United States Patent [19]

BEST AVAILABLE COPY

Bird

[11] **3,915,164**

[45] **Oct. 28, 1975**

[54] **VENTILATOR**

[76] Inventor: **Forrest M. Bird,** 212 N.W. Cerritors, Palm Springs, Calif. 92262

[22] Filed: **Aug. 22, 1974**

[21] Appl. No.: **499,554**

[52] **U.S. Cl.** **128/145.8;** 128/145.6

[51] **Int. Cl.²** **A61M 16/00**

[58] **Field of Search** 128/145.8, 145.5, 145.6, 128/188, 203, 142, 142.2, 142.3

[56] **References Cited**

UNITED STATES PATENTS

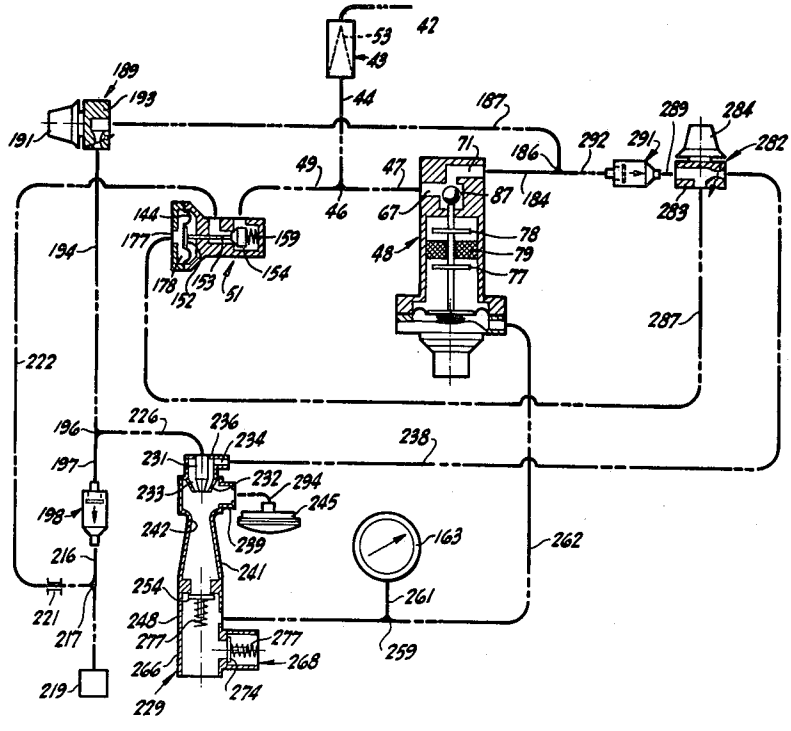
3,191,596	6/1965	Bird et al.	128/145.5
3,662,751	5/1972	Barkalow et al.	128/145.8
3,842,828	10/1974	Bird	128/145.8

Primary Examiner—Richard A. Gaudet
Assistant Examiner—Henry J. Recla
Attorney, Agent, or Firm—Flehr, Hohbach, Test, Albritton & Herbert

[57] **ABSTRACT**

Ventilator with an inhalation phase and an exhalation phase in its operative cycle having a servo controller with an inlet adapted to be connected to supply gas under pressure and also having an outlet. The controller has control valve means movable between open and closed positions to control the flow of gas from the inlet to the outlet of the servo controller. The control valve means is an open position during the inhalation phase of the ventilator and in a closed position in the exhalation phase of the ventilator. Means is provided for supplying gases to the patient from the servo controller until a predetermined pressure has been reached. After the predetermined pressure is reached, means is provided to supply an additional flow of gases to the patient to provide an inspiratory apneustic plateau for the patient. After a predetermined period of time, the patient is permitted to exhale and thereafter the same cycle is repeated.

14 Claims, 17 Drawing Figures



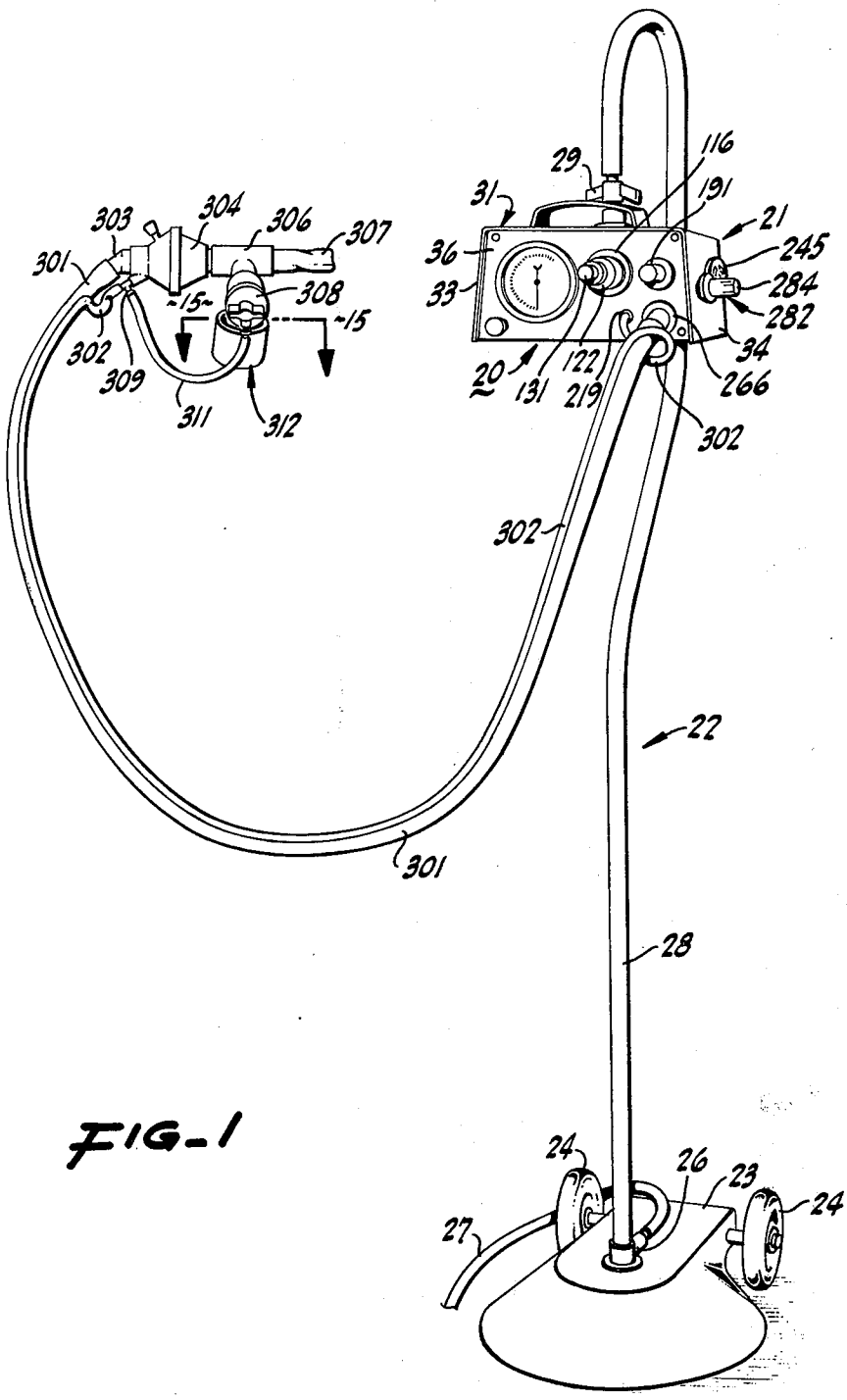

303
304
306
307
301
308
15
15
302
309
311
312
29
116
31
191
21
36
245
33
284
282
34
20
131
122
219
266
302
302
22
301
28
24
26
23
24
27

FIG-1

FIG-2

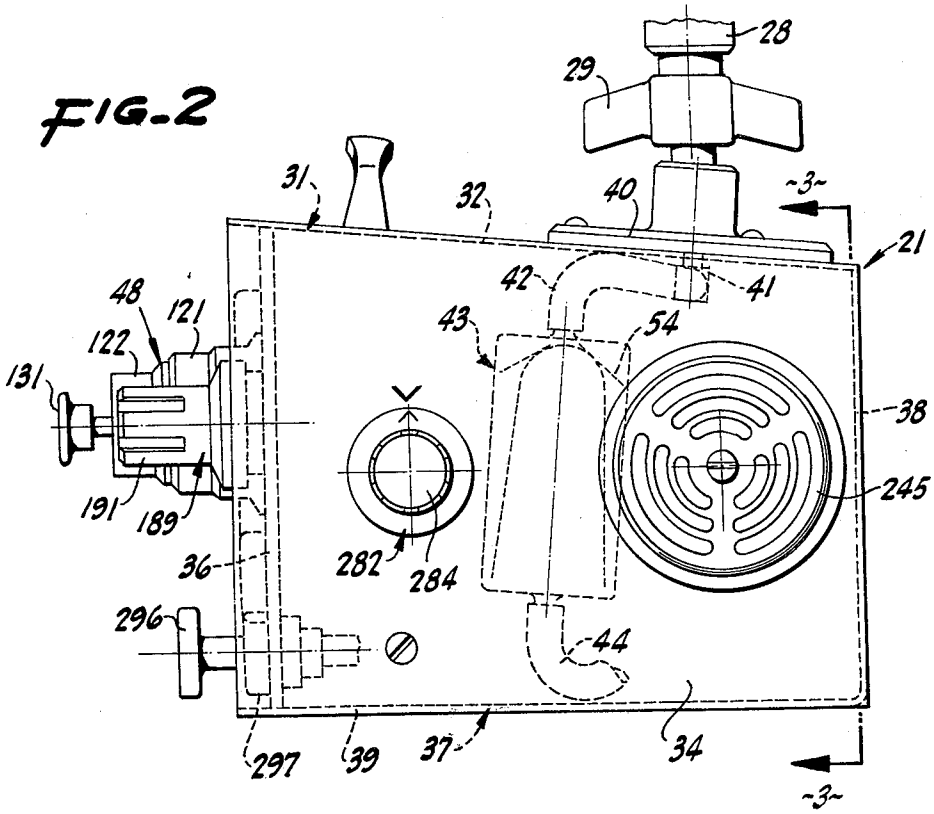

28
29
31
32
40
-3-
21
42
41
48
121
122
43
54
131
38
245
191
189
282
284
36
296
44
297
39
37
34
-3-

