line with the edge of splitter **46** so as to bias the control ports **87** and **51**.

Channel **108** communicates with the pressure in the inhalation channel and connects with gauge **28** via conduit **106**.

In certain applications, when the flow control valve **76** is set for minimum flow, it is possible that the switching will occur prematurely. This premature switching may be prevented by incorporating a fluid diode **58'** similar to, but having lower flow characteristics than, fluid diode **58**. This fluid diode will serve to decouple the main stream just downstream of valve **76** from the stream upstream of valve **76** during the exhalation cycle.

Still referring to FIG. 2, it will be noted that the width of channels **48** and **83** are wider at the point just downstream of the passage **84**. Walls **48'** and **83'** are stepped inwardly relative to the channels so that when the main stream is flowing through the respective channels **48** and **83** a negative pressure region will be created adjacent the recessed walls. This effectively induces flow from one channel to the other to increase the volume of flow to the lungs in the inhalation cycle and increase the volume of flow discharging out of the lungs in the exhalation cycle. Hence, it will be apparent that during the inhalation cycle, flow passing through channel **48** adjacent wall **48'**, creates a low pressure region which creates a pressure drop across the ends of channel **84**. As a result, flow will be induced from ambient via bleed valve **52** and channel **83**.

During the exhalation cycle the main stream being diverted to the left of splitter **46** passes through channel **42** and then through **83**. Similarly, adjacent the recessed wall **83'** a negative pressure will be created and a pressure drop will be evidenced across channel **84**. This will induce flow out of channel **48** when the breather is exhaling.

A respiratory unit as the one described above has proven to be efficacious with the following dimensions of the fluid amplifier. It is to be understood, however, that the example below is included herein for illustration purposes and is not to be construed as limiting the scope of the invention.

Splitter location, so that unit is a memory device
Aspect ratio, not smaller than 4 to 1
Power nozzle width, between .030 and .050 inch

	Inside diameter of 68 (in.)	Diameter 72 (in.)	Width of 70 (in.)
Diode 58	.400	.156	.060
Diode 58'	.400	.156	.032

While the amplifiers which have already been successfully tested were formed from plastic material, namely, acrylic type polymer and polycarbonate, it is to be understood that it is within the scope of this invention to use any other material whether it be metallic or non-metallic. However, it should be understood that the material selected must be capable of withstanding autoclaving.

The unit described above has not only been successfully employed to sustain respiration in open-chest surgery of dogs, it has also been successfully used by human patients afflicted with emphysema.

It should be understood that the invention is not limited to the particular embodiments shown and described herein, but that various changes and modifications may be made without departing from the spirit or scope of this novel concept as defined by the following claims.

We claim:

1. Breathing apparatus of the type that controls or assists in the respiratory cycle comprising a source of fluid under pressure, a mouthpiece, a pure fluid amplifier, conduit means interconnecting said mouthpiece, pure fluid amplifier and said source of fluid, said fluid amplifier including a body member having a power nozzle and inner action region adapted to inject fluid into one or the other legs of V-shaped passages formed in said body, one of the legs of the V-shaped passages communicating with said mouthpiece, the improvement comprising: fluid decoupling means including a fluid diode disposed in said one leg at a point intermediate the inner action region and mouthpiece for decoupling the load at the mouthpiece and the inner action region.

2. Breathing apparatus of the type that controls or assists in the respiratory cycle comprising a source of fluid under pressure, a mouthpiece, a pure fluid amplifier, conduit means interconnecting said mouthpiece, pure fluid amplifier and said source of fluid, said fluid amplifier including a body member having a power nozzle adapted to inject fluid into one or the other legs of V-shaped passages formed in said body, one of the legs of the V-shaped passages communicating with said mouthpiece, the improvement comprising: means associated with said one leg for controlling the flow in said one leg independently of the pressure in said mouthpiece.

3. Breathing apparatus of the type that controls or assists in the respiratory cycle comprising a source of fluid under pressure, a mouthpiece, a pure fluid amplifier, conduit means interconnecting said mouthpiece, pure fluid amplifier and said source of fluid, said fluid amplifier including a body member having a power nozzle and inner action region adapted to inject fluid into one or the other legs of V-shaped passages formed in said body, one of the legs of the V-shaped passages communicating with said mouthpiece the improvement comprising: a pair of fluid diode valves serially disposed in said one leg between the inner action region and the mouthpiece for decoupling the load at the mouthpiece and the inner action region.

4. Breathing apparatus of the type that controls or assists in the respiratory cycle comprising a source of fluid under pressure, a mouthpiece, a pure fluid amplifier, conduit means interconnecting said mouthpiece, pure fluid amplifier and said source of fluid, said fluid amplifier including a body member having a power nozzle, an inner action region and a pair of V-shaped pasages extending from said inner action region, one of the legs of the V-shaped passages communicating with said mouthpiece, a control port disposed angularly relative to said power nozzle interconnecting said mouthpiece and said inner action region for switching the fluid egressing from the power nozzle to one or the other legs of said V-shaped passages, the improvement comprising: means associated with one of said legs for controlling the flow in said one leg independently of the pressure in said mouthpiece, said means including a valve in said one leg adapted to regulate the flow therethrough and a fluid diode valve communicating with ambient adapted to bleed fluid out of said one leg at a faster rate than leaking air into said one leg.

5. Breathing apparatus of the type that controls or assists in the respiratory cycle comprising a source of fluid under pressure, a mouthpiece, a pure fluid amplifier, conduit means interconnecting said mouthpiece, pure fluid amplifier and said source of fluid, said fluid amplifier including a body member having a power nozzle, an inner action region and a pair of V-shaped passages extending from said inner action region, one of the legs of the V-shaped passages communicating with said mouthpiece, a control port disposed angularly relative to said power nozzle interconnecting said mouthpiece and said inner-action region for switching the fluid egressing from the power nozzle to one or the other legs of said V-shaped passages, the improvement comprising: means associated with one of said legs for controlling the switching pressure level in the mouthpiece without changing the flow in said leg for a given pressure level in the mouthpiece, said means including adjustable means adapted to regulate the flow through said control port and a fluid diode valve communicating with ambient adapted to bleed fluid out of said one leg at a faster rate than leaking air into said one leg.

References Cited

UNITED STATES PATENTS

3,368,555	2/1968	Beasley	128—145.8
3,379,194	4/1968	Ziermann	128—145.6
3,389,698	6/1968	Kadosch et al.	128—1
3,030,979	4/1962	Reilly	137—81.5
3,068,856	12/1962	Bird et al.	128—145.5
3,198,214	8/1965	Lorenz	137—81.5 XR
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	137—81.5 XR

RICHARD A. GAUDET, *Primary Examiner.*

KYLE L. HOWELL, *Assistant Examiner.*

U.S. Cl. X.R.

137—81.5