United States Patent [19]
Christianson

[11] 4,076,041
[45] Feb. 28, 1978

[54] PILOT VALVE OPERATED DEMAND REGULATOR FOR A BREATHING APPARATUS

[76] Inventor: **Raymond A. Christianson,** 120 8th St., Manhattan Beach, Calif. 90266

[21] Appl. No.: **587,272**

[22] Filed: **Jun. 16, 1975**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 508,580, Sept. 23, 1974, abandoned.

[51] **Int. Cl.**2 .... **F16K 31/126**

[52] **U.S. Cl.** **137/490;** 137/489.5; 137/492.5

[58] **Field of Search** .... 137/489.5, 485, 488, 137/484.2, 484.6, 484.8, 63 R, 490, 492, 492.5

[56] **References Cited**

U.S. PATENT DOCUMENTS

757,590	4/1904	Zindol	137/489.5
1,184,761	5/1916	Lytton	137/489.5
1,198,595	9/1916	Stolle	137/63 R
2,817,334	12/1957	Sajeck	137/63 R
3,047,001	7/1962	Hosford	137/490 X
3,381,707	5/1968	Andersen	137/489.5
3,495,619	2/1970	Iizumi	137/489.5
3,783,891	1/1974	Christianson	137/491

Primary Examiner—Alan Cohan
Attorney, Agent, or Firm—Spensley, Horn & Lubitz

[57] **ABSTRACT**

A scuba regulator second stage utilizes pneumatic amplification to achieve very low inhalation effort. The regulator includes (a) a main flow valve consisting of a poppet moveable within a valve housing inside the regulator body, (b) a pilot valve mounted within and carried by the main valve poppet, and (c) a pressure sensing diaphragm linked to the pilot valve.

During inhalation, the diaphragm and linkage open the pilot valve to admit gas at supply pressure into a space, between the poppet and a closed end of the housing. This gas displaces the poppet, thereby opening the main flow valve and supplying gas to the diver. Pneumatic amplification is achieved. The poppet displacement tends to close the pilot valve, so that the poppet-opening force is reduced. This feedback effect results in substantially linear relationship between inhalation demand and the amount of breathable gas supplied to the diver.

8 Claims, 10 Drawing Figures

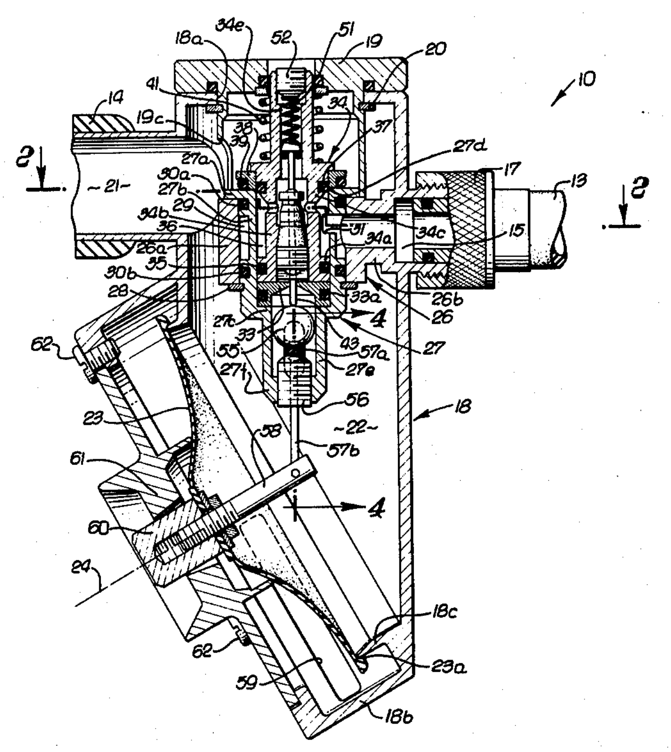


FIG. 1.

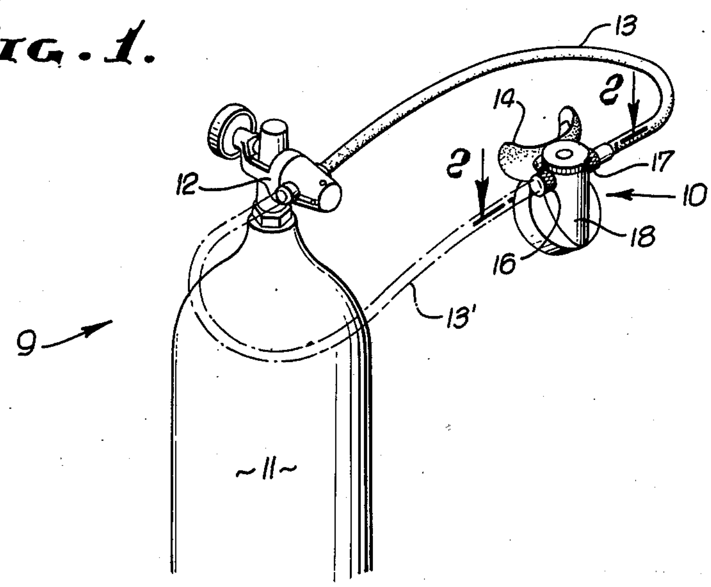

13
2
14
2
17
10
12
18
16
13'
9
~11~

FIG. 2.

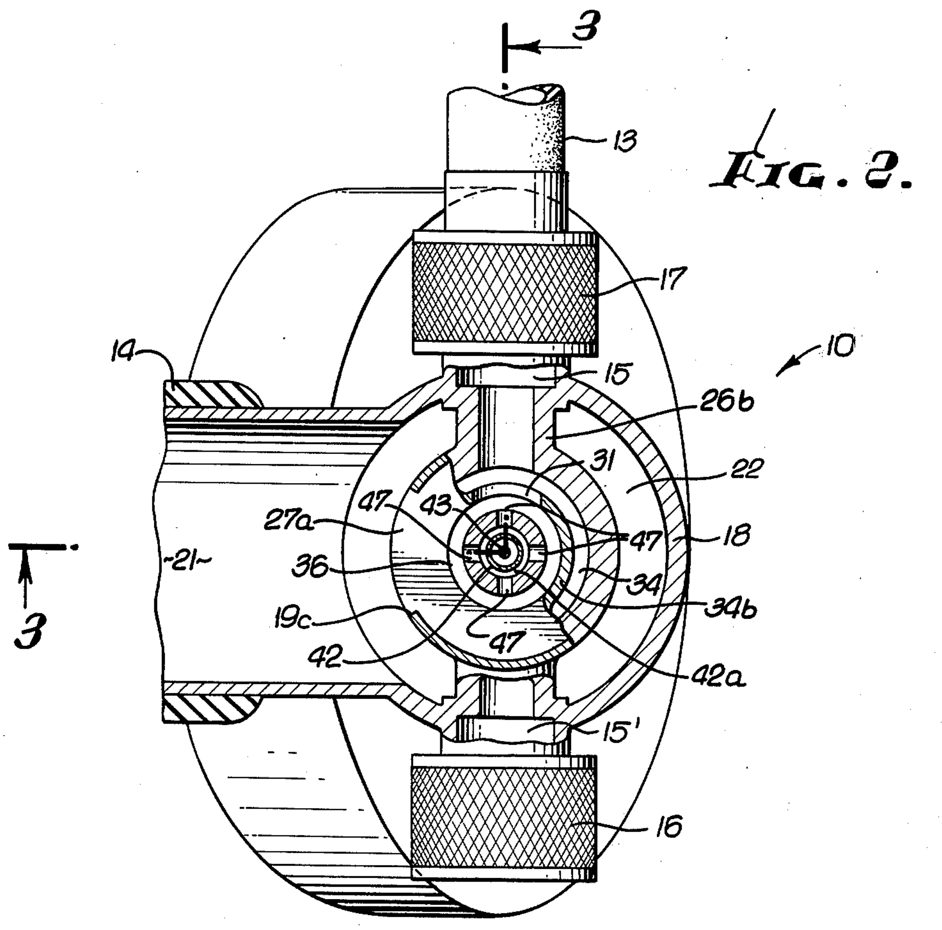

3
13
17
14
10
15
26b
31
22
47
43
27a
47
18
36
34
~21~
34b
3
19c
47
42
42a
15'
16

FIG. 3.