FIG-3

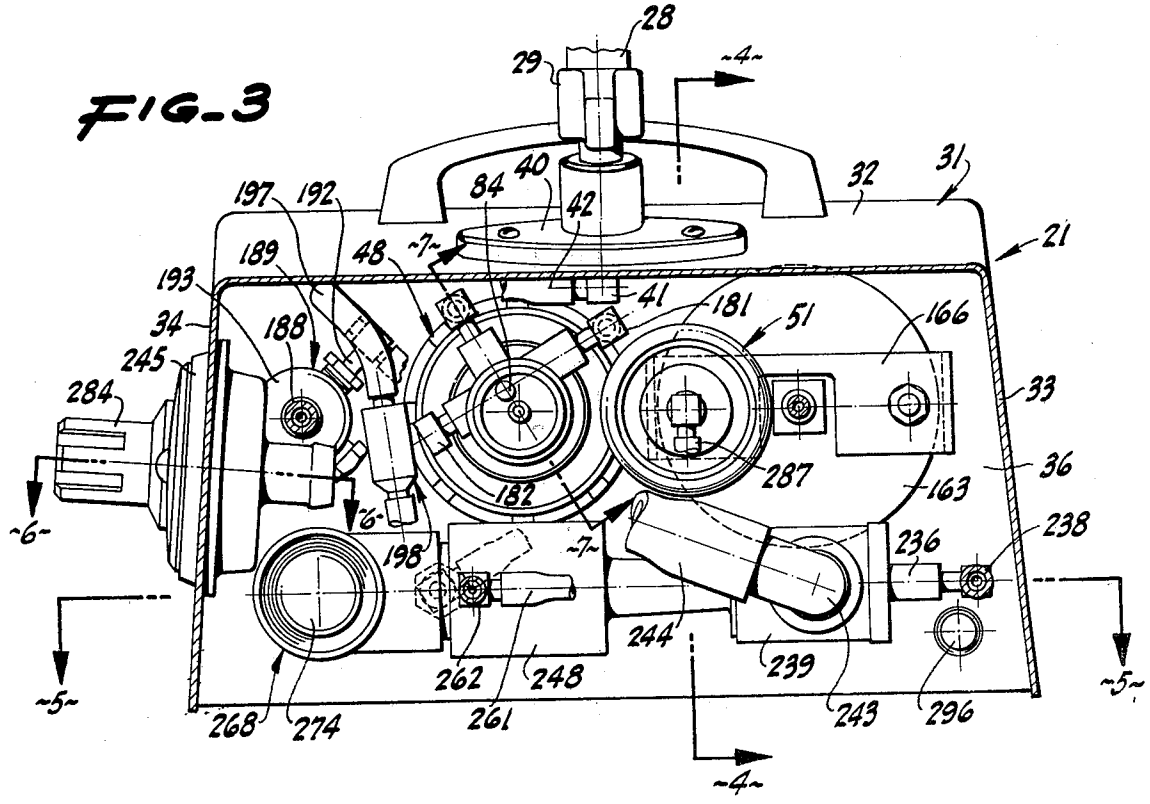

28
29
-4-
84
40
42
32
31
197
192
189
48
-7-
21
193
41
181
51
166
34
188
245
33
284
287
36
-6-
182
163
-6-
198
-7-
236
238
-5-
244
239
-5-
262
248
243
296
268
274
261
-4-

FIG-4

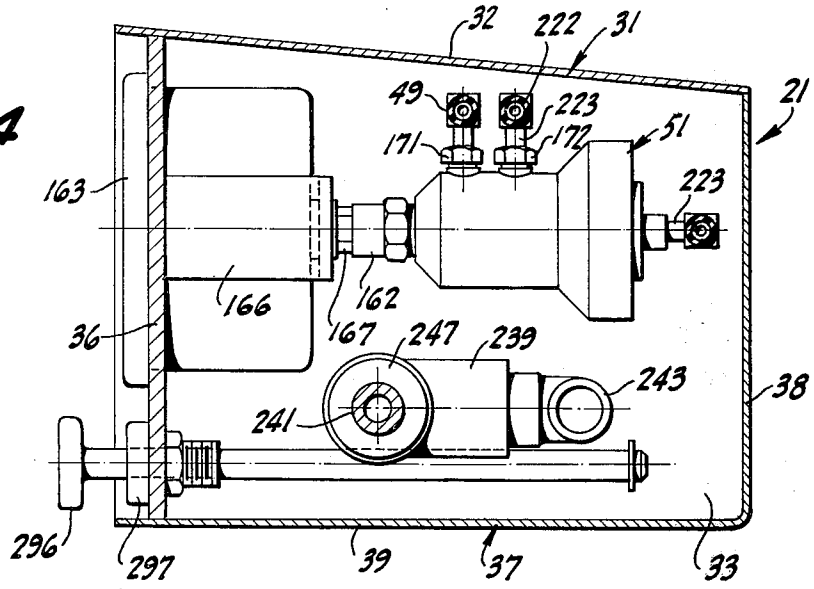
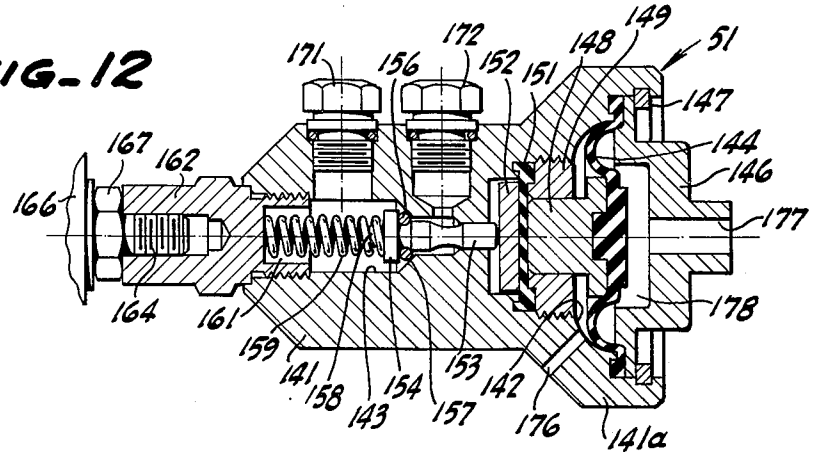


