

[54] UNDERWATER BREATHING APPARATUS

3,370,585 2/1968 O'Neill..... 128/142.2
3,402,711 9/1968 Emerson..... 128/142.2

[75] Inventor: Wilbur J. O'Neill, Severna Park, Md.

[73] Assignee: Westinghouse Electric Corporation, Pittsburgh, Pa.

Primary Examiner—Richard A. Gaudet

Assistant Examiner—G. F. Dunne

Attorney, Agent, or Firm—D. Schron

[22] Filed: June 12, 1969

[21] Appl. No.: 832,675

[52] U.S. Cl..... 128/142; 128/202

[51] Int. Cl..... A62b 7/00

[58] Field of Search 128/142, 202, 142.2, 142.3, 128/142.4, 142.5, 147; 9/32, 342, 341, 340, 337

[56] **References Cited**

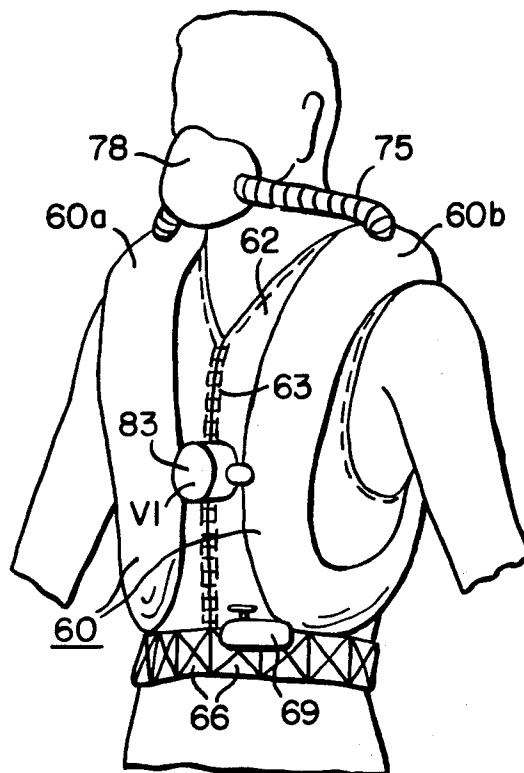
UNITED STATES PATENTS

3,129,707 4/1964 Becker et al..... 128/142.2
3,266,489 8/1966 Williams..... 128/142

[57] **ABSTRACT**

Breathing apparatus including first and second toroidal flexible breathing bags, each positioned over a diver's shoulder and extending down to the diver's waist area. The breathing bags are interconnected and carbon dioxide absorbent means and gas admission means are provided. First and second exhaust valves connected to one of the breathing bags are positioned on opposite sides of the diver and lie on a line passing through the vicinity of the centroid of lung pressure.

12 Claims, 27 Drawing Figures



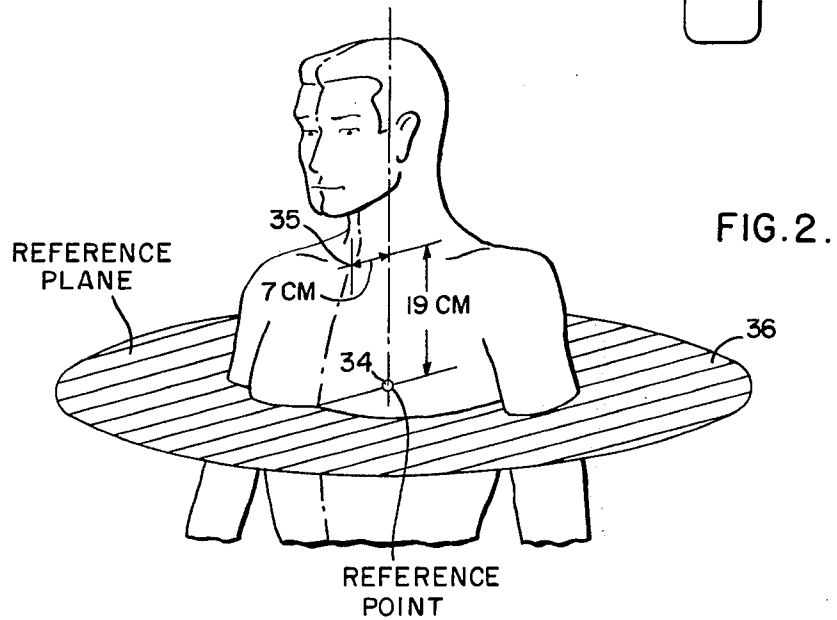
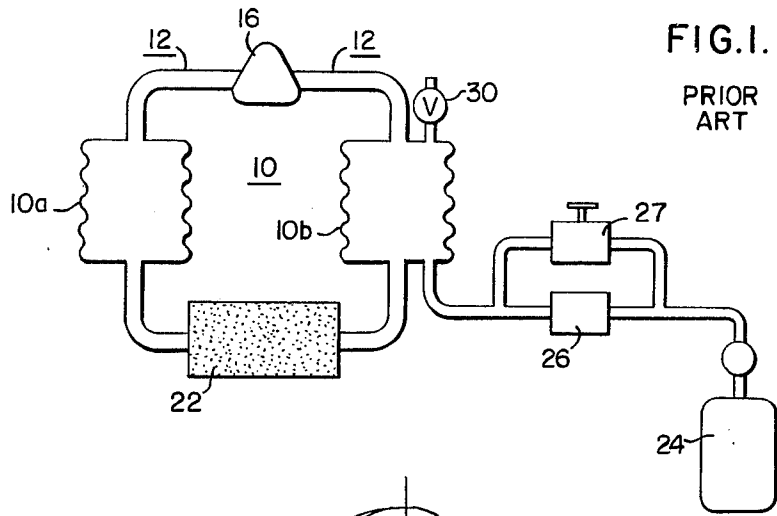


FIG. 2A.

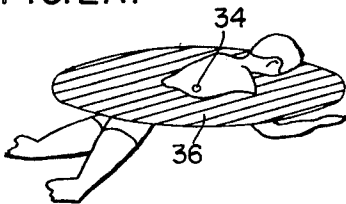


FIG. 2B.

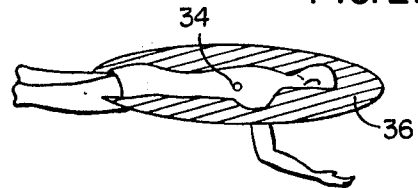


FIG. 2C.