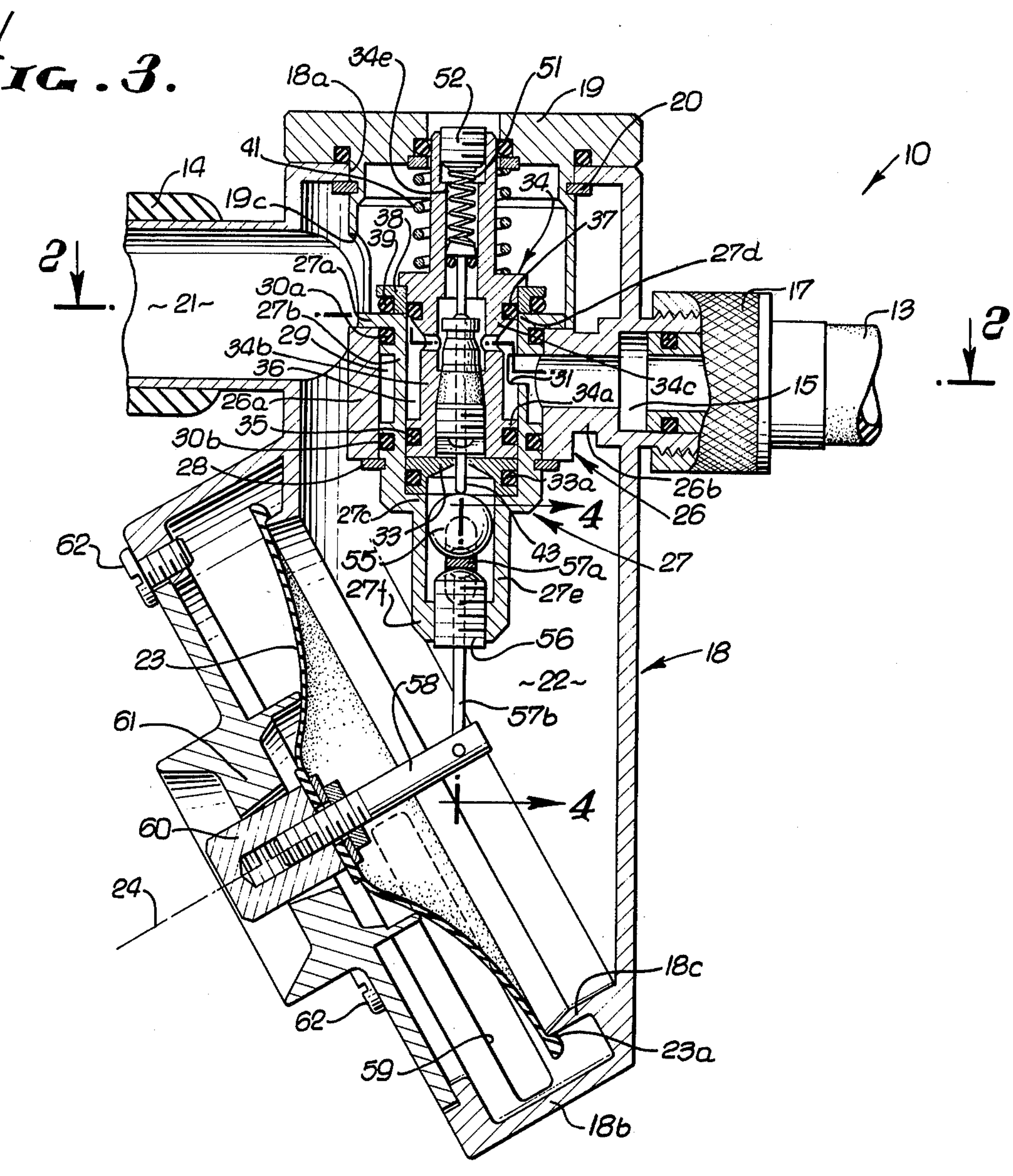

18a
34e
52
51
19
20
10
14
41
19c
34
38
37
39
27d
17
13
2
27a
30a
27b
~21~
29
34b
31
34c
36
15
26a
34a
35
30b
28
33a
26b
27c
4
26
33
55
43
57a
27
27f
27e
62
56
18
23
58
~22~
57b
61
60
24
18c
62
23a
59
18b

FIG. 4.

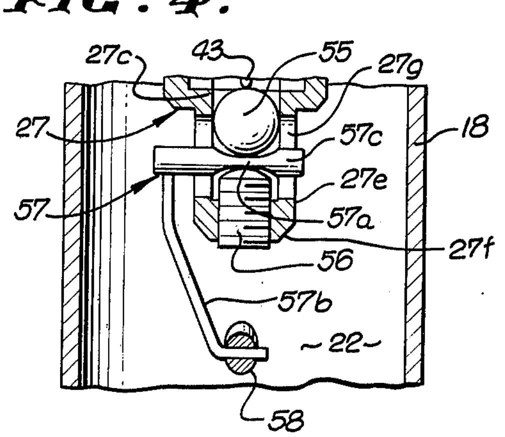

27c
43
55
27g
27
57c
18
27e
57
57a
27f
56
57b
~22~
58

FIG. 5.