FIG-12



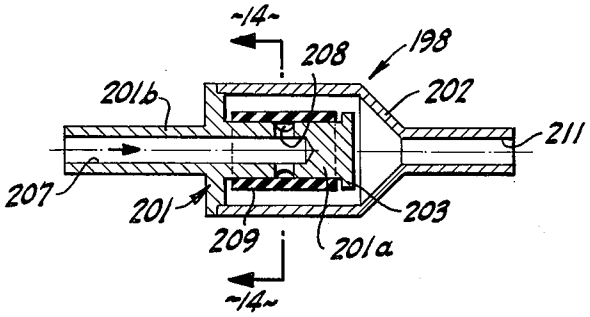


FIG-13

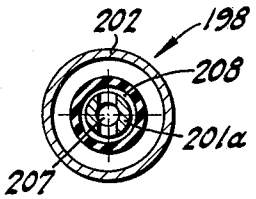


FIG-14

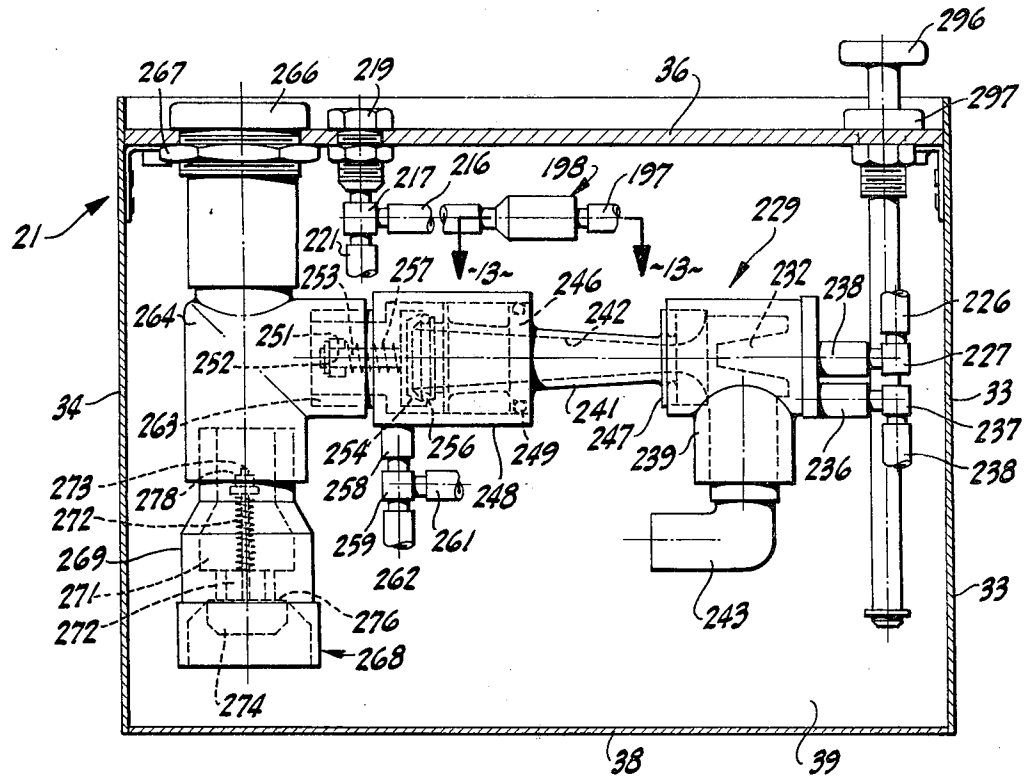


FIG-5

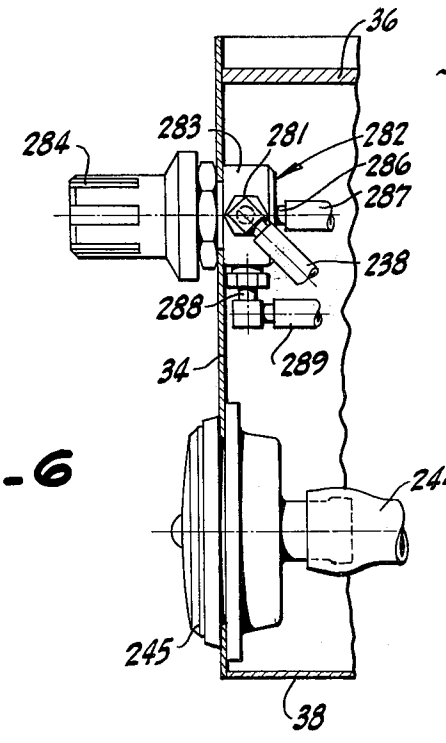


FIG-6

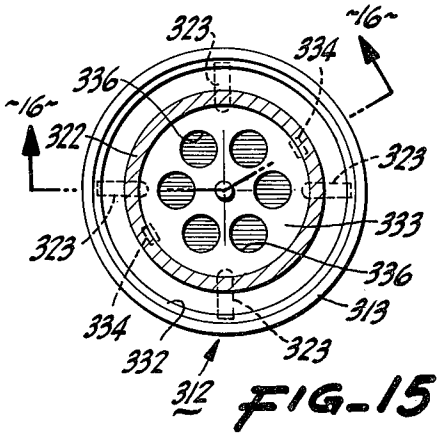


FIG-15

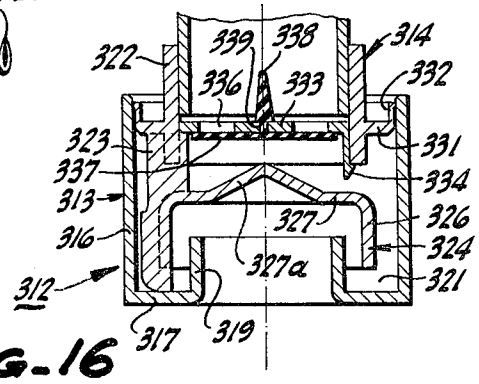


FIG-16

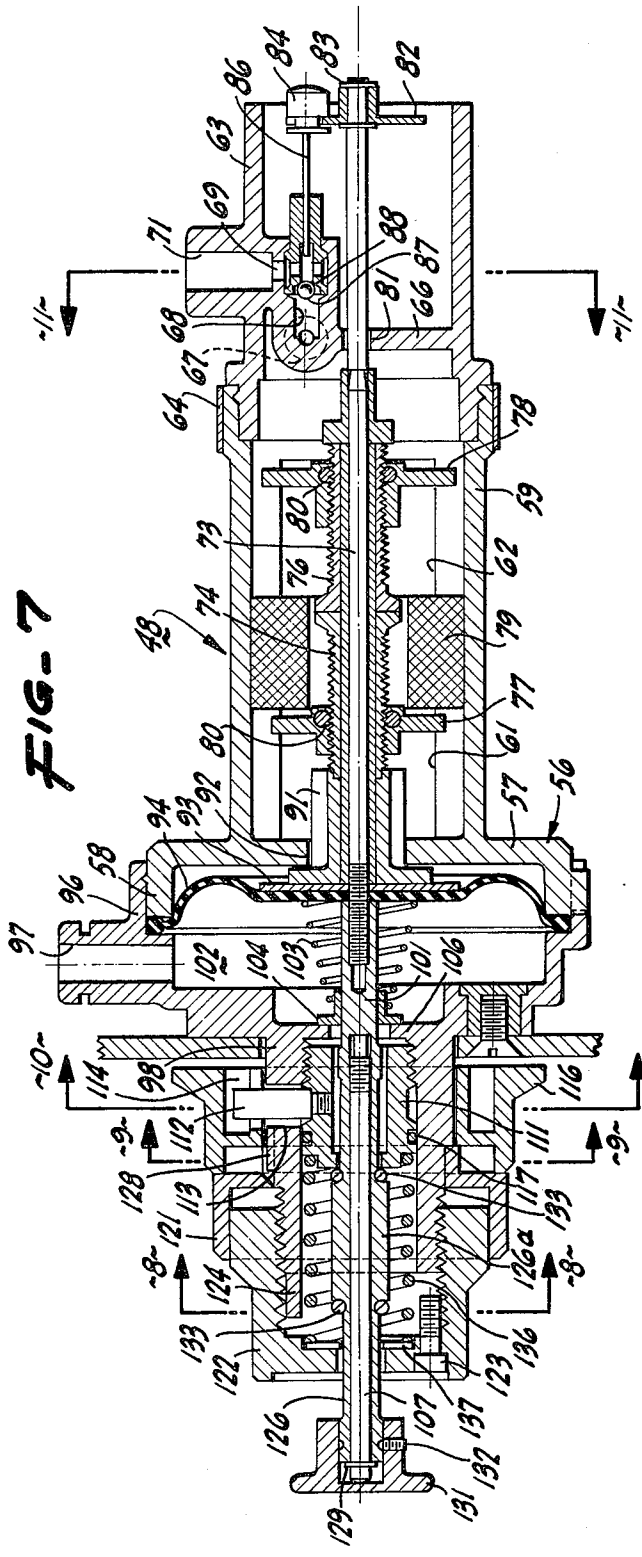


FIG-7

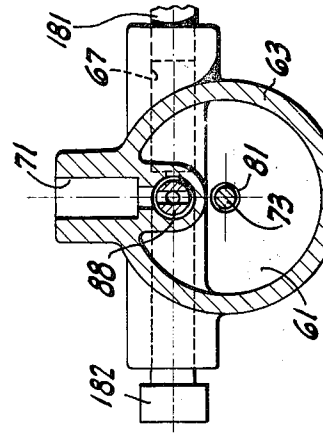


FIG-11

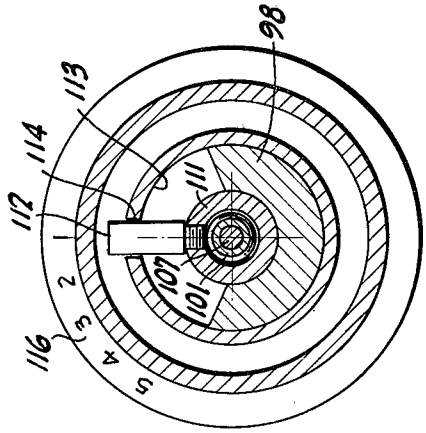


FIG-10

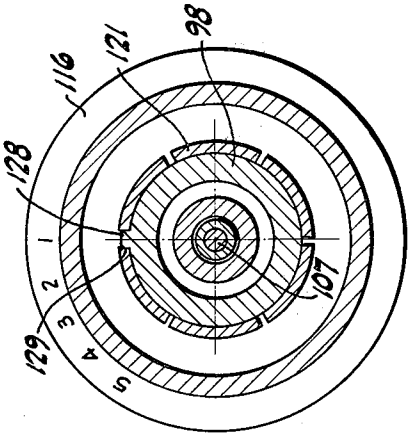


FIG-9

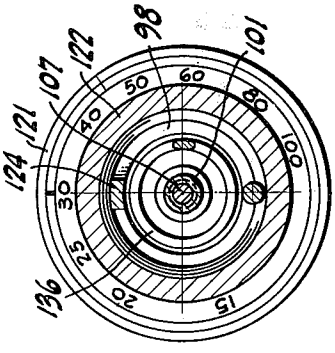


FIG-8

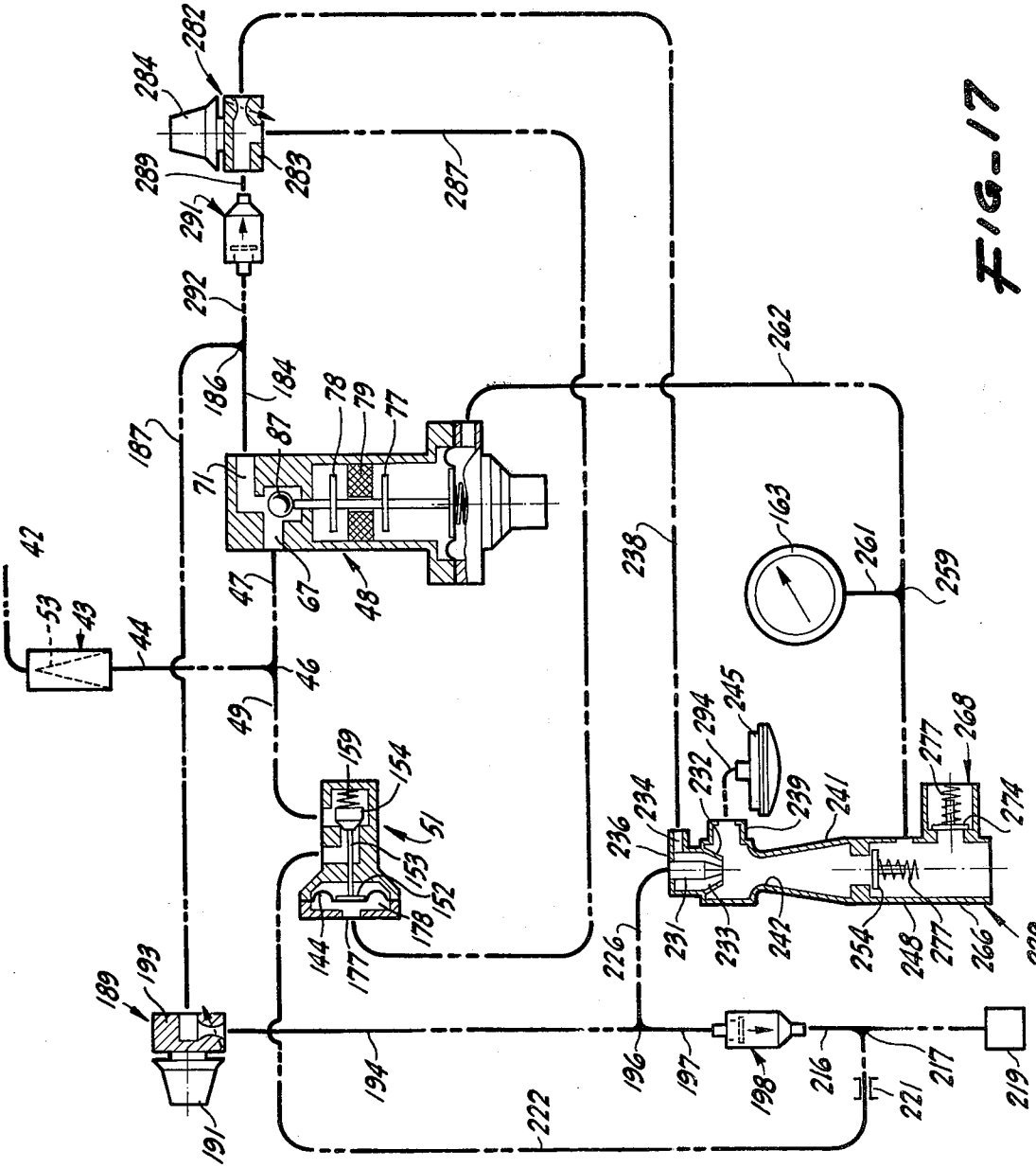

42
53
43
44
46
49
47
67
48
71
87
78
79
77
186
184
187
292
291
289
284
282
283
287
262
238
163
261
259
159
154
51
153
152
178
144
177
245
294
232
239
241
234
236
231
233
242
226
254
248
277
266
229
268
277
274
189
193
191
194
222
196
197
198
216
221
217
219

FIG-17

VENTILATOR

BACKGROUND OF THE INVENTION

Various ventilator and respirators have been provided. However, they have been deficient in that they have failed to provide an adjustable post-inspiratory flow. In the past, when post-inspiratory flow was developed by locking up the proximal airway in a static state, many subjects developed varying degrees of dyspnea. There is, therefore, a need for a new and improved ventilator and method which provides an adjustable post-inspiratory apneustic plateau flow for a period of time which does not have the above named disadvantages.

SUMMARY OF THE INVENTION AND OBJECTS

The ventilator has an inhalation phase and an exhalation phase in its operative cycle. A servo controller is provided having an inlet adapted to be connected to a supply of gas under pressure. The controller also has an outlet and control valve means disposed in the controller and movable between open and closed positions to control the flow of gas from the inlet to the outlet. The control valve means is in an open position during the inhalation phase of the ventilator and in a closed position during the exhalation phase of the ventilator. A patient adapter is provided. Means is also provided for supplying gas from the outlet of the servo controller to the patient adapter. Exhalation valve means is provided which is associated with the patient adapter and is movable between open and closed positions to permit exhalation by the patient during the exhalation phase. Means is provided for supplying gas from the outlet to the exhalation means to maintain it in a closed position during the time gas is being supplied from the outlet. Means is provided for sensing the pressure of the gas in the means for supplying gas from the outlet of the controller to the patient adapter and for switching the controller from an open to a closed position when a predetermined pressure has been reached. Apneustic plateau valve means is provided having an inlet and an outlet. A valve member is provided in the valve means movable between open and closed positions to control the flow of gas from the inlet to the outlet. Diaphragm operated means is provided for moving the valve member between open and closed positions. Means is provided for supplying gas from the outlet of the controller to the diaphragm operated means and to the patient adapter. The means for supplying gas including valve means for controlling the flow of fluid from the diaphragm operated means whereby after the servo controller is switched to a closed position an additonal flow of gas is supplied to the patient adapter for a predetermined period of time to thereby enhance the volume of gas and distribution of gas in the patient's lungs while maintaining a graded topping-off pressure dependent upon the pulmonary compliance of the patient's lungs.

In general, it is an object of the present invention to provide a ventilator and method which has means for providing an adjustable additional flow of gas to the patient after the major portion of the inspiration phase has been completed.

Another object of the invention is to provide a ventilator and method of the above character in which the additional flow of gases enhances the volume of gas and the distribution of gas in the patient's lungs.

Another object of the invention is to provide a ventilator and method of the above character in which a graded topping-off pressure dependent upon the pulmonary compliance of the patient's lungs is provided during the time of the additional flow of gas to the patient.