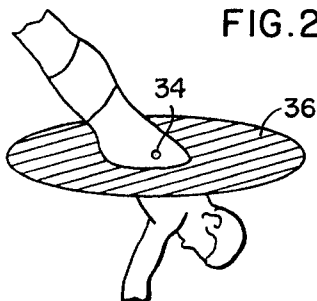
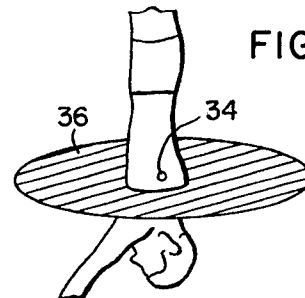
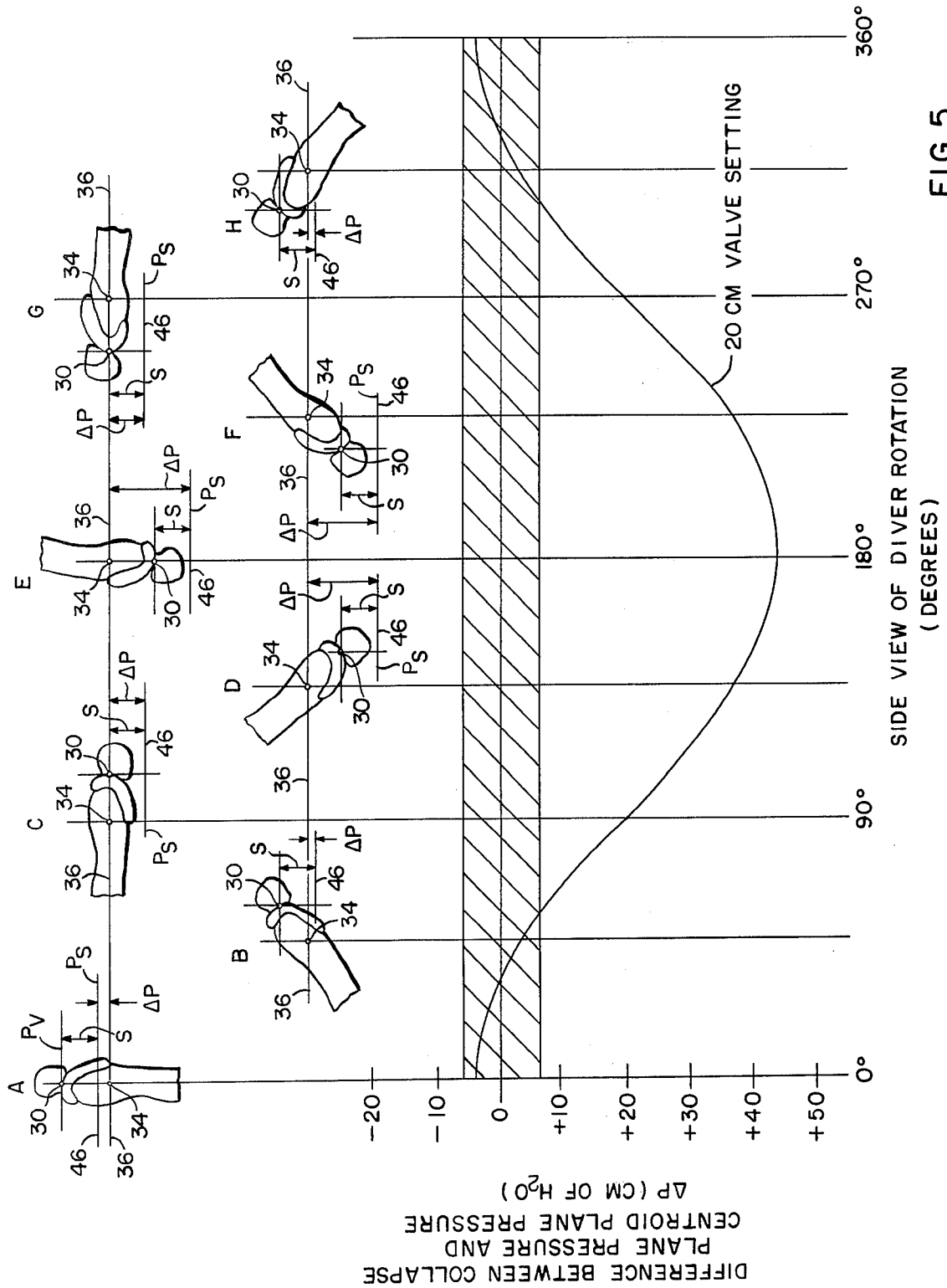
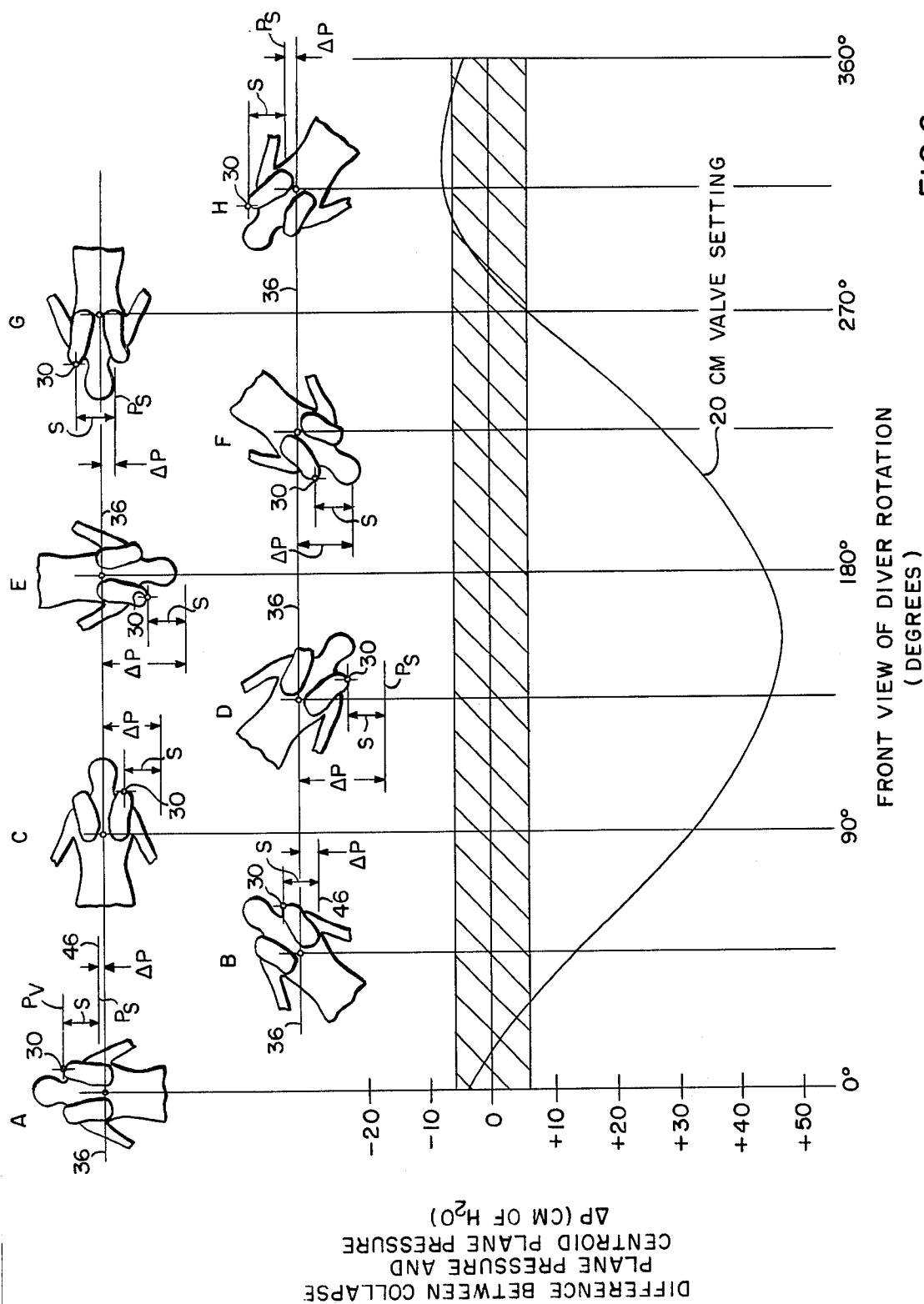


FIG. 2D.