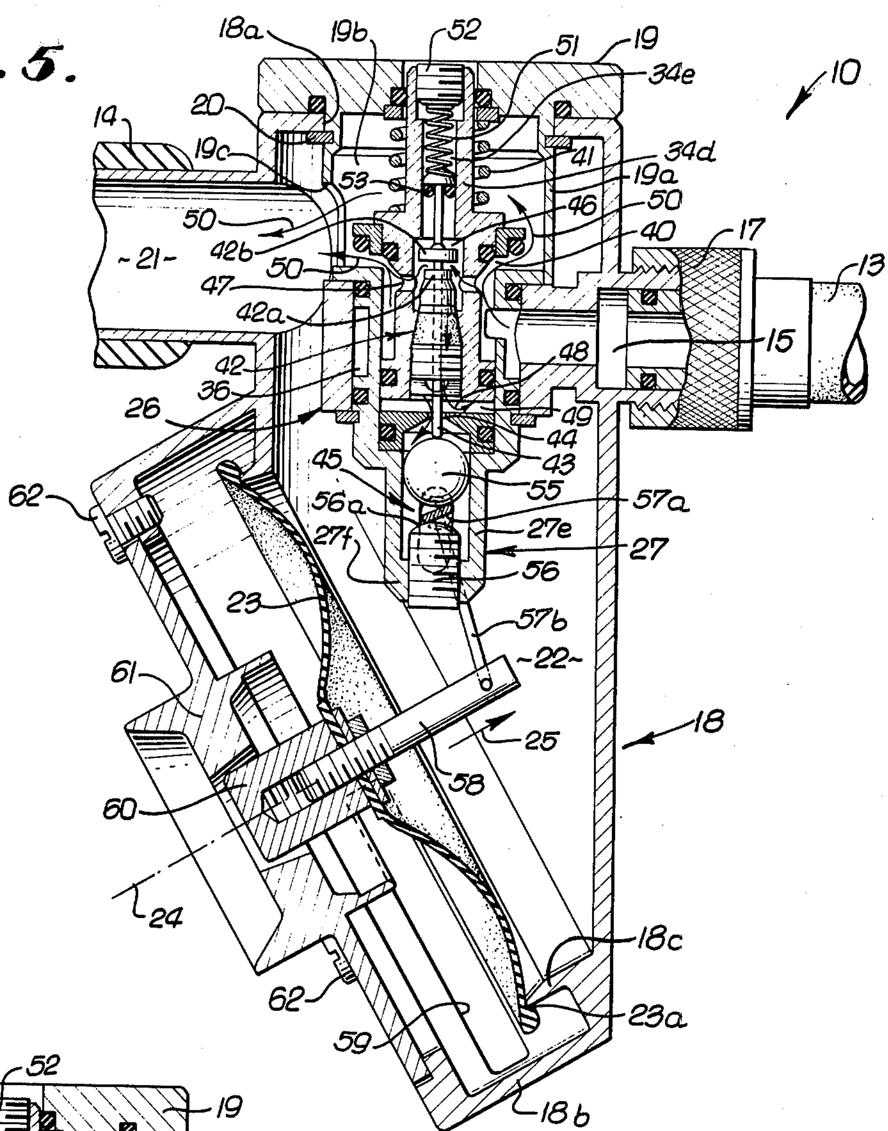


FIG. 6.

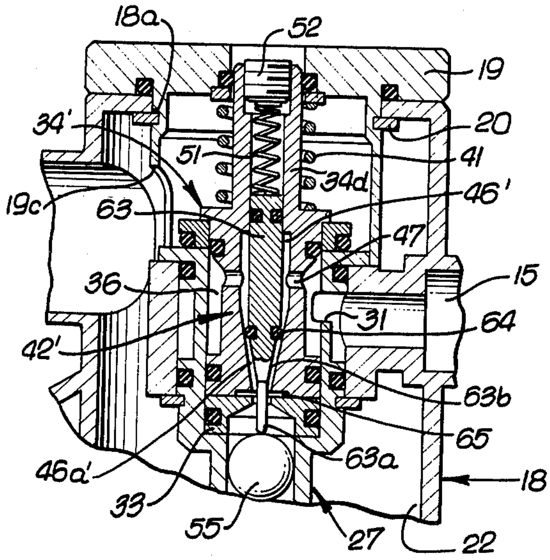


FIG. 7.

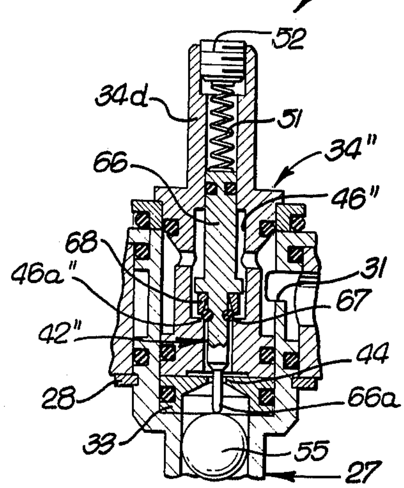


FIG. 8.

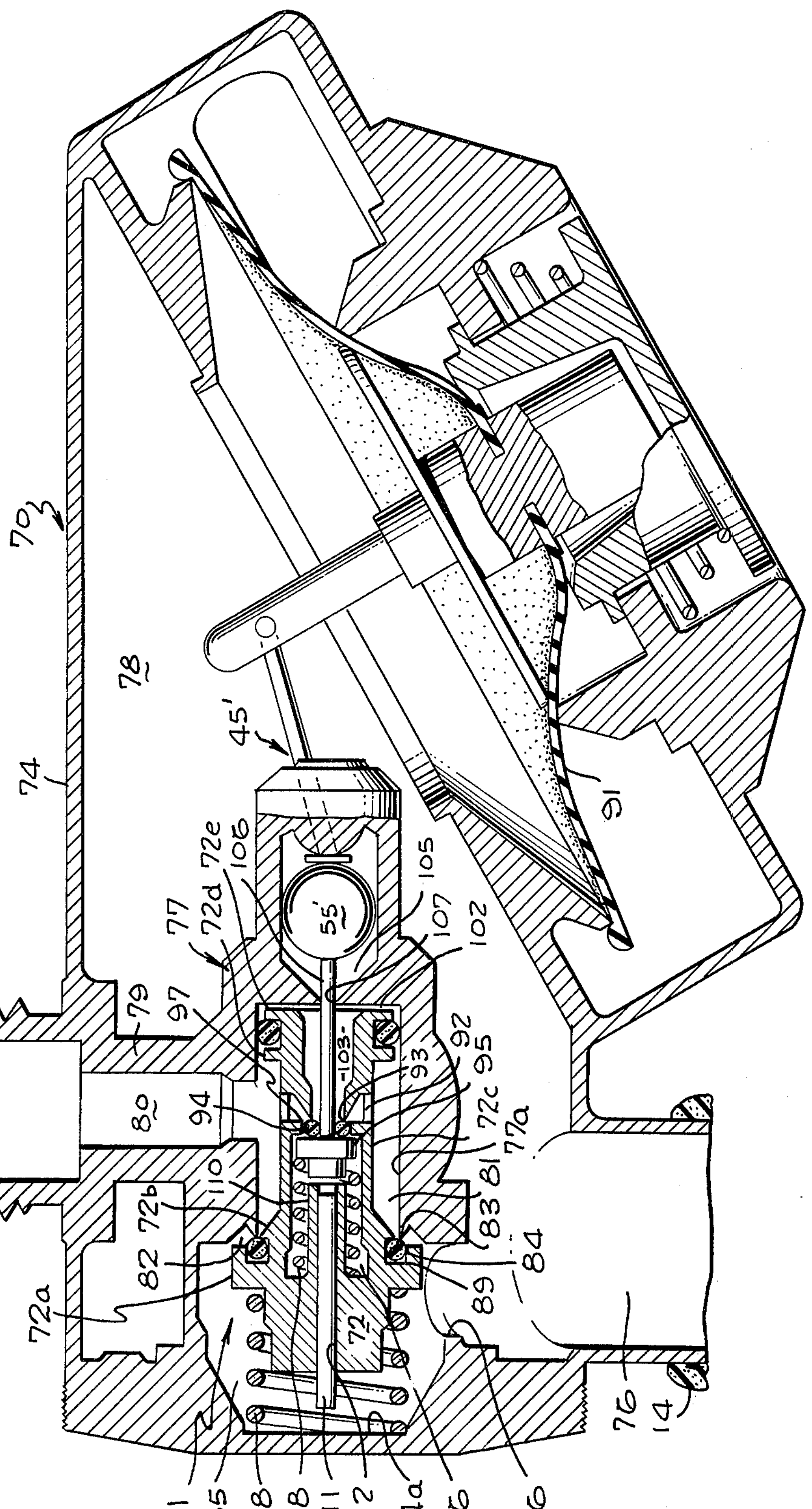

70
74
78
45'
91
75
80
79
77
72d
72e
106
105
55'
107
102
97
103
94
93
92
95
72c
77a
81
83
84
89
110
72b
82
72a
72
71
85
88
98
111
112
74a
96
86
76
14

FIG. 9.