Another object of the invention is to provide a ventilator of the above character which is relatively simple in construction and which can be readily cleaned.

Another object of the invention is to provide a ventilator of the above character which can be readily used by a patient.

Additional objects and features of the invention will appear from the following description in which the preferred embodiment is set forth in detail in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a ventilator incorporating the present invention.

FIG. **2** is a side elevational view of a portion of the ventilator shown in FIG. **1**.

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

FIG. **4** is a cross-sectional view taken along the line **4—4** of FIG. **3**.

FIG. **5** is a cross-sectional view taken along the line **5—5** of FIG. **3**.

FIG. **6** is a partial cross-sectional view of the ventilator particularly showing the apneustic control valve assembly and an inlet filter.

FIG. **7** is an enlarged cross-sectional view of the servo controller utilized in the ventilator.

FIG. **8** is a cross-sectional view taken along the line **8—8** of FIG. **7**.

FIG. **9** is a cross-sectional view taken along the line **9—9** of FIG. **7**.

FIG. **10** is a cross-sectional view taken along the line **10—10** of FIG. **7**.

FIG. **11** is a cross-sectional view taken along the line **11—11** of FIG. **7**.

FIG. **12** is a cross-sectional view of the normally closed apneustic control cartridge.

FIG. **13** is a cross-sectional view taken along the line **13—13** of FIG. **5**.

FIG. **14** is a cross-sectional view taken along the line **14—14** of FIG. **13**.

FIG. **15** is a cross-sectional view taken along the line **15—15** of FIG. **1**.

FIG. **16** is a cross-sectional view taken along the line **16—16** of FIG. **15**.

FIG. **17** is a flow diagram for the ventilator.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The ventilator **20** incorporating the present invention consists of a cabinet or case **21** which is supported in a suitable manner such as by a stand **22**. The stand **22** is of a conventional type and consists of a base **23** which is provided with a pair of wheels **24** so that it can be readily moved from one location to another. A fitting **26** is mounted on the base **23** and is connected to a suitable supply of a gas through a tube **27** for the ventilator such as a supply of oxygen which is connected to the tube **27**. The gas is supplied from the fitting **26** through an upright tubular member **28** which is mounted within the fitting and which has its upper end bent into a U with the extremity of the same connected to a wing-type connector **29**. The connector **29** can be

connectd to an oxygen blender (not shown) of the type described in U.S. Pat. No. 3,727,627. Alternatively, it can be connected directly to the ventilator **20** as shown in FIG. **1**.

The cabinet or case **21** consists of a U-shaped member **31** formed of sheet metal which is provided with a top wall **32** and side walls **33** and **34**. It also consists of a front wall or panel **36** and an L-shaped member **37** which forms the rear wall **38** and a bottom wall **39**. As can be seen, the cabinet is generally a rectangular six-sided enclosure. A flanged boss **40** is mounted on the top wall **32** of the cabinet and is connected to the wing nut connector **29**. A fitting **41** is mounted in the flange boss **40** and is connected by a tube **42** to one end of a filter **43**. Gas is supplied from the source at a pressure ranging from approximately 45 to 75 p.s.i. and preferably about 50 p.s.i. A tube **44** connects the other end of the filter **43** to a tee **46** and one end of the tee is connected by a tube **47** to the inlet of a sequencing servo cartridge or controller **48** and the other end of the tee **46** by a tube **49** to the inlet of an apneustic plateau cartridge **51**. The sequencing servo cartridge or controller **48** is generally of the type described in United States Letters Pat. No. 3,753,436. The filter **43** is in the form of a cylindrical cartridge which is sealed at both ends and which has a filter member **53** formed of a suitable filter material such as nylon mesh which is generally cup-shaped in form and which has its lower extremity supported by triangular supports **54** formed integral with the cartridge.