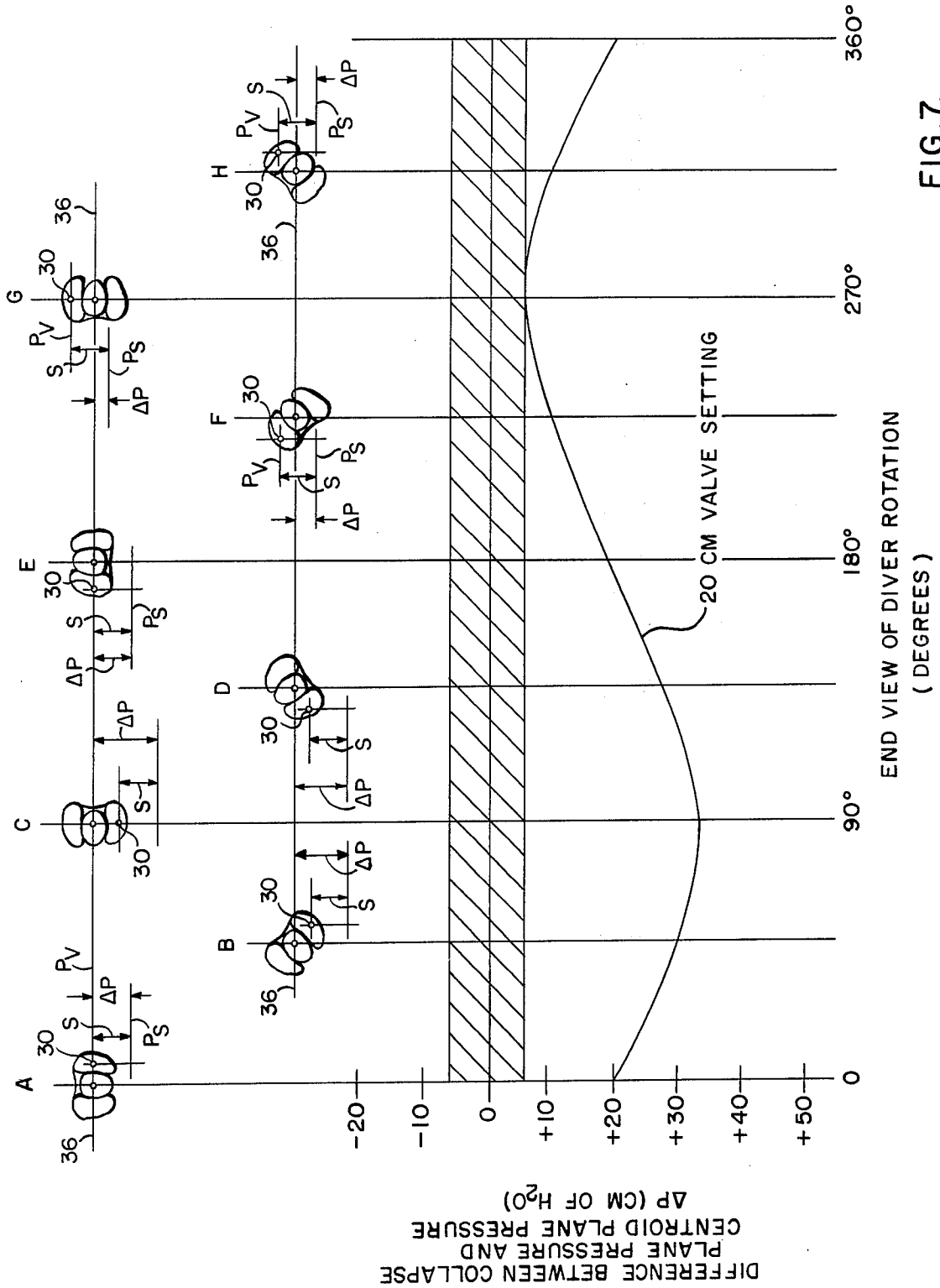


FIG. 8A.

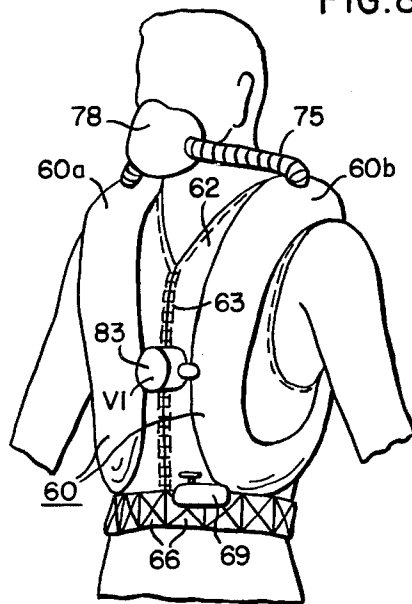


FIG. 8B.

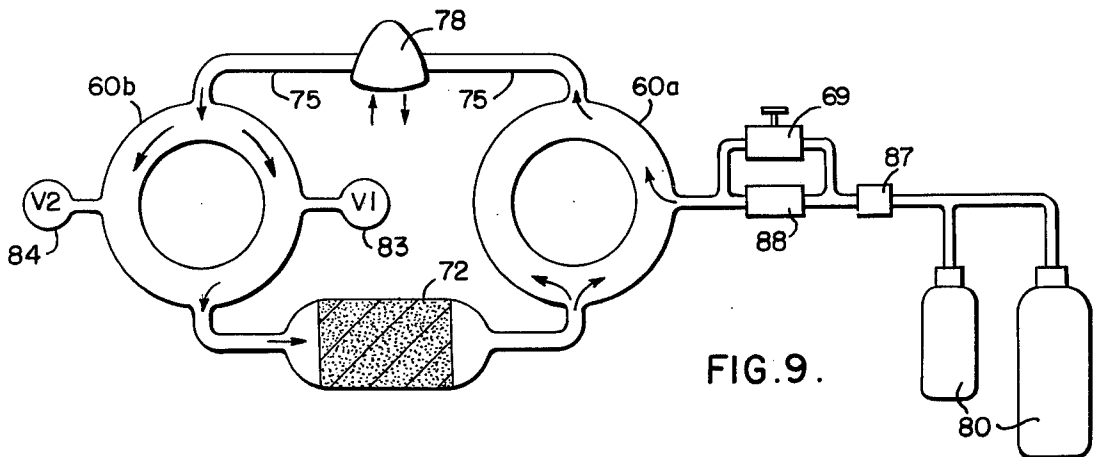
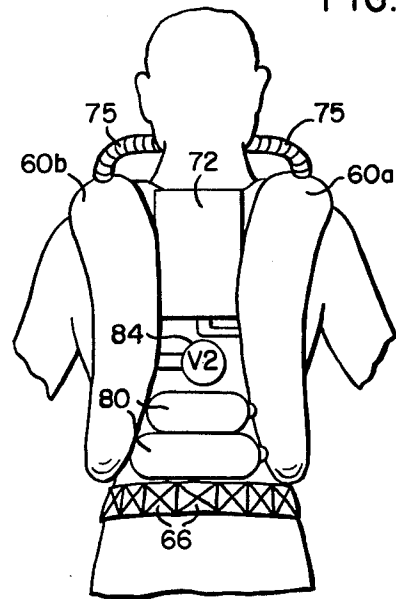


FIG. 9.