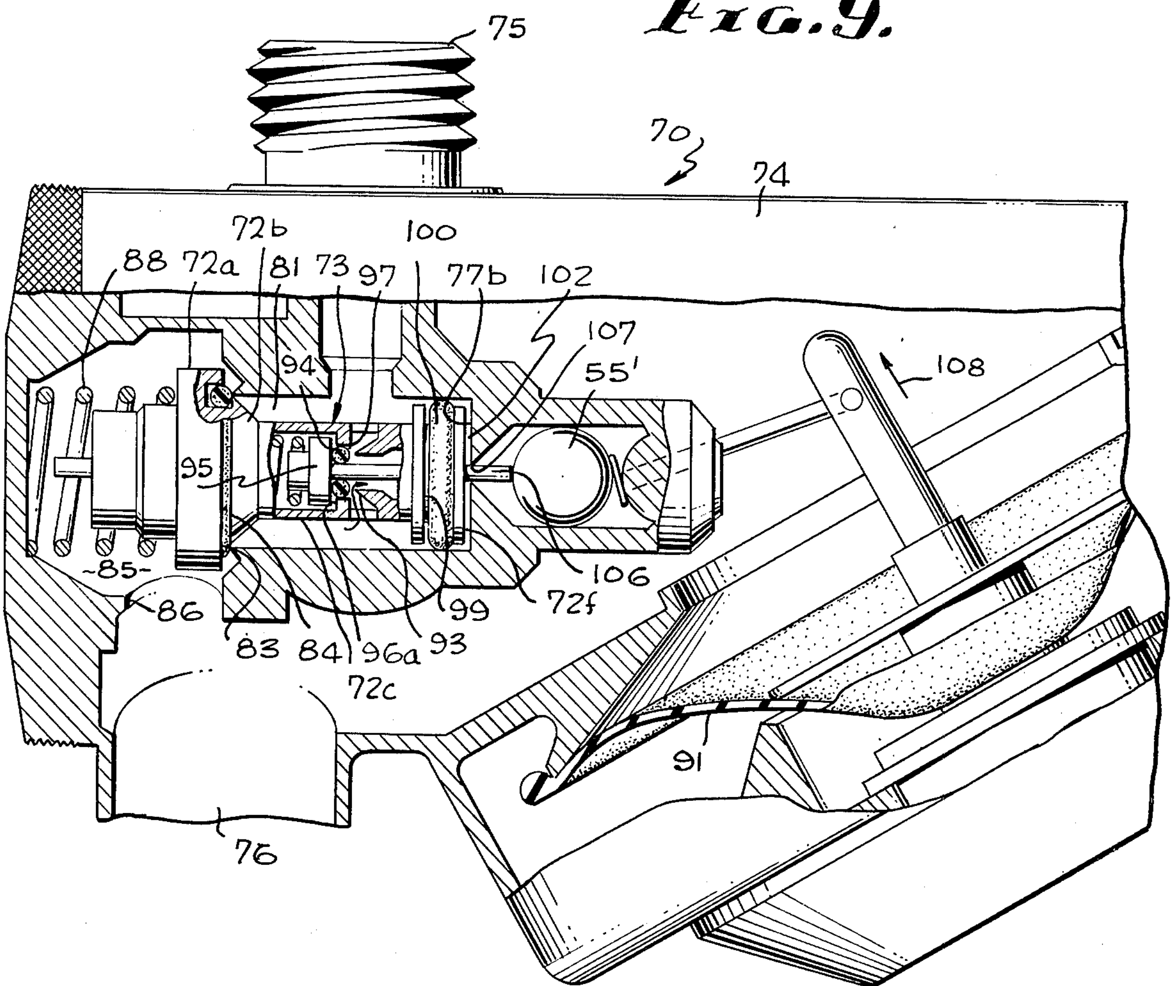
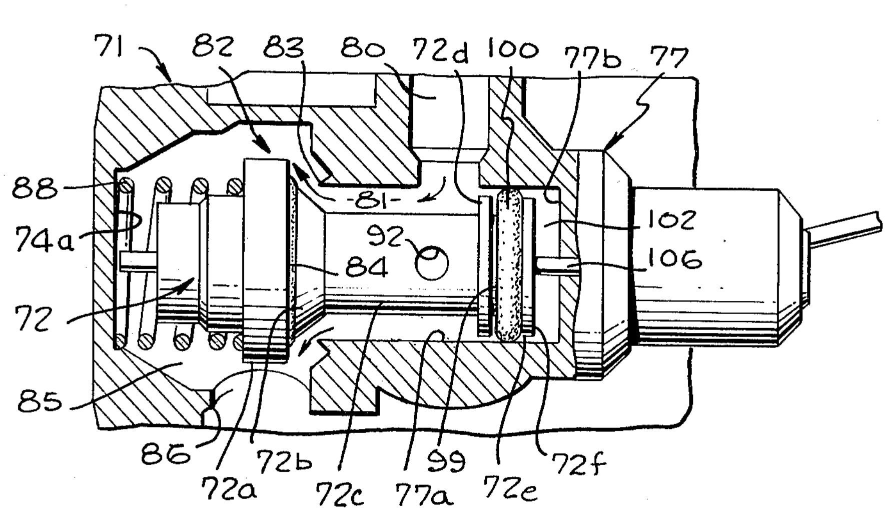

75
70
74
72b
100
88
72a
81
73
97
77b
102
107
55'
108
94
95
106
85
86
99
72f
83
84
96a
93
72c
91
76

FIG. 10


71
82
83
80
72d
100
77b
77
88
81
102
74a
92
84
106
72
85
86
72b
72a
72c
77a
99
72e
72f

PILOT VALVE OPERATED DEMAND REGULATOR FOR A BREATHING APPARATUS

RELATED APPLICATIONS

The present application is a continuation-in-part of application Ser. No. 508,580, filed Sept. 23, 1974 now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a pilot valve operated demand regulator for an underwater breathing apparatus, and more particularly to such a regulator using pneumatic amplification and feedback to achieve very low inhalation effort and substantially linear relationship between inhalation effort and supplied breathable gas.

2. Description of the Prior Art

A self contained underwater breathing apparatus (scuba) typically employs a supply tank of air or other breathable gas under high pressure and a two stage regulator to provide this air to the diver. The regulator first stage is mounted at the supply tank and functions to reduce the air pressure to about 140 psi above the ambient pressure. A conduit supplies this reduced pressure air to a regulator second stage at the diver's mouthpiece. The second stage includes a demand valve system which opens to supply breathable gas in response to the inhalation effort of the diver. An exhaust port may be provided to discharge gas exhaled through the mouthpiece.

Ideally the regulator second stage should provide to the diver exactly the volume of air required, without excessive inhalation effort. The problems associated with achieving such performance are discussed in the inventor's U.S. Pat. No. 3,783,891 which discloses a balanced regulator second stage employing pneumatic amplification.

In that patented demand regulator, a balanced primary valve controls the flow of breathable gas from the supply conduit inlet to an outlet chamber leading to the mouthpiece. The primary valve is not controlled directly by a mechanical linkage to the demand-sensing diaphragm. Rather, it is responsive to the pressure differential between the inlet and a control chamber the pressure in which is established by a pilot valve linked to the diaphragm. Thus pneumatic amplification isolates the diaphragm from the flow control valve to achieve sensitive response between inhalation demand and volume of air supplied to the diver.

To achieve this performance, the patented balanced regulator includes a small orifice through the primary valve to bleed some air into the control chamber. The pilot valve includes a pilot orifice in a secondary flow path from the control chamber to the outlet chamber. This pilot orifice is selectively blocked or unblocked by a valve poppet that is linked to the diaphragm. As the diaphragm senses reduced pressure in the outlet chamber, signifying an inhalation demand, the pilot orifice is slightly unblocked to lower the control chamber pressure. The resultant pressure differential between the inlet and the control chamber causes the primary valve to open proportionately, until the unbalanced pressure force exerted on the primary valve is balanced by the bias spring force. Supplied breathable gas flows past the primary valve directly to the outlet chamber and the mouthpiece.