The sequencing servo cartridge **48** consists of a housing **56** formed of a suitable material such as plastic. The housing **56** is provided with a circular flat bottom wall **57** which has a rim **58** formed integral therewith and extending outwardly at right angles from the bottom wall. The housing **56** is also provided with a cylindrical extension **59** formed integral therewith which extends outwardly from the flat bottom wall **57** and in a direction opposite the rim **58**. The hollow cylindrical extension **59** is provided with pairs of spaced opposing openings **61** and **62**. A hollow cylindrical control body **63** formed of a suitable material such as a transparent plastic has one end mounted within the outer extremity of the cylindrical extension **59** and is retained therein by a metal retaining ring **64** which slides over the outer extremity of the cylindrical extension **59** after the control body **63** is mounted therein. The control body is provided with a wall **66** which extends diametrically across the control body. The control body **63** is formed to provide a flow passage **67** which serves as a pressure inlet port **68** normally in communication with a passage **69** opening into an outlet port **71**.

A master shaft **73** is slidably mounted in the housing **56**. The master shaft **73** is formed of a suitable material such as steel. A pair of sleeve-like parts **74** and **76** formed of a suitable material such as plastic are mounted on the master shaft **73** so that they are in engagement with each other. The exteriors of the bushings **74** and **76** are threaded and have threadedly mounted thereon a magnetic starting effort armature **77** and a magnetic pressure armature **78**. The plastic parts **74** and **76** are provided with teeth which engage each other so that the two parts will not rotate with respect to each other. The armatures **77** and **78** are adapted to be attracted by a cylindrical magnet **79** mounted within the cylindrical extension **59** of the housing **56** between the openings **61** and **62**. The starting effort armature **77** and the pressure armature **78** can be adjusted longitudinally of the master shaft **73** by rotating the same on the bushings **74** and **76** to increase or decrease the force applied to each of the armatures by the magnet **79**. O-rings **80** are provided between the armatures **77** and **78** and the bushings **74** and **76** to provide a desired amount of friction.

The master shaft **73** extends through a hole **81** provided in the wall **66** of the control body **63**. A circular servo plate **82** is mounted on the outer extremity of one end of the master shaft **73** and is retained in this position by snap rings **83**. A fitting **84** is mounted in the servo plate **82** adjacent the outer margin of the same and carries a servo plunger **86**. The servo plunger **86** is adapted to engage a ball **87** that serves as a valve member which is adapted to engage an annular valve seat **88** whereby flow passages between the inlet port **68** and the outlet port **71** can be established or interrupted depending upon the position of the ball **87**.

An anti-rotation hub **91** which is rectangular in cross-section is mounted upon the master shaft **73** and is mounted in an opening **92** provided in the flat bottom wall **57** to prevent rotation of the master shaft. A metal plate **93** is mounted on the shaft and supports the inner margin of a flexible diaphragm **94**. The outer margin of the diaphragm **94** is clamped between the rim **58** and the pressure bell **96**. The anti-rotation hub **91** prevents possible "wind up" of the diaphragm **94** and splints the backside of the diaphragm **94**. The pressure bell **96** is frictionally retained on the housing **56** by a cooperating ridge and groove (not shown) and is provided with a sensing port **97**. The pressure bell is provided with a cylindrical extension or hub **98** formed integral therewith. An accessory shaft hub **101** is threaded onto the master shaft and extends into the extension **98** of the pressure bell **96**. A pressure chamber **102** is formed within the pressure bell and is in communication with the sensing port **97**. Yieldable means in the form of a helical spring **103** is provided within the chamber **102** which has one end engaging the diaphragm **94** and has the other end engaging a flanged sleeve **104** slidably mounted on the accessory shaft hub **101**. The flanged sleeve **104** engages a wall **106** formed in the extension **98**. An accessory shaft **107** has one end threaded into the accessory shaft hub **101** and extends axially of the extension **98**.

An adjustable sensitivity stop member **111** is threadedly mounted within the interior of the extension **98** and can be moved axially of the accessory shaft **107** by rotation of the same through the limiting screw **112** threaded into the adjustable sensitivity stop member **111** and extends through a slot **113** provided in extension or hub **98**. The limiting screw **112** extends into a slot **114** provided in a sensitivity control dial **116** which is used for rotating the adjustable sensitivity stop member **111**. O-ring **117** provides friction between the member **111** and the interior of the extension **98** and with the screw **112** holding the dial **116** in place.

An index hub **121** is mounted upon the extension **98**. An adjustable pressure limiting knob **122** is mounted within the index hub **121**. The pressure limiting knob **122** is threadedly mounted on the exterior of the extension **98**. It is provided with a pin **123** extending inwardly which is adapted to engage an abutment **124** provided on the extension **98** to limit the rotation of the knob **122**. The pressure limiting knob **122** and the sensitivity control knob **116** serve as a compound knob for operation of the servo cartridge **48**.

A cam shaft **126** is mounted on the accessory shaft **107** and is retained thereon by a retaining ring **127.** A key **128** is formed integral with the extension **98** and engages a wide slot **129** provided in the index hub **121.**

A manual override knob **131** is secured to the cam shaft **126** by a set screw **132.** The cam shaft **126** is provided with an enlarged cylindrical portion **126***a* which has O-rings **133** mounted thereon that serve as bumpers. A helical drag spring **136** is mounted within the extension **98** and has one end engaging the adjustable sensitivity stop member **111** and has the other end engaging an inner surface of the knob **122.** A flat washer **137** is provided between **136** spring and **122** knob to add friction to inhibit rotation of the pressure limiting knob **122.** The drag spring **136** performs two functions. One is providing indirect friction for the starting effort dial or knob **116** and direct function for the pressure limiting knob **122.** The other is eliminating possible backlash in the coarse threads of both travel limiting stops for the knobs **116** and **122** by maintaining tension between the stops.

The apneustic control cartridge **51** is shown in detail in FIG. **12,** and as shown therein, consists of housing **141** which is provided with an enlarged portion **141***a.* The portion **141***a* has a cup-shaped cavity **142** which is in communication with a bore **143** extending longitudinally of the housing. A flexible diaphragm **144** is disposed within the cavity **142** and has its outer margin clamped between the enlarged portion **141***a* and an end or retainer cap **146** which is retained within the enlarged portion **141***a* by a retaining ring **147.** A rigid cam button **148** engages a central portion of the diaphragm **144** and extends through a seal retainer **149** threaded into the enlarged portion **141***a.* A flexible sealing member **151** has its outer margin engaged between the retainer **149** and the interior of the housing **141.** One side of the sealing ring **151** is engaged by the button **148** and the other side engages a rigid disc or button **152.** The button **152** engages a valve stem **153** forming a part of a valve member or puppet valve **154** which carries an O-ring **156** adapted to make sealing engagement with a valve seat **157** formed on the interior of the housing **141.** The valve member **154** is provided with a boss **158** in which there is mounted one end of helical coil spring **159** extending axially of the bore **143.** The outer end of the spring **159** is seated in a well **161** of a fitting or mounting cap **162** threaded into the end of the housing **141.**

A pressure gauge **163** is mounted on the front panel **36** by a screw **164** which is part of the gauge **163** and extends through a U-shaped bracket **166** mounted on the front panel **36** and is secured thereto by a nut **167.** The cartridge **51** is mounted on the outer extremity of the screw **164** by threading the mounting cap **162** upon the screw **163.**

First and second fittings **171** and **172** with fitting **171** being the inlet fitting and fitting **172** being the outlet fitting are threaded into the body **141** and are in communication with the bore **143** on opposite sides of the valve seat **157.** A bleed hole **176** is provided in the housing **141** and serves to prevent any build-up of pressure against the diaphragm which could give a false indication. The end cap **146** is provided with a servo port **177** which is in communication with a chamber **178** provided on one side of the diaphragm **144.**

The tube **47** is connected to a fitting **181** which is mounted in one end of the means forming the flow passage **67.** The other end is closed by a plug **182.** The outlet port **71** has a fitting **183** mounted therein which is connected to a tube **184.** The tube **184** is connected to a tee **186.** One end of the tee **186** is connected by tube **187** which is connected to a fitting **188** mounted in a flow rate valve **189** of the conventional type. The flow rate valve is provided with a control knob **191** for adjusting the rate of flow of gas through the flow rate control valve **189** through a fitting **192** which is mounted in the body **193** of the valve. The fitting **192** is connected by a tube **194** to a tee **196.** One end of the tee **196** is connected by a tube **197** to a check valve assembly **198.**

As shown in FIG. **13,** the check valve assembly **198** consists of a central body **201** on which there is mounted a housing **202** both of which are formed of a suitable material such as plastic and are fastened together in a suitable manner such as by ultrasonic welding to provide a bubble tight seal. The central body **201** has a cylindrical portion **201***a* of reduced diameter as shown in FIG. **13.** It is also provided with a flange **203** on the end of the portion **201***a* of reduced diameter. A passage or bore **207** is provided in the central body and extends longitudinally thereof through a stem-like portion **201***b* of the central body. The passage **207** empties into a passage **208** extending diametrically of the central body **201.** The passage **208** is normally closed by a sleeve **209** formed of a suitable elastic material such as rubber which is slipped over the portion **201***a* and is retained thereon by the flange **203.** It can be seen that if air is entering under pressure in the passage **207** in a direction indicated by the arrow that it can cause the elastic member **209** to expand and to permit the gas to escape into the housing **202** and to be discharged therefrom through a passage **211.** When the air ceases to be applied under pressure through the passage **207,** the elastic member will close the openings or passage **208** and prevent gas flow in an opposite direction.