FIG. 10.

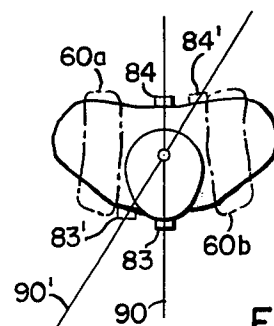
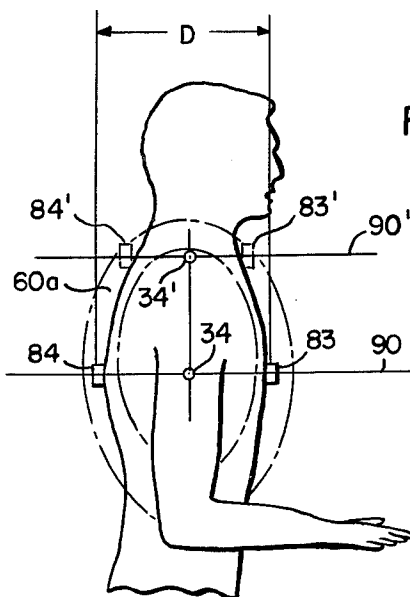


FIG. 10A.

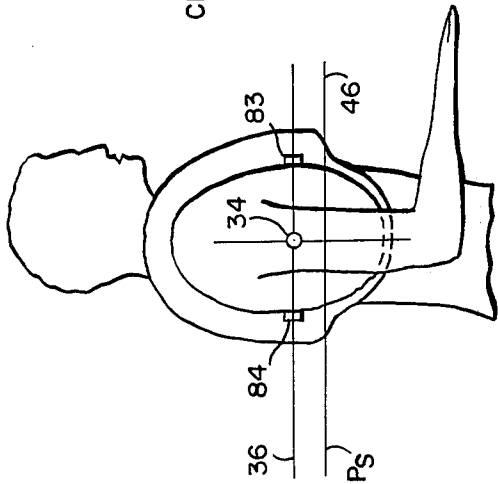


FIG. IIA.

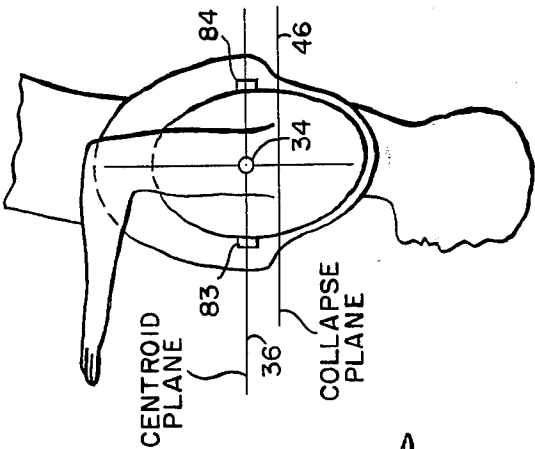


FIG. IIB.

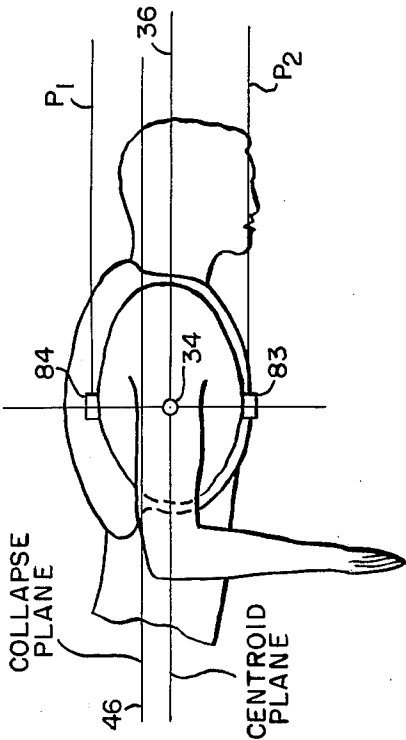
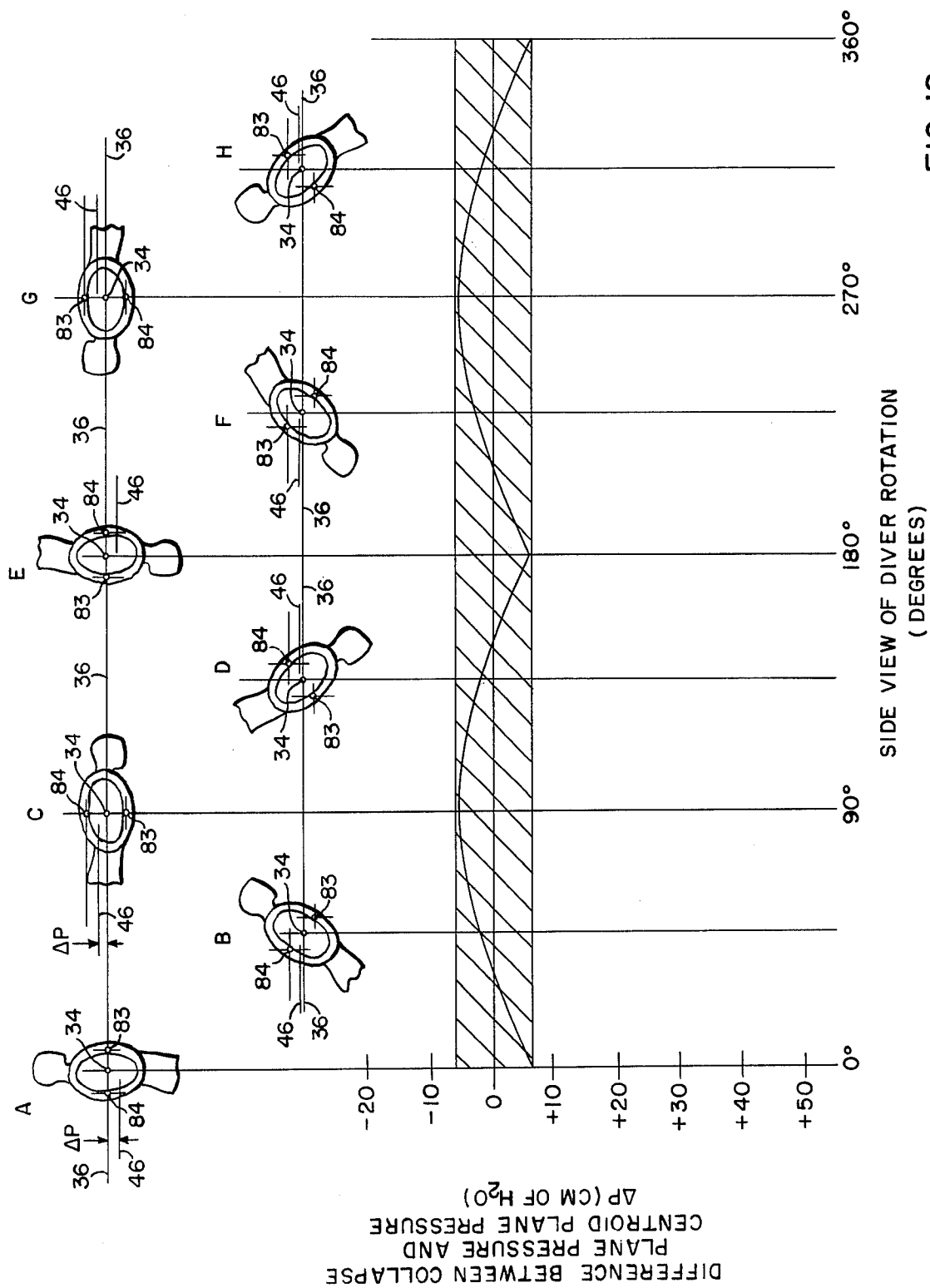


FIG. IIC.