An object of the present invention is to provide a regulator second stage which, though utilizing pneumatic amplification, is of different configuration and simpler construction than known regulators. Another object is to provide a demand regulator which employs both pneumatic amplification and feedback to achieve low inhalation effort and a linear relationship between inhalation demand and the amount of supplied breathable gas. A further object of the present invention is to provide an improved demand regulator in which the flow of breathable gas is controlled by a main flow valve having a moveable poppet, and in which motion of the poppet is imparted pneumatically by the pressure of supplied gas under control of a pilot valve that is moounted within and carried by the moveable poppet. Yet another object is to provide a demand regulator having no pressure control chamber and requiring no bleed passage through the main valve component to a pressure control region.

SUMMARY OF THE INVENTION

These and other objectives are achieved by providing a demand regulator in which a valve housing is supported within the interior chamber of the regulator body. A movable poppet is situated within the housing and biased toward a substantially closed end thereof. Breathable gas is introduced into an annular space defined by the interior wall of the housing and a region of reduced diameter in the poppet. The flow of breathable gas from this annular space to the mouthpiece, via the body interior chamber, is controlled by a flow valve consisting of the annular edge of the housing open end and a sealing ring mounted on an adjacent shoulder on the poppet. This flow valve normally is biased closed.

Mounted within the poppet is a normally closed pilot valve. The control pin of the pilot valve extends through a small opening in the substantially closed end of the valve housing. A diaphragm situated in the body interior chamber is linked to this control pin. Diaphragm displacement in response to inhalation demand moves the pin to open the pilot valve. As a result, gas under pressure is admitted to the space between the poppet and the housing closed end. The force of this admitted gas overcomes the bias and causes the poppet to move away from the housing closed end. This opens the flow valve, permitting breathable gas to be supplied to the mouthpiece. As the inhalation demand is satisfied, the pilot valve closes and the poppet returns to the flow-blocking position. This return is not abrupt, but rather follows the inhalation demand so that the diver receives just the desired amount of breathable gas.

BRIEF DESCRIPTION OF THE DRAWINGS

A detailed description of the invention will be made with reference to the accompanying drawings wherein like numerals designate corresponding parts in the several figures. These drawings, unless described as diagrammatic, or unless otherwise indicated, are to scale.

FIG. **1** is a pictorial view of an underwater breathing apparatus incorporating the inventive pilot valve operated regulator second stage.

FIG. **2** is a sectional view of the inventive regulator second stage as seen along the line **2—2** indicated in FIGS. **1** and **3**.

FIG. **3** is a transverse sectional view of the demand regulator as seen along the line **3—3** of FIG. **2**, and shown with the flow valve closed.

FIG. 4 is a fragmentary sectional view of the diaphragm to pilot valve linkage, as seen along the line 4—4 of FIG. 3.

FIG. 5 is a transverse sectional view like FIG. 3, but with both the pilot valve and the flow valve open.

FIGS. 6 and 7 are fragmentary transverse sectional views showing alternative pilot valve configurations.

FIG. 8 is a transverse sectional view of another, preferred embodiment of the invention, with the main flow valve and the pilot valve both shown in the flow-blocking position.

FIG. 9 is a side view, partly broken away and in section, of the regulator second stage of FIG. 8, showing the pilot valve open and the main flow valve closed.

FIG. 10 is a fragmentary sectional view of the valve assembly of the FIG. 8 embodiment with the main flow valve open.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following detailed description is of the best presently contemplated modes of carrying out the invention. This description is not to be taken in a limiting sense, but is made merely for the purpose of illustrating the general principles of the invention since the scope of the invention is best defined by the appended claims.

Structural and operational characteristics attributed to forms of the invention first described also shall be attributed to forms later described, unless such characteristics obviously are inapplicable or unless specific exception is made.

In FIG. 1 there is shown a self-contained underwater breathing apparatus 9 incorporating the inventive demand regulator 10. The scuba system 9 includes a supply tank 11 containing breathable gas under high pressure. Attached to the tank 11 is a conventional regulator first stage 12 which provides the breathable gas at a reduced pressure, typically 140 psi above ambient, to a conduit 13. The inventive regulator second stage 10 is connected to the other end of the conduit 13 and functions to deliver breathable gas to a diver via a mouthpiece 14 upon inhalation demand. Advantageously the regulator 10 has two inlet ports 15, 15' so that the diver can use either a conduit 13 over his left shoulder or alternatively a conduit 13' over his right shoulder. The unused inlet connector 15 or 15' is closed by a cap 16 as shown in FIG. 2, and the conduit 13 is attached by a connector 17.

Referring to FIGS. 2 and 3, the demand regulator 10 has a body 18 generally in the shape of a truncated cylinder. An opening 18*a* at the upper end of the body 18 is covered by a cap 19 that is held in place by a snap ring 20. The rubber or plastic mouthpiece 14 is attached to an outlet 21 which communicates to the interior chamber 22 of the body 18.

At the truncated lower end of the body 18 there is a generally cylindrical body portion 18*b* which encloses a diaphragm 23 that is responsive to the pressure within the interior chamber 22. When the diver inhales, the pressure in the outlet 21 and the chamber 22 is lowered, causing displacement of the diaphragm 23 along its central axis 24 in the direction of the arrow 25. As described below, this diaphragm displacement initiates a flow of breathable gas from the inlet conduit 13 to the mouthpiece outlet 21 so as to satisfy the inhalation demand.

Contained within the interior chamber 22 is a support structure 26 including a ring section 26*a* that is concentric with the body 18. This ring section 26*a* is suspended by a pair of tubular members 26*b* which project inwardly from the associated inlet ports 15, 15'.

A generally cylindrical valve housing 27 is held within the support structure 26. This mounting is accomplished by the cooperation of an annular flange 27*a* which seats on the upper end of the ring section 26*a* and by a snap ring 28 at the bottom end of the ring section 26*a*. Note that the maximum diameter of the flange 27*a* is slightly less than the diameter of the opening 18*a* so that the valve housing 27 can be inserted through this opening when the cap 19 is removed.

The cylindrical wall 27*b* of the valve housing 27 is of smaller diameter than the interior of the ring section 26*a*. Thus there is defined an annular space 29 that is in communication with the inlet port 15. A pair of O-rings 30*a*, 30*b* held by the valve housing 27 define the upper and lower limits of this annular space 29. One or more milled slots 31 through the valve housing wall 27*b* provide a flow path for incoming breathable gas into the interior of the valve housing 27.

The upper end of the valve housing 27 is open, but the lower end is substantially closed by a generally disc-shaped member 33 which seats on a shoulder 27*c*. An O-ring 33*a* prevents gas escape around the outer periphery of this member 33. Alternatively, the member 33 could be an integral part of the valve housing 27 itself.

Movably mounted within the valve housing 27 is a spindle or poppet 34. An annular flange 34*a* at the bottom of the poppet 34 has an outer diameter corresponding to the inner diameter of the valve housing cylindrical wall 27*b*. An O-ring 35 held by the flange 34 prevents air flow around this flange.

Above the flange 34*a* the poppet 34 has a region 34*b* of reduced diameter which together with the valve housing wall 27*b* defines an annular space 36. The upper end of this annular space 36 is defined by a shoulder 34*c* of the poppet 34. This shoulder 34*c* holds an O-ring 37. In the valve closed position illustrated in FIG. 3, the O-ring 37 is in contact with the corner or edge 27*d* that defines the open end of the valve housing 27. As a result, no gas can flow from the annular space 36 past the O-ring 37 and edge 27*d* to the interior chamber 22. An annular ring 38 of inverted-L-shaped cross-section retains the O-ring 37 in place and prevents the housing edge 27*d* from biting in too far into the O-ring 37. An O-ring 39 around the outer periphery of the retainer 38 prevents contaminants such as sand from reaching the O-ring 37 that serves as the flow valve member.