The passage **111** is connected by a tube **216** to a tee **217.** One end of the tube **216** is directly connected to the inspiratory power fitting **219** mounted on the front panel **36** which can be termed a second outlet. The other end of the tee **217** is connected through a member **221** providing a restricted orifice and then through a tube **222** which is connected by an elbow **223** which is mounted in the fitting **172.** (See FIG. **4**)

The end of the tee **196** is connected by tube **226** to a fitting **227** mounted in a boss **228** provided on a venturi assembly **229.** The boss is provided with a main passage **231** which is centrally disposed in the nozzle **232** to provide a main venturi jet of gases. Additional passages **233** are provided in the nozzle **232** and are disposed around the centrally disposed passage **231** to provide secondary venturi jets. The passages **233** are in communication with a passage **234** provided in a boss **236.** A fitting **237** is provided in the boss and is connected to a tube **238.** The nozzle **232** is disposed in a T-shaped housing **239.** One end of the housing **239** is threaded onto a venturi housing **241** which has a venturi passage **242** therein in communication with the jets of gas discharging from the passages **231** and **233** in the nozzle **232.**

A fitting **243** is mounted in the other end of the housing **239** and is connected by a large tube **244** to an air inlet filter **245** mounted in the side wall **34.** The venturi housing **241** is provided with first and second spaced parallel radially extending flanges **246** and **247** which

are adapted to seat within a gate valve housing **248.** An O-ring **249** is mounted in the flange **246** and establishes a seal between the venturi housing **241** and the gate valve housing **248.**

The gate valve housing **248** is provided with an interior spider **251** which forms a centrally disposed hole **252** that receives the dish-shaped gate valve **254** which is adapted to engage the outer extremity of the venturi housing **248.** An O-ring **256** is provided on the exterior of the venturi housing **241** to establish a good seal between the gate valve **254** and the venturi housing. Yieldable means is provided for urging the gate valve into engagement with the O-ring and consists of a helical spring **257** mounted on the stem **253** and having one end engaging the spider **251** and having the other end engaging the valve **254.** The housing **248** is provided with a boss **258** which has a tee **259** mounted therein. One end of the tee **259** is connected by a tube **261** to the pressure manometer **168.** The other end of the tee **259** is connected by a tube **262** to the sensing port **97** of the servo cartridge **48.**

The gate valve housing **248** is provided with an outlet **263** which is connected to a tee **264.** One end of the tee **264** is mounted in a breathing tube receptacle **266** which is mounted on the front panel **36** and which can be termed a first outlet. The receptacle **266** is contained within the front panel **36** by nut **267** which is threaded thereon. The other end of the tee **264** has a safety-blow off valve assembly **268** mounted therein.

The valve assembly **268** consists of a generally cylindrical housing **269** with a flow passage **271** therein. An apertured wall **272** is provided in the passage and has a valve stem **273** slidably mounted therein. A valve member **274** is carried by the valve stem and is adapted to engage a valve seat **276** which is formed on the housing and surrounds the passage **271.** Means is provided for yieldably urging the valve member into engagement with the seat and consists of a spring **277** having one end engaging the wall **272** and having the other end engaging a nut **278** provided on the valve stem **273.**

The tube **238** is connected to a fitting **281** mounted in an apneustic plateau control valve assembly **282.** The control valve assembly **282** is provided with a valve body **283** having a control knob **284** for adjusting the flow through the valve assembly. A fitting **286** is mounted on the valve assembly **282** and is connected to the tube **287** which is connected to a fitting (not shown) of the apneustic control valve assembly **51.** The valve assembly **282** is provided with another fitting **288** (FIG. **6**) which is connected by a tube **289** to a check valve assembly **291.** The check valve assembly **291** is similar to the check valve assembly **198** and, therefore, will not be described in detail. The check valve assembly **291** is connected by a tube **292** to the tee **186.**

A hanger rod **296** is slidably mounted in a fitting **297** provided in the front panel **36.**

As shown in FIG. **1,** a large breathing tube **301** is adapted to be mounted in the breathing tube receptacle **266.** A small tube **302** is mounted in the inspiratory power control fitting **219.** The other end of the large breathing tube **301** is connected to a fitting **303** which is connected into a nebulizer **304** of the type described in U.S. Pat. No. 3,172,406. The other end of the nebulizer **304** is connected to a tee **306** which has a patient adapter or mouthpiece **307** mounted in one end thereof and which has an exhaust valve assembly **308** mounted in the other end thereof. The small tube **302** is connected to a tee **309** which has one end mounted in the nebulizer **304.** The other end of the tee **309** is connected by a tube **311** to the exhalation valve assembly **308.** The exhalation valve assembly **308** is of a conventional type. A vapor trap assembly **312** is mounted on the exhalation valve assembly to collect moisture which has precipitated out of the airstream.

The vapor trap assembly **312** consists of an outer cup-like housing **313** in which there is removably mounted a gate valve and diffuser assembly **314.** The housing **313** is generally cylindrical in shape and is provided with an upstanding cylindrical wall **316** with a bottom wall **317** formed integral therewith. A central opening **318** is provided in the bottom wall and is circumscribed by an upstanding lip or flange **319** so that there is provided an annular recess **321** between the upstanding flange **319** and the upstanding cylindrical wall **316.** One end of the housing **313** is open and is adapted to receive the gate valve and diffuser assembly **314.**

The gate valve and diffuser assembly **314** consists of a hollow cylindrical member **322** which is carried by a plurality of upstanding circumferentially spaced ribs or posts **323.** The ribs or posts **323** are formed integral with a diffuser member **324.** The diffuser member **324** is provided with a cylindrical wall **326** which is closed at its top by a transversely extending top wall **327.** The top wall **327** is provided with a centrally disposed upwardly extending cone-shaped portion **327***a* which underlies the hollow cylindrical member **322.** As will be noted, the lower extremities of the posts or ribs **323** extend below the bottom of the cylindrical wall **326** and are adapted to seat within the annular recess **321***a* in the housing **313.** The annular rim **331** is formed integral with the hollow cylindrical member **322** and is provided with an upstanding flange **332** which is adapted to engage the inner surface of the cylindrical wall **316** of the housing **313** to frictionally retain the gate valve and diffuser assembly **314** within the housing **313.** The lower extremity of the hollow cylindrical member **322** is spaced above the top wall **327.**

A circular plate **333** is mounted within the hollow cylindrical member **322** and is seated upon the upper extremities of the ribs **323.** The plate **323** is provided with downwardly depending ears **334** which are adapted to snap over the lower extremity of the hollow cylindrical member **322** to retain the plate **333** within the hollow cylindrical member **322.** The plate **336** is formed with a plurality of openings **336** which are arranged in a circle. An umbrella-type flapper valve **337** formed of a suitable material such as a flexible plastic is provided to form a gate valve in conjunction with the openings **336.** The flapper valve **337** is provided with a centrally disposed tit **338** which is mounted in a centrally disposed hole **339** provided in the plate **333** to retain the flapper valve **337** in engagement with the bottom side of the plate **333** to normally close the openings **336.** The flapper valve **337** generally overlies the cone-shaped portion **337***a* so that when air passes through the openings **336** and pushes the flapper valve downwardly the air will be diffused outwardly over the diffuser member **324** and through the ribs and downwardly and then up and over the flange **319** and to the atmosphere through the opening **318.**

Operation and use of the ventilator **20** may now be briefly described as follows. Let it be assumed that the ventilator **20** is to be utilized by a patient who is in a

comfortable supine position or sitting erect in an armchair. The nebulizer **304** is filled with a suitable solution which is to be utilized by the patient and as may be prescribed by a physician. The tee **306** with the exhalation valve assembly **308** is then mounted on the nebulizer **304** with a mouthpiece or patient adapter **307.** The water trap assembly **312** is mounted upon the exhalation valve assembly **308.** The breathing tube **301** is placed in the breathing tube socket **266** and the tube **302** is mounted in the expiratory power fitting **219.**

The starting effort for the patient is set by utilizing the control dial **116** which carries indicia ranging from 1 to 5. An appropriate setting is **2** which represents −2 cm of water. Next, the inspiratory positive pressure is set by utilizing the dial or knob **122.** The dial or knob carries indicia ranging from 15 to 60 cm H_2O and can be set within this range. For starting it should be set to **15.** If desired a dual range can be provided with the one range of 15 to 60 p.s.i. as a therapy range and with another range of 15 to 100 p.s.i. as an intensive care range.

The flow rate is next adjusted by operating the knob **191** so that an arrow (not shown) carried by the knob is in the twelve o'clock position.

The manual control timer knob **131** is depressed inwardly and thereafter, the oxygen or air supply is turned on to supply oxygen or air or a mixture of the same through the tube **27** to the ventilator **20.** The manual timer control knob **131** is then pulled out so that the ventilator is "on". There should be a dense flow of aerosol from the nebulizer **304.** The manual timer control knob **131** is then pushed in to the ventilator "off" position. After this for a specific period of time (between 0.25 to 3 seconds) there should still be a flow of aerosol from the nebulizer **304.** This is the apneustic flow time. The knob **284** is then rotated fully counterclockwise to the minimum period (0.25 second). The ventilator is then ready for use by the patient.

In operation of the ventilator, air from the source at suitable pressure such as 50 p.s.i. is supplied through the filter **43** and then through the tube **44** and the tubing **49** to the apneustic plateau cartridge **51** and also through the tube **47** to the servo cartridge **48.**

Let it be assumed that the control knob **131** is moved to the left from the position shown in FIG. **7** to cause the master shaft **73** to be moved to the left which, in turn, causes movement of the servo plate **82** and the fitting **84** to the left. Movement of the fitting **84** to the left causes movement of the plunger **86** to the left to engage the ball **87** to move it out of engagement with the seat **88.** In this position of the ball **87,** source gases with flow around the ball and through the orifice or valve seat around the plunger **86** and out the outlet port **71.** During this on or open period, the flow of the source gas around the ball literally spins the ball **87** on the end of the plunger **86** and serves to keep the ball free of microcontaminations such as could be carried by water. This flow through the port **71** can be identified as inspiratory flow gas.