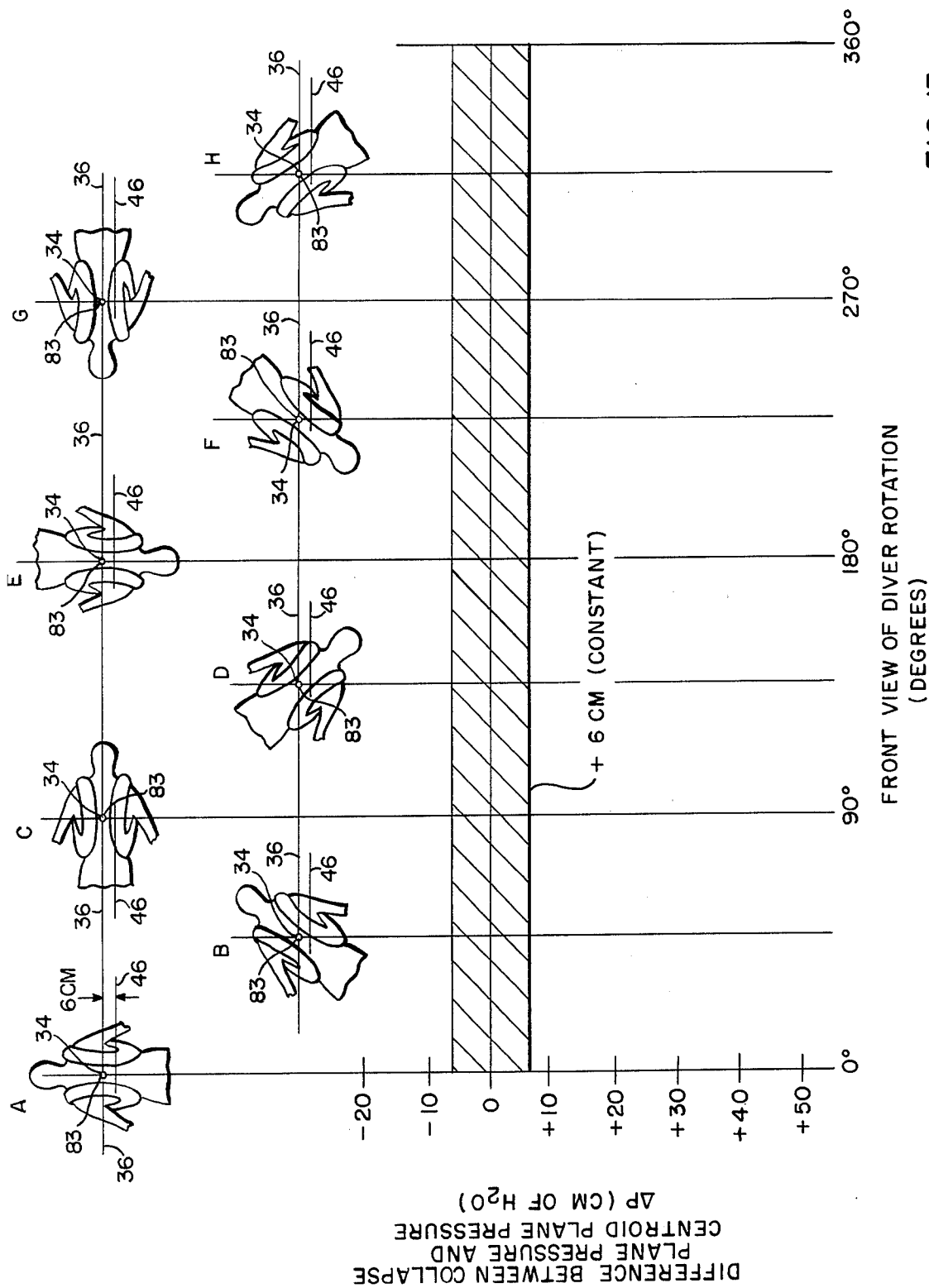
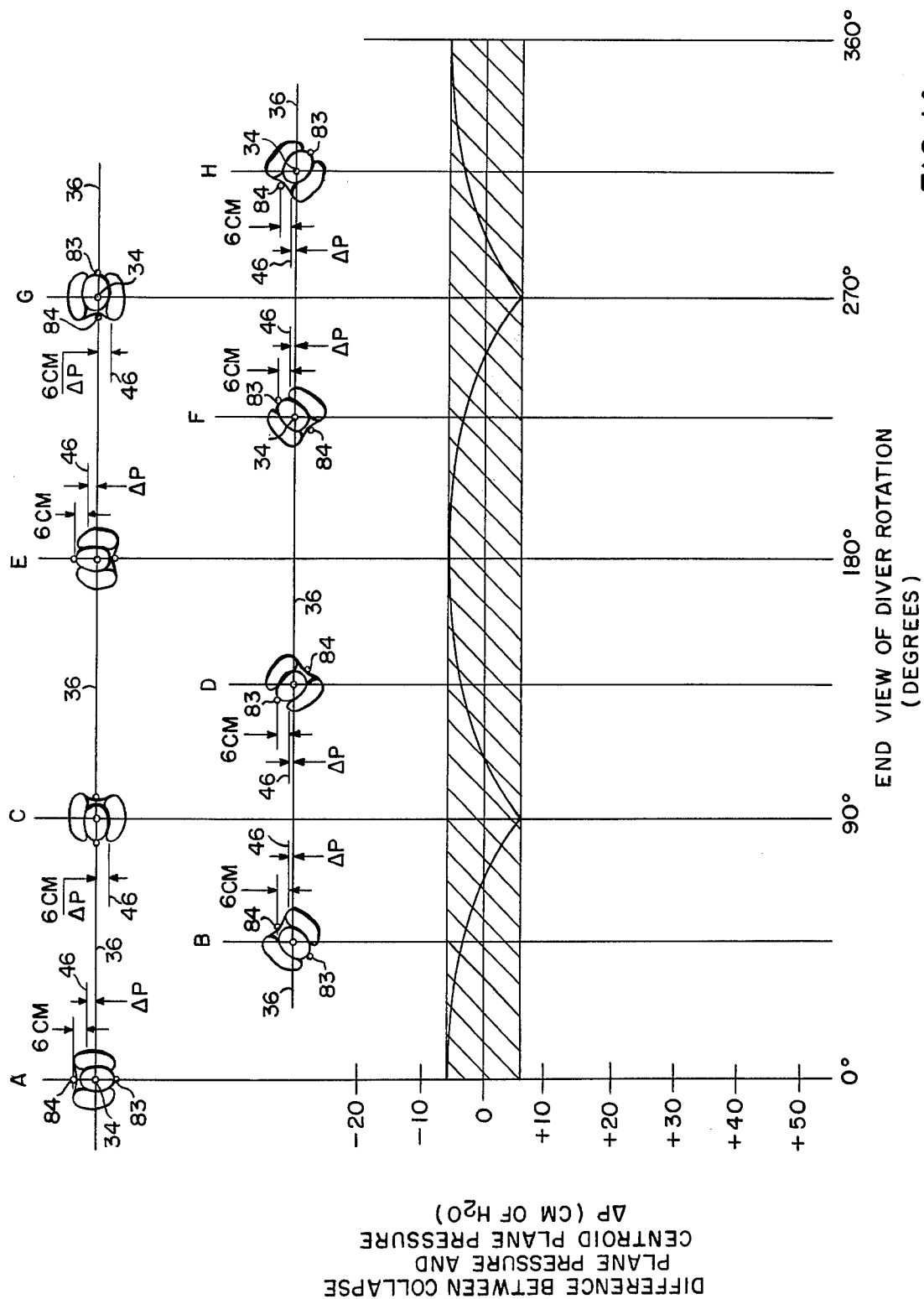
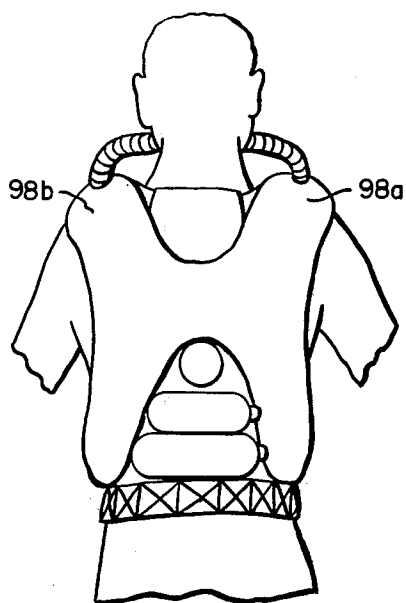
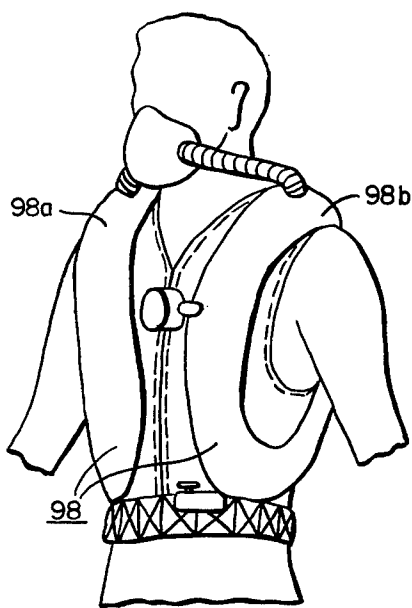
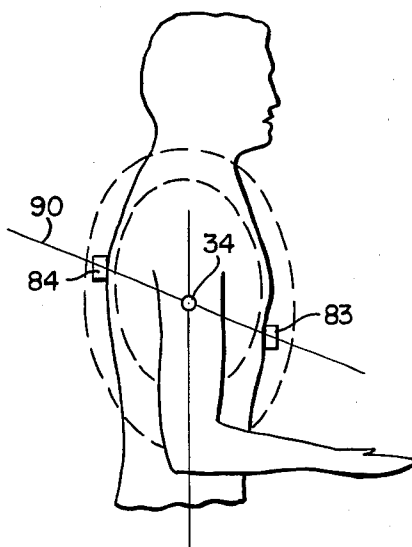