As described below, upon inhalation demand the poppet 34 moves upward to the position shown in FIG. 5. There the poppet shoulder 34*c* and the O-ring 37 are spaced away from the housing edge 27*d*. As a result, breathable gas from the inlet 15 can flow through the support tubular member 26*b*, the slot 31, and the annular space 36, and thence past the annular opening 40 that is formed when the poppet 34 is open. From there the breathable gas flows through the interior chamber 22 to the mouthpiece outlet 21. Normally, however, a spring 41 around the neck 34*d* of the poppet 34 biases the poppet to the closed position of FIG. 3.

From the foregoing, it is evident that the poppet 34 and the valve housing 27 cooperate to function as a flow valve which controls the supply of breathable gas from the inlet port 15 to the mouthpiece outlet 21. Opening and closing of this flow valve in turn is controlled by a pilot valve 42 which is mounted within the poppet 34 itself. Advantageously, but not necessarily, this valve **42** comprises a conventional tire inflation valve or so-called "Schrader" valve. Alternative pilot valves are shown in FIGS. **6** and **7**.

The valve **42** includes a control pin **43** which extends through a small opening **44** in the closed end of the valve housing **27**. Normally the valve **42** is closed, so that the control pin **43** projects into a cylindrical extension **27e** of the valve housing **27**, as shown in FIG. **3**. A linkage **45**, described below, interconnects the diaphragm **23** to the pilot valve control pin **44**.

The upper or inlet end **42a** of the pilot valve **42** is situated within a chamber **46** within the poppet **34**. One or more small holes or orifices **47** extend laterally through the reduced diameter region **34b** of the poppet **34**. These holes **47** provide flow communication from the annular space **36** into the chamber **46**.

As a result, when the pilot valve **42** is opened, gas at the supply pressure flows from the inlet **15** via the annular space **36**, the holes **47** and the chamber **46** through the pilot valve **42**. As indicated by the arrows **48** in FIG. **5**, this gas then flows into the space **49** between the flanged end **34a** of the poppet **34** and the substantially closed end **33** of the valve housing **27**. The gas pressure overcomes the bias of the spring **41**, and hence forces open the poppet **34**. Breathable gas is supplied to the mouthpiece outlet **21** as shown by the arrows **50**.

An aspirator effect is achieved by providing the cap **19** with a cylindrical skirt **19a** that extends downwardly to the support structure **26**. The inner diameter of this skirt **19a** is just slightly greater than the outer diameter of the housing upper flange **27a**. Thus the skirt **19a** defines a chamber **19b** into which the breathable gas flows through the valve opening **40**(FIG. **5**). The skirt **19a** has an orifice **19c**, advantageously facing the mouthpiece outlet **21**, which serves as the aspirator opening. The orientation of this orifice **19c** can be changed by rotating the cap **19**, thereby permitting the diver to adjust the aspirator effect even underwater.

The pilot valve **42** is biased closed by a spring **51** contained in a bore **34e** through the neck **34d** of the poppet **34**. A plug **52**, threaded into the end of the bore **35e**, permits adjustment of the spring pressure that biases the valve **42** closed. An O-ring **53** prevents the escape of gas through the bore **34e**. The pilot valve closure **42b** may consist of a washer or like flange member mounted to the control pin **43** and cooperating with a valve seat formed at the valve upper end **42a**.

The linkage **45** (FIGS. **3**, **4** and **5**) includes a rigid ball **55** situated within the cylrindical extension **27e** of the valve housing **27** and having a diameter equal thereto. The ball **55** can only move axially in the extension **27e**. An opposing member **56** is threaded to the end **27f** of the extension **27e** and has a spherical or other arcuate surface **56a** facing the ball **55**. Between the ball **55** and the surface **56** is a lever part **57a** of a connector **57** having an arm **57b** that is attached to a central shaft **58** of the diaphragm **23**. The transverse cross-section of the lever part **57a** advantageously, but not necessarily, is rectangular as shown in FIGS. **3** and **5**. This lever **57a** comprises the middle of a rod **57c** that extends through opposed, longitudinal slots **27g** (FIG. **4**) in the cylindrical extension **27e**.

When the diaphragm **23** is at rest (as in FIG. **3**) there is point contact between the lever **57a** and both the ball **55** and the spherical surface **56a** along the axis of the housing extension **27e**. The force of the spring **51**, exerted via the pin **43** and the ball **55**, maintains this contact. During inhalation the diaphragm **23** and its shaft **58** are displaced in the direction of the arrow **25**. This causes the rod **57c** to rotate in the slots **27g** so that the lever **57a** pivots about the surface **56a** of the member **56**.

As shown in FIG. **5**, the contact points with the lever **57a** now are displaced away from the axis of the housing extension **27e**. Since the member **56** is fixed, the pivotal motion of the lever **57a** imparts an axial movement to the ball **55** in a direction away from the member **56**.

This motion in turn pushes the control pin **43** upward, so as to open the pilot valve **42**. For small displacement of the diaphragm **23** and concomitant small rotation of the lever **57a** there is very slight motion imparted to the ball **55** and thence to the pilot valve control pin **43**. With increasing displacement of the diaphragm **23**, an equal angular pivoting of the lever **57a** imparts a relatively larger motion to the ball **55** and hence to the control pin **43**. This is beneficial since more sensitive control is achieved at the beginning and end of the inhalation cycle when the pressure differential within the chamber **22** is very slight.

At the beginning of the inhalation cycle, the very slight displacement of the diaphragm **23** is translated into a slight opening of the pilot valve **42** which in turn causes a slight opening of the flow-controlling valve poppet **34**. Since the poppet **34** carries the pilot valve **42** with it, that pilot valve tends to close, thereby reducing the gas flow into the space **49** (FIG. **5**) and limiting the movement of the poppet **34**. If the amount of breathable gas supplied to the mouthpiece **21** does not quite satisfy the inhalation demand, the diaphragm **23** will be displaced further, so that the pilot valve **42** will open slightly more. This causes further opening of the poppet **34**, supplying additional breathable gas to the diver.

As the demand is satisfied, the pressure in the interior chamber **22** increases so that the diaphragm **23** tends to return to its rest position. The spring **51** biases the pilot valve **42** toward its closed position. The control pin **43** does not have to move far, since the open poppet **34** has moved the body of the pilot valve **42** toward the closure **42b**. When the pilot valve **42** closes, no more gas flows into the space **49**. The gas already in that region vents through the opening **44**, decreasing the pressure in the space **49** sufficiently so that the bias spring **41** will return the poppet **34** to its rest position (FIG. **3**). Thus as the inhalation demand is satisfied, the flow valve is closed.

As a result of the cooperation of the pilot valve **42** and the poppet **43**, the volume of breathable gas supplied to the diver very closely follows the inhalation demand. The pilot valve **42** in effect provides pneumatic amplification for the slight motion imparted by the diaphragm **23** and the linkage **45**. Since the pilot valve **42** is carried toward a closing position as the poppet **34** opens, there also is a negative feedback effect which adds to the linearity between inhalation demand and the supply of gas to satisfy that demand. The sensitivity and response of the regulator can be controlled by choice of the diameter of the opening **44** and by adjustment of the spring **51** force using the threaded plug **52**. The member **56** can be adjusted to establish the amount of diaphragm **23** displacement required to begin opening of the pilot valve **42**.

In the embodiment shown, the diaphragm **23** is configured also to operate as a flap-valve facilitating the exhaust of exhaled gases. During exhalation the increased pressure in the chamber **22** forces the outer edge **23***a* of the diaphragm **23** away from the annular ring **18***c* that normally supports the diaphragm periphery. The exhaled gases are expelled around this periphery **23***a* and out through a slot **59** in the body portion **18***b*.