Inspiratory flow gas is supplied through tube **184** and the tube **187** to the flow rate valve **189,** then through the tube **194** and the tube **226** through the center venturi passage **231** of the venturi assembly **229.** The jet of gases passing from the passage **231** in the nozzle **232** will pass down through the venturi **242** which will cause aspiration of additional gases which will be drawn in through the filter **245** and through the large bore tube **244** as shown particularly in FIG. **6.** The gases which are supplied by the venturi passage **242** apply positive pressure to the gate valve **274** against the yieldable force of the spring **277** to open the gate valve and to permit the gases to be discharged through the receptacle **266** and thence through the large tube **301** through the nebulizer **304,** the tee **306** and the mouthpiece **307** to the patient. At the same time, inspiratory gases are being supplied by the tube **197** to a check valve assembly **198** to the inspiratory power socket **219** provided on the front panel **36.** The small tube **302** is connected to this inspiratory power socket and supplies inspiratory gases under pressure to the nebulizer **304** and to the exhalation valve assembly to maintain the same closed during the inhalation or inspiratory phase of the ventilator. The safety blow-off valve assembly **268** is provided to protect the patient from over-pressure as, for example, a pressure above 67 cm of water, to prevent damaging the patient's lungs.

As herein before pointed out, means is provided for sensing the pressure of the gases being supplied to the patient and consists of the manometer **168** which is connected to the outlet receptacle **266.** It also is connected through the tube **262** to the sensing port **97** of the servo cartridge **48.**

Inspiratory gas is also supplied through the tube **292** through a check valve assembly **291** through the apneustic control valve assembly **282** through tube **238** to the passage **234** provided in the venturi assembly **229.** The passage **234** is connected to a plurality of passages **233** provided in the nozzle **232** to provide additional or secondary venturi jets of gas which are directed through the throat of the venturi assembly to augment the flow of gases through the venturi. The gas under pressure is also supplied from the apneustic control valve **282** through a tube **287** to the normally closed apneustic plateau cartridge **51** to move it to the open position. Additional inspiratory gases are supplied to the inspiratory power socket **219** through the orifice **271** at a fixed rate as determined by the size of the orifice **271.** The orifice **271** is supplied with inspiratory gases from the tube **222** which is fed from the open apneustic plateau cartridge **51** which in turn is fed by the tube **49.** These additional inspiratory gases augment the flow of gases through the nebulizer **304.**

The initial flow of inspiratory gases during the inspiratory phase of the ventilator delivers inspiratory air into the distal airway or ducts of the patient's lungs. Automatic nebulization occurs during inspiratory phase because the inspiratory gases pass through the nebulizer **304.** The rate of inspiratory flow determines the volume of inspiratory nebulization. As flow rate is increased, the pressure behind the primary jet of gases from the nozzle **232** increases causing an increased flow into the breathing circuit. In the present invention the basic inspiratory flow rate is supplemented or augmented by parallel flows of inspiratory gases one of which is through the apneustic plateau cartridge **51** and the other of which is through the apneustic control valve **282.** The flow through the cartridge **51** which is fixed by the size of the orifice **271,** continues throughout the inspiratory phase and for a period of time after the end of the inspiratory phase as determined by the setting of the apneustic control valve **282.** Thus there is provided a minimum flow from the nebulizer regardless of the slowing of the inspiratory flow rate near the

end of the inspiratory phase. In this manner it is possible to effectively double the volume of particulate delivery from the micronebulizer **304** during slow flow techniques.

From the foregoing it can be seen that a "topping low flow" is introduced into the patient's breathing circuit during the period of apneustic hold which is encountered after termination of the inspiratory phase. Decreasing the apneustic flow time increases the rate of flow of bleed down gases through the secondary venturi jets during the apneustic plateau and conversely increasing the apneustic flow time decreases the rate of flow of bleed down gases through the secondary venturi jets during the apneustic plateau. Also there is an analog tapering off of the rate of flow of the bleed down gases near the end of the apneustic plateau which creates a gradual pressure drop within the physiological system of the patient to prevent an abrupt rapid expiratory flow. These latter features are important because they make it easy to teach the patient how to use the ventilator to provide a satisfactory apneustic plateau.

With the present ventilator, a post-inspiratory apneustic plateau ranging from 0.25 to 3 seconds in duration can be provided by adjustment of the control knob **284** of the apneustic control valve **282.** In this way, it is possible to further enhance the total inspiratory distribution of respiratory gases transporting topically active aerosols. By way of example, it has been found that during apneustic flow approximately 200 cc of inspiratory gas is delivered per second so that during a maximum **3** second apneustic plateau, as much as 600 cc of dense aerosol can be delivered to the patient's lungs. Thus, it can be seen that during the initial inspiratory flow the humidity deficits are resolved, whereas during apneustic flow a larger particle high volume aersol is delivered into the tracheobronchial tree to effectively enhance the mobilzation of retained tracheobronchial secretions.

When a certain pressure is reached in the lungs of the patient as measured by the manometer **168** and since through the tube **262** connected to the servo cartridge, the pressure present in the chamber **102** will cause movement of the diaphragm **94** and the master shaft **73** to the right as viewed in FIG. **7.** This movement of the master shaft causes the plunger **86** to move to the right towards a closed position and permits the ball **87** to approach its orifice seat or valve seat. The size of the passage between the ball **87** and the orifice seat decreases to increase the flow velocity of the gases. This minimizes the tendency for the ball to fly off the seat during low flow when the plunger is withdrawn to the off position. To completely eliminate the possibility of a flying ball (during expected low flow conditions) causing an incompetent switch over (from the inspiratory to the expiratory phase), circumferentially spaced, longitudinally extending spoiler strips (not shown) are formed in the cylindrical walls of the passage **68.** These spoiler strips cause the ball to stall out on its orifice seat during low flow serving to further guarantee a competent closing. Since the plunger **86** is mechanically linked by the servo disc **82** to the master shaft **73,** the plunger **86** is pulled to permit the ball **87** to move to a closed position and is pushed to move the ball from the closed position.

Opening and closing of the switch of which the ball **87** forms a part occurs at approximately the mid point of the master shaft travel. Over-travel in both the on and off directions accomodates master shaft travel between the magnetic on and off clutches as described.

At the servo cartridge **48** off position, the ball valve **87** is held in closed position by the pressure of the source gas which enters at inlet port **67** and passes into cavity **68** and then pushes ball **87** against seat **88.** The magnetic force of magnet **79** holds armature plate **77,** which through shaft **73** and servo plate **82** keeps pin **86** away from ball **87.** At the servo cartridge **48** on position, the magnet **79** holding armature plate **78,** which through shaft **73** and servo plate **82** pushes pin **86** which holds ball **87** away from seat **88.** Source gases are allowed to pass through from cavity **68** to outlet port **71.** Magnetic fields are created by the fixed ring magnet **79.** The strong front field is used to attract the large (pressure limiting) armature **78.** The weaker back field of the magnet influences the smaller (starting effort) armature **77.**

When beginning inspiratory break-away occurs within the servo cartridge **48** by reducing the pressure in the chamber **102,** the starting effort armature **77** moves away from its magnetic field and the pressure limiting armature moves into its magnetic field under the influence of increasing magnetic force. The magnetic opening force is necessary to prevent a stall (peak starting effort sensitivity) against the piston effect created during opening of the ball valve. This is provided in the design of the servo cartridge by controlling the distance between the pressure limiting armature and its magnetic field to provide sufficient "pull-through" forces as servo plunger **86** contacts the ball during movement to the switch on position.

As the pressure limiting armature moves towards the front field of the magnet, the pulling force of the magnet pulls rapidly right. The opposite is true with the starting effort armature as it moves progressively out of the influence pf the magnetic back field. Because of the proportionate increase and decrease of the distances as one armature approaches and the other departs its magnetic field, only one magnetic field can capture its armature at a time. This establishes the positive snap on-snap off function of the pneumatic ball valve.

The functions of the magnetically controlled valve are interfaced with the servo sensing diaphragm **94** which is capable of applying servoing forces to the master shaft **73** carrying the magnetic armatures **77** and **78.** The diaphragm area is of sufficient size to override and magnetic on-off clutches at their maximum torques.

At the commencement of the inspiratory phase, the pressure inside the airways of the lung start to drop below ambient. Thus sub-ambient condition is transmitted through the sensing port **97** to the back side of the diaphragm **94** so that the diaphragm will apply force to move the master shaft **73** to the left as viewed in FIG. **7.** This movement is resisted by the magnetic (starting effort) source supplied to the starting effort armature **77.** As the physiological diaphragm of the patient continues to descend during the initial inspiratory phase, sub-ambient pressures acting against the servo diaphragm **94** increase until the ON servoing force supplied by the diaphragm **94** exceeds the opposing force supplied by the preset commanding magnetic off force set up by the starting effort armature **77.** As soon as this occurs, the master shaft **73** will travel to the left causing the pneumatic ball valve **87** to open.

A controlled inspiratory flow of gas into the breathing circuit occurs as hereinbefore described. As the

lungs of the patient gradually fill with the respiratory gases into the breathing circle connected to the patient, pressures within the physiological and mechanical ventilatory systems begin to rise. The previous pressure drop across the servo diaphragm favoring switching to the on position is now reversed and the pressure favoring switching to the off position is created. When sufficient pressure is supplied to the chamber **102** to create a force large enough to overcome the force applied by the pressure limiting armature **78,** the master shaft **73** is shifted to the right as viewed in FIG. **7** so that the starting effort armature comes into control of the magnetic field supplied by the magnet **79.** The servo cartridge **48** is switched to the opposite position by movement of the plunger **86** to the right and the ball valve **87** seats upon its valve seat to prevent further flow of source gases through the servo cartridge **48.**

By adjustment of the armature **77** on the master shaft **73,** it is possible to preselect a definite value of patient effort required to switch the ventilator on during mechanically assisted spontaneous breathing. In addition, it is possible to preselect a definite positive inspiratory pressure limit by adjusting the position of the armature **78.** Positioning of the armatures **77** and **78** can be adjusted in relation to calibrated adjustable sensitivity and pressure control knobs **116** and **122,** respectively. Calibration of the starting effort sensitivity is expressed in negative centimeters of H_2O and is indexed counterclockwise **1** to **5** and represents the pressure drop required in centimeters of H_2O during spontaneous inspiration to trigger the servo cartridge **48** to the on position for assisted mechanical respiration.