FIG. 13.





UNDERWATER BREATHING APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention:

Breathing apparatus utilizing flexible breathing bags.

2. Description of the Prior Art:

In the field of diving equipment there is a class of underwater breathing apparatus which utilizes a flexible breathing chamber into which a breathable gas is admitted. A carbon dioxide absorbent is included in the breathing system and the diver inhales from and exhales to the breathing chamber which is generally divided into an inhalation and an exhalation section.

An exhaust valve is connected to the breathing chamber and will open when the pressure within the breathing system exceeds a predetermined value. This type of underwater breathing apparatus is known to be quite diver position sensitive and causes large ranges of undesirable inspiratory or expiratory effort. For underwater work it is absolutely required to conserve as much as possible of the diver's total expendable energy so that it may be fully applied toward his specific task, or countering an emergency. The increasing inspiratory or expiratory effort when the diver is in an other than upright position causes unnecessary work for the diver and tends to exhaust him earlier than would be the case with a system requiring less breathing effort. In addition, large inspiratory or expiratory pressures inhibit the proper cleansing of carbon dioxide from his lungs.

It is therefore an object of the present invention to provide underwater breathing apparatus having a flexible breathing chamber, and which apparatus maintains the pressure of breathable gas in the system within a range for diver comfort for any positional orientation of the diver.

SUMMARY OF THE INVENTION

Briefly, underwater breathing apparatus is provided which includes a flexible breathing chamber means having first and second interconnected sections. When worn by a diver the flexible breathing chamber means extends above and below the centroid of lung pressure and in front of and in back of the diver. In the preferred embodiment each of the first and second sections of the breathing chamber means has an available gas volume substantially defining a closed loop or toroid with a first section around the other shoulder of the diver and the other section around the other shoulder of the diver and extending to approximately the waist area.

The first and second sections are interconnected via carbon dioxide absorbent means and passageway means are provided for the diver to be communicative with the breathing chamber means.

Valving means are provided and includes first and second exhaust valves connected to the breathing chamber means and positioned on opposite sides of the diver along a line which passes approximately through the vicinity of the centroid of lung pressure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram illustrating a typical underwater breathing apparatus utilizing breathing bags;

FIG. 2 is a view of a diver illustrating the centroid of lung pressure and the plane passing through that centroid;

FIGS. 2A to 2D illustrate the centroid plane in relation to various diver orientations;

FIGS. 3A through 3C illustrate breathing bag apparatus of the prior art and various pressure considerations;

FIG. 4 illustrates a typical exhaust valve in sectional view;

FIGS. 5, 6, and 7 are curves illustrating breathing system pressure relative to the pressure at the lung centroid for various diver orientations and with the prior art apparatus as in FIG. 3A;

FIG. 8A is a three-quarter front view and FIG. 8B is a rear view of a preferred embodiment of the present invention;

FIG. 9 is a schematic of the preferred embodiment; FIGS. 10 and 10a illustrate the valving arrangement of the preferred embodiment in relation to the centroid of lung pressure;

FIGS. 11A through 11C illustrate breathing bag collapse with respect to three diver orientations;

FIGS. 12 to 14 are similar to FIGS. 5 to 7 and show pressure difference with the preferred embodiment;

FIG. 15 illustrates an alternative valving arrangement; and

FIGS. 16a and 16b illustrate a modified arrangement of breathing bags.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, there is illustrated a typical prior art underwater breathing apparatus commonly known as a semi-closed system.

The apparatus includes a flexible breathing chamber means 10 having first and second sections 10a and 10b. Section 10a is commonly referred to as an inhalation bag and section 10b as an exhalation bag.