The diaphragm **23** itself may be secured at its center by a member **60** into which the shaft **58** is threaded. This member **60** is mounted for reciprocation in an appropriate structure **61** that is attached to the regulator body **18** by screws **62**.

FIGS. **6** and **7** show alternative pilot valve structures for the inventive demand regulator. In FIG. **6**, the pilot valve **42'** consists of a valve shaft **63** that reciprocates in the space **46'**. This space **46'** is provided with a tapered lower region **46***a'* that serves as the valve seat. The valve shaft **63** includes a protruding nose **63***a* which serves as the control pin that contacts the ball **55** in the linkage **45**. A tapered section **63***b* of the shaft **63** is provided with an O-ring **64** that rests on the valve seat region **46***a'* to close the pilot valve **42'**. The bottom surface of the poppet **34'** includes a recess **65** in communication with the lower end of the space **46'**. When the pilot valve **42'** is opened, breathable gas is admitted to this recess **65** to force open the poppet **34'**. Such a recess also could be provided in the poppet **34** of FIGS. **3** and **5**.

FIG. **7** shows a similar structure in which the pilot valve **42"** includes a valve shaft **66** that has an O-ring **67** about its lower periphery. This O-ring **67** is held in place by a retaining member **68** and functions to open and close against a valve seat **46***a"* consisting of a shoulder in the space **46"**. A protruding nose **66***a* of the shaft **66** extends through the opening **44** into contact with the ball **55**, so that diaphragm **23** motion will be imparted via the nose **66***a* to open the valve **42"**.

In the illustrated embodiments, the poppet **34** is balanced. That is, the supplied gas in the annular space **29** exerts a force equally in opposite directions against the lower flange **34***a* and the upper shoulder **34***c*. However, this is not necessary, and an unbalanced arrangement could be employed, to bias the poppet closed. This could eliminate the need for the bias spring **41**. Similarly, the pilot valve shaft **63, 66** of FIGS. **6** or **7** could be unbalanced to eliminate or reduce the bias requirements of the spring **51**.

In the preferred embodiment of FIGS. **8, 9** and **10**, the scuba regulator **70** also employs pneumatic amplification and feedback to achieve low inhalation effort and close relationship between demand and supply of breathable gas. Like the above described embodiments, the regulator **70** has a valve assembly **71** including a unitary valve poppet **72** that controls gas flow to the diver and that carries the pilot valve **73** in a manner which provides both pneumatic amplification and feedback.

The regulator body **74** generally is configured like the body **18** and includes one or two inlet ports **75** and an outlet port **76** which receives the mouthpiece **14**. The valve poppet **72** is situated within a generally cylindrical valve housing **77** mounted within the interior chamber **78** of the body **74**. A tubular member **79** helps support the valve housing **77** and provides flow communication from the inlet port **75** via a channel **80** to a generally annular inlet chamber **81** within the housing **77**.

Air flow from the chamber **81** to the diver is controlled by a main valve **82** consisting of an annular valve seat **83** formed in the housing **77** and a valve closure

consisting of an O-ring **84** retained in a shoulder of valve poppet **72**. The valve poppet **72** is axially moveable within the housing **77**. When it is moved away from the valve seat **83** as shown in FIG. **10**, breathable gas is supplied from the inlet port **74** via the channel **80**, the chamber **81**, the annular space between the valve seat **83** and the valve closure ring **84**, an annular chamber **85** surrounding an end of the poppet **72**, an aspirator opening **86** and the outlet port **76**.

Normally the main valve **82** is held closed (FIG. **8**) by a bias spring **88** situated in the chamber **85** between a closed end **74***a* of the body **74** and an annular shoulder section **72***a* of the valve poppet **72**. The spring force biases the O-ring **84** into flow-blocking contact with the valve seat **83**. The O-ring **84** itself is situated in a groove **89** formed in the shoulder section **72***a* and retained therein by an annular tapered flange section **72***b*. Only a portion, typically about 90°, of the O-ring **84** is exposed. The valve seat **83** is of generally pointed cross-section, and comes to an apex at about the center of the exposed portion of the O-ring **84**.

Movement of the valve poppet **72** is controlled by the pilot valve **73** which itself is linked to a diaphragm **91** that senses pressure in the chamber **78**. The pilot valve **73** is situated within a reduced diameter valve poppet section **72***c* (FIG. **10**) that defines the inner wall of the inlet chamber **81**. One or more lateral ports **92** extend from the chamber **81** through the poppet section **72***c*. These ports lead to an annular space within the poppet section **72***c* containing an annular tapered valve seat **93** for the pilot valve **73**.

Cooperating with the valve seat **93** is an O-ring **94** that serves as the valve closure. Behind the O-ring **94** is a generally disc-shaped backup member **95** that can move axially within a chamber **96** formed within the valve poppet **72**. One end **96***a* of the chamber **96** includes a central aperture **97** within which the O-ring **94** is situated. This aperture **97** opens into the lateral ports **92** so that a portion of the O-ring **94** is exposed to the high gas pressure from the inlet chamber **81**. However, in the rest position of FIG. **8**, the O-ring **94** is biased into flow-blocking contact with the valve seat **93** by a spring **98** situated within the chamber **96**.

The outer wall of the inlet chamber **81** is defined by a cylindrical bore **77***a* within the valve housing **77** having a closed end **77***b*. Adjacent this closed end, the valve poppet **72** has a pair of axially spaced, enlarged diameter flanges **72***d*, **72***e* that form a channel **99** to retain an O-ring **100**. This O-ring **100** is in sealing contact with the bore **77***a* so as to prevent the flow of gas from the inlet chamber **81** to the space **102** between the end **72***f* of the valve poppet **72** and the closed end **77***b* of the bore **77***a*.

An axial bore **103** extends into the valve poppet **72** from the end **72***f* thereof and communicates with the interior of the pilot valve seat **93**. When the pilot valve **73** is open, as shown in FIG. **9**, gas at the supply pressure flows through the ports **92**, past the space between the valve seat **93** and the O-ring **94**, through the bore **103** into the space **102**. The resultant gas pressure exerted on the poppet end **72***f* causes the valve poppet **72** to move toward the flow-open position, shown in FIG. **10**, in which breathable gas is supplied to the diver.

The pilot valve **73** is opened in response to inhalation demand as sensed by the diaphragm **91**. Movement of the diaphragm **91** is transmitted to the valve **73** by means of a linkage **45'**, similar to the linkage **45** described above, that imparts axial movement to a ball **55'** that is constrained within a chamber **105** in the housing **77** on the other side of the bore end **77b**. An axial pin **106** extends between the ball **55'** and the O-ring backup disc **95**. This pin **106** passes through a slight clearance opening **107** in the wall between the chamber **105** and the bore end **77b**, through the bore **103**, through the center of the O-ring **94**, and abuts against the end of the backup disc **95**. Preferably the outer diameter of the pin **106** is the same as, or even slightly greater than the inner diameter of the O-ring **94**, so as to insure seating of the O-ring **94** against the opening **97**.

As the diver inhales, the pressure in the chamber **78** is reduced, causing slight movement of the diaphragm **91** in the direction of the arrow **108** (FIG. **9**). This imparts axial movement to the pin **106** via the linkage **45'** and the ball **55'** in a direction that pushes the O-ring backup disc **95** away from the pilot valve seat **93**. The pressure of the gas in the inlet chamber **81** then urges the O-ring **94** away from the seat **93**, so that gas can flow through the bore **103** into the space **102**. As a result, the valve poppet **72** moves away from the bore end **77b** into the flow-permitting position of FIG. **10**.