Pressurization of the chamber **178** occurs as soon as inspiratory gases are supplied through the apneustic plateau control valve **282** to the servo port **177** of the apneustic plateau cartridge **51.** Diaphram **147** is urged to the left to open the pocket valve **154** from a normally closed position. The apneustic plateau control cartridge utilizes a diaphram seal in place of dynamic O-ring seals because of varying frictional loads associated with decreasing surface lubrication and service for O-ring seals.

As soon as the poppet valve **154** is moved to an open position, source gases are supplied through the inlet fitting **171** and out through the outlet fitting **172** through the tube **222** and then through the restricted orifice **221** to the receptacle **219.**

When the servo cartridge **48** senses that a predetermined pressure has been reached in the patient's lungs, the servo cartridge is shifted from on to off. This is accomplished because as the pressure builds up in the patient's lungs, it also builds up in the chamber **102** to cause the diaphragm **94** to apply a pressure to move the master shaft **73** to the right as viewed in FIG. **7** to move it to the off position in a manner hereinbefore described. As soon as this occurs, the ball valve **88** will seat on its seat to prevent further flow of source gas to the check valve **291** and to the apneustic plateau control valve **282.** At the same time that the servo cartridge **48** moves to the off position, source gas under pressure is no longer supplied to the apneustic plateau cartridge.

At the time of sequencing of the servo cartridge **48,** the apneustic plateau cartridge will still have a certain volume of gas in the chamber **178** which is at the pressure of the inlet source gas. This gas must be brought out through the line **287** through the apneustic plateau control valve **282** and through the tube **238** through the venturi assembly **229.** The time required to bleed down this chamber **178** is determined by the adjustment of the knob **284** of the apneustic plateau control valve **282.** Thus, source gas under the 50 p.s.i. pressure will be supplied through the tube **49,** through the inlet fitting **171,** through the outlet fitting **172** and through the tube **222,** through the restricted orifice **221** to the receptacle **219** so that even after the servo cartridge **48** has servoed to the off position, source gas will be supplied to the breathing tube receptacle **219** and to the patient. At the same time, source gas under pressure will be supplied to the inspiratory power fitting **219.** Thus, after the servo cartridge **48** has switched to the off position to end the inspiratory phase, there will still be a diminishing topping off or a supplemental flow of source gas through the secondary venturi jets **333** to the lungs of the patient as hereinbefore described.

It is only after sufficient gas has been bled out of the chamber **178** to permit the spring **159** to move the valve member **154** to a closed position that the flow of source gas to the patient ceases. At the same time, source gas under pressure is no longer supplied to the socket **219** and to the exhalation valve so that the exhalation valve can open and the patient can exhale through the exhalation valve.

The exhalation gases from the exhalation valve assembly **308** are exhausted through the vapor trap assembly **312.** These exhalation gases must pass through the openings **336** and must urge the flapper valve **337** away from the openings to permit the exhalation gases to pass downwardly and outwardly over the diffuser member **324** and down past the ribs **323** and then upwardly over the flange **319** through the central opening **318** to the atmosphere. The flapper valve forces the patient to breathe or exhale against a graded positive pressure as for example **3** centimeters of water. As is well known to those skilled in the art, the use of means requiring the patient to exhale against a positive pressure is paticularly efficacious with patients having obstructive pulmonary diseases. The flapper valve is of a type which serves to retard the flow of gases very little at peak flows of gases but does serve to retard the flow of gases at slow rates of flow. Thus it can be seen that the vapor trap assembly **312** does provide a retard function and in addition serves to collect vapors from the exhalation gases within the housing **313.** The housing **313** can be readily removed from the gate valve and diffuser assembly **314** and emptied when necessary.

As soon as the expiratory phase has been completed, the patient will cause the sub-ambient condition to occur in the chamber **102** of the servo cartridge **48** to switch the servo cartridge **48** to the on position in the manner hereinbefore described to start another cycle.

From the foregoing, it can be seen that there has been provided a ventilator or respirator in which a topping low flow is introduced into the pulmonary structures of the patient during the period of apneustic hold at the end of the inspiratory phase. This topping low flow at the post inspiratory apneustic plateau can be from 0.25 to 3 seconds in duration and is particularly useful to permit topically active particles of aerosol to rain out in the pulmonary structures concommitant with increased diffusion and mechanical mixing of the expiratory gases in the lung of the patient. In addition, it can be seen that the ventilator which has been provided is of a construction which can be readily manu-

factured. Its construction is such that it is relatively simple to operate. It is also readily cleaned and maintained.

I claim:

1. In a ventilator having an inhalation phase and an exhalation phase in its operative cycle, a servo controller having an inlet adapted to be connected to a supply of gas under pressure, said controller also having first and second outlets, control valve means disposed in said servo controller and movable between open and closed positions to control the flow of gas from the inlet to the first outlet, said control valve means being in an open or on position during the inhalation phase of the ventilator and in a closed or off position during the exhalation phase of the ventilator, a patient adapter, means for supplying gas from the first outlet to the patient adapter, an exhalation valve assembly coupled to the patient adapter and movable between open and closed positions and in the open position permitting gases to flow from the patient adapter to the atmosphere and in a closed position preventing the flow of gases from the patient adapter to the atmosphere, means for supplying gas from the second outlet to the exhalation valve assembly to maintain the exhalation valve assembly in a closed position during the time the gas is being supplied from the outlet of the servo controller, means for sensing the pressure of the gas in the means for supplying gas from the outlet of the servo controller to the patient adapter and for switching the servo controller from an open position to a closed position when a predetermined pressure is reached, apneustic plateau valve means having having an inlet and an outlet, said apneustic plateau valve means having a valve member movable between open and closed position to control the flow of gases from the inlet to the outlet, means adapted to connect the inlet of the apneustic plateau valve means to the source of gas under pressure, means connecting the outlet of the apneustic plateau valve means to the second outlet, diaphragm operated means for moving said valve member between open and closed positions, means for supplying gas from the outlet of the servo controller to the diaphragm operated means and to the first outlet, said means for supplying gas from the outlet of the controller to the diaphragm operated means and to the first outlet, including valve means for controlling the rate of flow of gas from the diaphragm operated means to the first outlet whereby after the servo controller is switched to a closed position, an apneustic topping flow will be supplied to the patient adapter for a period of time determined by the time required to reduce the pressure in the diaphragm operated means to a value to permit the valve member of the apneustic plateau valve means to return from an open to a closed position.

2. A ventilator as in claim **1** wherein said last named valve means is adjustable for varying the rate of flow of fluid from the diaphragm operated means to thereby control the period of time during which apneustic flow is supplied to the patient.

3. A ventilator as in claim **2** together with adjustable valve means for adjusting the rate of flow of gas from the outlet of the servo controller to the patient adapter.

4. A ventilator as in claim **1** wherein said means for supplying gas from the outlet of the servo controller to the exhalation valve includes a check valve assembly.

5. A ventilator as in claim **1** wherein said means for supplying gas from the outlet of the controller to the diaphragm operated means and to the first outlet includes a check valve assembly.

6. A ventilator as in claim **5** wherein said check valve assembly includes a body having a passage extending into the body generally axially thereof and extending out of the body generally radially thereof and a resilient sleeve on said body and normally covering said passage extending out of the body.

7. A ventilator as in claim **1** together with fixed orifice means for controlling the rate of flow of gas from the outlet of the apneustic plateau valve means to the second outlet.

8. A ventilator as in claim **1** wherein said means for supplying gas from the first outlet to the patient adapter includes a nebulizer through which the gas must flow and wherein said means for supplying gas from the second outlet to the exhalation valve assembly includes means for supplying gas from the second outlet to the nebulizer so that there is nebulization of gases after the controller has moved to a closed position.

9. A ventilator as in claim **1** together with a venturi assembly coupled to said first outlet for receiving the gases supplied through the first outlet, said venturi assembly including a venturi-like passage and means for forming a main jet of gases passing through the venturi-like passage and means forming a secondary jet of gases passing through said venturi-like passage and wherein said means for forming said main jet of gases is coupled to the second outlet of the controller and wherein the means for forming the secondary jet of gases is connected to the means for supplying gas from the outlet of the controller to the diaphragm operated means and to the first outlet.

10. A ventilator as in claim **1** together with a vapor trap assembly coupled to the exhalation valve assembly, said vapor trap assembly having means for causing the patient to exhale against a positive pressure.

11. A ventilator as in claim **10** wherein said vapor trap assembly includes a valve member having a plurality of openings therein and a gate valve normally closing said openings.

12. A ventilator as in claim **10** wherein said vapor trap assembly includes a valve member having a plurality of openings therein and a gate valve normally closing said openings.

13. A ventilator as in claim **10** wherein said vapor trap assembly includes a housing having an opening therein, a valve member mounted in the housing and having at least one opening therein, a flapper-type vale secured to said member and normally closing said opening in said member and means mounted in the housing for diffusing gases which are discharged through the flapper valve assembly.

14. A ventilator as in claim **1** wherein said controller is provided with a compound knob arrangement in which one knob is utilized for pressure control and the other knob is utilized for sensitivity control.

* * * * *