Passageway means 12 including oral-nasal mask 16 connects the inhalation bag 10a with the diver and connects the diver with the exhalation bag 10b. The flexible breathing bags are also interconnected through a carbon dioxide absorbent means 22.

A source of breathable gas 24 provides a breathable gas to the breathing bags, by connection for example to exhalation bag 10b, by means of an arrangement including a flow orifice 26 which governs the flow rate of gas into the system, and a purge valve 27 for quickly admitting large quantities of gas to the system when activated by the diver.

Exhaust valve 30 is connected to breathing bag 10b and when the pressure in the system, as evidenced by the pressure in exhalation bag 10b, exceeds the ambient pressure at the valve 30 by a predetermined amount, the valve 30 will open.

When breathing bags are incorporated into diving apparatus, the hydrostatic pressure upon the bags is transmitted to the gas space within the chest. Within the upper and lower limits of the external hydrostatic pressure on the chest, there is an internal pressure, conventionally referenced to an intermediate depth point in water, which is the center of pressure, herein referred to as the centroid of lung pressure. When the diver is provided with gas at this pressure, there is no net chest volume change, because the lower lobe compression and the upper lobe expansion of the lungs are balanced. This centroid of lung pressure is illustrated in FIG. 2. The centroid of lung pressure 34 is believed to be, for an average man, located as illustrated in FIG. 2, at a point approximately 19 centimeters (cm) below, and 7

cm behind suprasternal notch 35 which is the notch at the top of the sternum or breast bone. A horizontal plane passing through the centroid of lung pressure 34 is designated 36 and is herein referred to as the centroid plane.

Although the present invention will be described with respect to this centroid of lung pressure there may, upon further study, or with different diver communication means, be other points which should be matched with respect to breathing system pressure. Generically, the term "pressure centroid" will be utilized and will mean a point, referenced to a diver, the hydrostatic pressure at the depth of the point, being the most desirable breathing gas system pressure to minimize the effort required by the diver to breathe.

FIGS. 2A and 2D illustrate the constant horizontal orientation of the centroid plane 36 with respect to various diver positions.

If a breathing bag apparatus would provide breathing gas to the diver at a pressure approximating the pressure at the centroid 34, the diver would not have to breathe under the excessive positive and negative pressure conditions prevalent in most underwater breathing apparatus incorporating breathing bags. Examples of balanced, positive, and negative pressure breathing situations are illustrated in FIGS. 3A to 3C.

FIGS. 3A is a side view of a diver wearing what is commonly termed chest or front mounted breathing bags of which the right one, 10b, is shown and having an exhaust valve 30 which is a spring loaded valve with a knob or nut that can be turned to increase or decrease the pressure in the breathing bag. A simplified sectional view of a typical exhaust valve is illustrated in FIG. 4 to which reference is now made.

The valve 30 includes a valve housing 37 and a flexible diaphragm 38 held in position by means of retaining nut 39. The flexible diaphragm has a central aperture 40 and the diaphragm is forced down onto valve seat 41 by means of spring 42, the construction defining annular chamber 43.

The upper part of the spring 42 bears against spring retainer 50 through which passes rod 51 threadedly engaged with valve seat 41. Adjusting nut 52 is provided in order to vary the spring pressure.

The annular chamber 43 is connected to the breathing bag and the pressure in it will be the same as the system pressure, herein designated P_s . If P_r is the average ambient water pressure acting on the flexible diaphragm to close the valve, then $P_s = P_r + S$, where S is the equivalent pressure contributed by the spring tending to close the valve. For any P_r , the greater the valve of S (that is, the greater the nut 41 is tightened down), the greater the pressure will be in the breathing system.

When the pressure P_s in the breathing system attains a value just greater than $P_r + S$, the flexible diaphragm 38 is forced off of the valve seat 41 and breathing gas escapes to the surrounding water medium through aperture 40. The escape of gas will continue until the pressure within the breathing system reduces to a value equal to the ambient pressure P_r plus the spring setting S . Referring once again to FIG. 3A, there is additionally shown the centroid of lung pressure 34 and the horizontal centroid plane 36 passing through it and through a lung 44 shown in outline.

In addition to the centroid plane 36, another plane must be considered in the design of such breathing ap-

paratus and that plane is the collapse plane. The collapse plane as described herein is the horizontal plane, the pressure at which equals the system pressure. The collapse plane, which is always horizontal, may separate the inflated and deflated portions of the breathing bag or may be positioned below the breathing bag depending upon valve setting. The collapse plane illustrated in the figures is pictured at a point in the breathing cycle just at the end of expiration and the beginning of inspiration when it is assumed that the exhaust valve has just been opened and that the bag is at maximum inflation as determined by the exhaust valve setting.

If, for the diver illustrated in FIG. 3A, the valve 30 is set at 24 cm, that is, the spring setting S is equivalent to a pressure equal to 24 cm of water, then when the pressure within the breathing bag 10b reaches a value of the ambient water pressure on the valve plus an additional 24 cm of water, the valve will open to maintain the system pressure at $P_r + 24$. For the diver's dimensions the pressure thus established in the breathing system is equivalent to a pressure at a point 24 cm deeper than the valve 30 and is equivalent to the pressure at the centroid plane 36 acting on the centroid of lung pressure 34. A collapse plane 46 is therefore established and is coincident with the centroid plane 36. The portion of the breathing bag 10b above the collapse plane 46 is inflated and the portion below it is deflated.

Since the pressure within the breathing system is equal to the pressure at the centroid plane 36, the diver will experience no difficulty in breathing and the situation is referred to as balance pressure breathing. Ambient water pressure is transmitted to the lungs and since the pressure within the lungs is the same as the breathing system pressure within the bag 10b, the portion of the lungs 44 above the centroid plane 36 will have a pressure differential thereacross directed outwardly and the pressure differential thereacross below the centroid plane 36 directed inwardly, as depicted by the arrows.

FIG. 3B illustrates an example of negative pressure breathing. The setting of valve 30 is equivalent to 12 cm of water to thereby establish the system pressure P_s within the bag 10b at a value equal to the pressure 12 cm below the valve 30. The collapse plane 46 is thus established at this point and it is seen that the pressure within the system as determined by the collapse plane is less than the pressure acting on the centroid 34 by an amount equivalent to 12 cm of water. In the vicinity of the diver's lungs, the hydrostatic pressure outside and below the collapse plane 46 is greater than the pressure within the lungs, the lungs being at a pressure equal to the pressure at the collapse plane 46. The diver therefore must provide extra muscular energy to pull the breathing gas in; the pressure difference is acting inwardly over a major portion of the lungs, as depicted by the arrows.

FIG. 3C illustrates an example of positive pressure breathing. The exhaust valve 30 is set to 34 cm thereby establishing a system pressure P_s equal to the ambient pressure at the valve P_r plus an additional 34 cm of water thereby defining the collapse plane 46 at a position 10 cm below the centroid plane 36. Since the pressure P_s within the breathing bag 10b is greater than the ambient water pressure acting on the lungs, the diver will experience no difficulty in inhaling, however extra energy is required to exhale against the increased positive pressure encountered during the latter part of ex-

halation. As depicted by the arrows in lung 44 the pressure difference acts in an outward direction.

Since the system pressure is determined by the ambient pressure at the valve plus a spring pressure, the exhaust valve under water will always establish a collapse plane hydrostatically deeper than itself by a constant amount S.