Pneumatic amplification thus is achieved. The diaphragm and linkage do not open the main valve **82** directly, as in regulators without pneumatic amplification. Rather, the diaphragm operates only the pilot valve **73**, which requires far less force to operate than does the main valve **82**. When the pilot valve **73** is opened, the supply gas is admitted into the sapce **102** where the gas itself provides the force necessary to open the main valve poppet **72**.

As the main valve poppet **72** begins to move toward the open position (FIG. **10**), it carries the backup disc **95** and the O-ring **94** in a direction away from the ball **55'**, so that the pin **106** no longer is abutting against the disc **95**. The spring **98** then urges the disc **95** and O-ring **94** toward the valve seat **93** so that the pilot valve tends to close. This in turn limits the extent to which the main valve poppet **72** is urged open. If the inhalation demand is satisfied, the pilot valve closes, the gas in the space **102** bleeds through the opening, and the bias spring **88** returns the main valve poppet **72** toward the closed position of FIG. **9**. In this manner, a feedback effect is achieved such that a very close relationship exists between inhalation demand and the amount of breathable gas supplied by the valve assembly **71**.

As a safety feature, a boss **110** is provided within the chamber **96** to limit the extent of travel of the O-ring backup disc **95**. A pin **111** is situated in a bore **112** that extends from the chamber **96** through the boss **110** to the chamber **85**. Should the pilot valve **73** malfunction and remain open so that the main valve poppet **72** is urged toward an extreme open position, one end of the pin **111** will abut against the inner end wall **74a** of the body **74**. Continued movement of the valve poppet **72** will cause the other end of the now stationary pin **111** to push the backup disc **95** and O-ring **94** into closed relationship with the valve seat **93**, thereby closing the pilot valve. As a result, the gas in the space **102** will bleed off through the opening **107** and the bias spring **88** will close the main valve poppet **72**.

Intending to claim all novel, useful and unobivious features shown or described, I make the following claims:

1. A demand regulator for use with a breathing apparatus comprising:
 - a regulator body having an interior chamber, a mouthpiece outlet communicating from said interior chamber, a diaphragm responsive to pressure within said interior chamber, an inlet port, an annular support member within said interior chamber, and a tublar member communicating between said inlet port and said support member,
 - a generally cylindrical valve housing removably supported within said annular support member, said housing having an open end and a substantially closed end,
 - a poppet movably mounted within said valve housing, said inlet port communicating via said tubular member and an inlet opening in said valve housing to a space between said valve housing and said poppet, the flow of breathable gas from said inlet port to said interior chamber being controlled by a flow valve formed by said poppet and a portion of said housing, said poppet being biased to a position closing said flow valve, and
 - a normally closed pilot valve mounted within said poppet for movement therewith, and controlling the flow of gas from said space via a flow channel through said poppet to a position between an end of said poppet and said substantially closed end of said housing, the force of said gas admitted to said position being exerted directly on said poppet end to cause displacement of said poppet against said bias, thereby opening said flow valve, said pilot valve being linked to said diaphragm and being mounted so that said pilot valve is urged closed as said poppet is displaced in the flow valve opening direction.

2. A demand regulator according to claim **1** wherein;
 - said valve housing and said poppet each are generally cylindrical,
 - said poppet has a central annular region of reduced diameter, said space being annular and defined by said poppet central region and the interior wall of said valve housing, there being a passageway for breathable gas from said inlet into said annular space, and wherein
 - said flow valve is defined by an annular edge of said valve housing at said open end in cooperation with a sealing member mounted on a shoulder of said poppet.

3. A demand regulator according to claim **2** wherein said pilot valve is situated in said flow channel which extends through said poppet from said space to said position between said poppet end and said housing closed end, said pilot valve comprising;
 - a control member extending through a small relief opening in said housing substantially closed end, said diaphragm being operatively connected to said control member by a linkage,
 - a valve seat and a valve closure member situated within said poppet and cooperating to control the flow of gas through said flow channel, said control member being mounted to urge said valve closure away from said valve seat in response to diaphragm displacement, and
 - a bias spring situated completely within said poppet urging said valve closure toward said valve seat, so that as said poppet moves toward said flow valve opening position said valve closure member and said valve seat are carried in a direction away from said control member and linkage, whereby said bias spring urges said pilot valve closed.

4. A demand regulator according to claim **3** wherein said flow channel comprises an axial bore extending

partway through said poppet from said poppet end, and at least one lateral port extending from said axial bore to the exterior of said poppet central region, wherein a valve seat is situated within said flow channel, wherein said valve closure member is situated in a chamber interior of said poppet and communicating to said axial bore, said closure member comprising a sealing ring and a rigid backup disc therefor, said bias spring being situated within said poppet chamber and cooperating with said backup disc so as to urge said sealing ring into flow-blocking contact with said valve seat, said control member comprising a pin extending coaxially through said small opening, through said axial bore and through the center of said sealing ring and abutting against said backup disc.

5. A pneumatically assisted demand valve for a scuba regulator second stage, said second stage having a body including an inlet port to which breathable gas is supplied from the regulator first stage, and a valve support structure within said body including a support ring and a tubular member ridigly connecting said ring to said body, said valve comprising:

a flow control valve having a relatively stationary housing that is removably mounted within said support ring, said housing having an inlet chamber therein to which breathable gas is supplied via said inlet port and said tubular member, said inlet chamber having an open end forming a valve seat and a closed end, said flow control valve also having a relatively movable poppet situated for reciprocation within said inlet chamber and having a portion that cooperates with said valve seat to block or open a flow path for breathable gas from the regulator first stage past the inlet chamber open end to the mouthpiece, said poppet being biased toward the flow blocking position in which said portion closes said inlet chamber open end, said poppet having sealing means for preventing the flow of breathable gas from said regulator first stage to a space between said poppet and the closed end of said inlet chamber, and

a pilot valve mounted within and carried by said poppet for controllably admitting input breathable gas through a channel within said poppet to said space between said poppet and said inlet chamber closed end so that the pressure of said admitted gas urges movement of said poppet against said bias toward the open flow position, said pilot valve comprising;

a pilot valve seat formed as an integral part of said poppet,

a closure within said poppet, and

bias means comprising a spring carried completely within said poppet for biasing said closure against said pilot valve seat so as to block the flow of input breathable gas into said space via said channel, said closure being opened by movement away from said pilot valve seat in a direction the same as opening movement of said poppet, said spring urging said closure back toward said pilot valve seat during opening movement of said poppet.

6. A demand valve according to claim **5** wherein said regulator second stage has a mouthpiece and a pressure sensing diaphragm, said valve further comprising a control pin extending from said closure through said channel and projecting externally of said valve through a hole in said inlet chamber closed end, there being a linkage connecting said diaphragm to said control pin to cause movement thereof in the direction urging said closure away from said valve seat when inhalation through said mouthpiece is sensed by said diaphragm, the resultant flow-opening movement of said poppet in the same direction causing said pilot valve to be carried away from said linkage, so that said bias means urges said closure back toward said pilot valve seat, thereby implementing negative feedback in the demand valve operation.

7. A demand valve according to claim **5** wherein said housing includes an inlet opening aligned with said tubular member to provide an input flow path for breathable gas from said first stage via said inlet port, said tubular member and said aligned inlet opening into said inlet chamber, and further including a second spring mounted between said poppet and said body to bias said poppet toward said flow blocking position.

8. A demand valve according to claim **7** wherein said body has a removable end cap, said valve housing, poppet and pilot valve being insertable as a unitary assembly through the end of said body and into said support ring when said end cap is removed, said second spring being mounted between said poppet and said end cap, there being a skirt extending from said end cap to cover the portion of said poppet extending from said housing to form an outlet chamber for breathable gas from said flow control valve, said skirt having an aspirator opening through which said breathable gas flows to said mouthpiece.

* * * * *