Considering a piece of apparatus as in FIGS. 3A, 3B or 3C, a typical valve setting may be in the order of 20 cm. That is, the exhaust valve 30 is set to retain a pressure of 20 cm of water over ambient, which setting is approximately equivalent to a pressure of one-third pounds per square inch. This setting produces a collapse plane 20 cm below the valve location and 4 cm above the centroid plane. The pressure in the breathing system therefore is 4 cm less than the pressure exerted on the centroid of lung pressure, however, the 4 cm difference is well within a tolerable range for diver breathing comfort. This 4 cm difference will exist as long as the diver remains in a vertical position. As the diver assumes different positions the difference between the system pressure and the pressure at the centroid plane varies. This situation is graphically illustrated, to an approximation, in FIGS. 5, 6, and 7 wherein the vertical scale represents the difference between the collapse plane pressure (which is the pressure in the breathing system) and the centroid plane pressure (which is the desired pressure from a physiological stand point), the vertical scale being a pressure difference ΔP in centimeters of water. The horizontal scale represents diver rotation in degrees.

In FIG. 5 the diver is rotated forwardly about an axis passing through the centroid of lung pressure. In all diver positions the system pressure P_s is always S units of pressure greater than the pressure P_c at the valve and the collapse plane 46 is always at a deeper position than the valve.

When the diver is in vertical position A (0° of rotation) the pressure P_s within the system will be 4 cm less than the pressure at the centroid plane 36, recalling that the valve setting S is 20 cm and the distance from the valve to the centroid plane is 24 cm. At position A therefore there exists a condition of negative pressure breathing, as in FIG. 3B but within approximate tolerable limits as indicated by the shaded area between ± 6 cm. Further rotation to position B, the 45° position, will lower the collapse plane 46 to a point approximately 3 cm below the centroid plane thereby increasing the system pressure to a value 3 cm greater than the pressure at the centroid plane, a condition of positive pressure breathing as in FIG. 3C but still within tolerable limits. In the 90° position C the valve lies in the centroid plane so that the system pressure is exactly 20 cm greater than the pressure at the centroid plane. Further rotation to position D at 135° , increases the degree of positive pressure breathing with the pressure difference ΔP increasing to a maximum when the valve is directly below the centroid of lung pressure as illustrated in the 180° position E. Since the valve is 24 cm deeper than the centroid of lung pressure and the valve setting is 20 cm then the difference between the system pressure and optimum pressure at the centroid plane is $24 + 20$ or 44. This curve is symmetrical about the 180° position and further diver rotation is illustrated at positions F, G and H representing respectively rotations of 225° , 270° and 315° . At 360° the diver is in the same orientation as position A.

It is seen from FIG. 5 therefore that with an initial setting for comfortable breathing in an upright position, the diver would be extremely limited in the degree of forward rotation since for rotation from about 54° to about 306° he would be experiencing positive pressure breathing outside of the tolerable range.

FIG. 6 is similar to FIG. 5 except that the diver rotation is laterally about an axis passing through the centroid of lung pressure. With a valve setting of 20 cm the diver experiences a pressure difference between the system pressure and pressure at the lung centroid ranging from approximately -10 cm to $+48$ cm. Diver positions A to H correspond to 45° increments as in FIG. 5. It is seen from FIG. 6 that for most positions of rotation an undesirable situation is presented.

If the diver in position C of FIG. 5 is rotated about a horizontal axis drawn longitudinally down his body through the centroid of lung pressure, then the curve of FIG. 7 results. 45° increments of rotation are illustrated in respective positions A to H and with a valve setting of 20 cm the diver is always outside of the tolerable range and is constantly overpressured.

The breathing apparatus of the present invention maintains system pressure very close to the pressure at the centroid plane, for any conceivable positional orientation of the diver in the water. A preferred embodiment of the apparatus is illustrated in FIGS. 8A and 8B.

The apparatus includes a flexible breathing chamber means 60 having a first section 60a and a second section 60b, each section having an available gas volume defining a closed loop and being somewhat toroidal in shape. The sections are worn around respective shoulders of the diver and extend to the vicinity of the hip area. The first section 60a may constitute an inhalation breathing bag and the second section 60b may constitute an exhalation breathing bag. The breathing bags, which may be fabricated from flexible breathing bag materials known to those skilled in the art, are fastened to a diving vest or jacket 62 having closure means 63 extending down the front thereof. Conventional weighting means 66 may be worn around the diver's waist and an easily accessible purge valve 69 is also included. Weighting means such as described and claimed in copending application Ser. No. 832,670, filed June 12, 1969, now U.S. Pat. No. 3,656,196, and assigned to the same assignee as the present invention, may also, and preferably, be used.

The breathing bags 60a and 60b are interconnected via a carbon dioxide absorbent canister 72 positioned on the back of the diver. Passageway means 75 including an oral-nasal breathing mask 78, for example, communicates the diver with the breathing bags.

A breathable gas is provided to the breathing system by means of gas supply 80 or by means of a remote supply and umbilical, in which case the gas supply 80 would be for emergency purposes.

The breathing system includes exhaust valve means in the form of first exhaust valve 83 and second exhaust valve 84 with the valves 83 and 84 being positioned on opposite sides of the diver and being connected into the breathing system, the connection being by way of example to exhalation breathing bag 60b.

FIG. 9 is a schematic diagram of the apparatus of FIGS. 8A and 8B and additionally shows gas inlet means 87 for supplying a breathable gas through flow orifice 88 to the breathing bags. The remaining components have been given the identical reference numerals

as their counterparts in FIGS. 8A and 8B. A breathable gas such as from the supply 80 is continually provided to the inhalation breathing bag 60a through the gas inlet means 87 and at a rate determined by the flow orifice 88. When the diver inhales, the gas from the inhalation breathing bag 60a is supplied to the diver via passageway means 75 and the oral-nasal mask 78. Upon exhalation, the exhaled gas passes into exhalation breathing bag 60b via the passageway means 75. The breathing bags 60a and 60b are interconnected through the carbon dioxide absorbent canister 72 and the pressure in both breathing bags is the same. Each time a diver inhales he is supplied with gas that has been treated to remove the carbon dioxide and upon exhalation when the pressure within the system exceeds a predetermined value relative to the ambient water pressure, one or both of the valves will open.

It has been stated that the valves 83 and 84 are on opposite sides of the diver. In addition, and as illustrated in FIG. 10, the valves 83 and 84 (in particular the center of aperture 40 in FIG. 4) lie on a line 90 which passes through the centroid of lung pressure 34. As a practical matter, due to equipment variation, diver size variation, and allowable tolerances, the line 90 passes through the vicinity of the centroid of lung pressure 34, for example within several centimeters of it.

Relative to the generic concept of pressure centroid, the valves would be located on either side of the diver on a line passing in the vicinity of the pressure centroid. For example if the pressure centroid has been determined to be at point 34' then the exhaust valves designated 83' and 84' lie on the line 90' passing through 34'.

FIG. 10A shows a top view of the diver and the valves 83 and 84 positioned as shown in FIGS. 8A and 8B. It is not necessary that the line 90 have the orientation as shown. For example and with reference to the valves 83' and 84' the line 90' may pass through the centroid 34' in a diagonal manner as illustrated.

The toroidal breathing bags 60a and 60b are constructed and arranged so that approximately half the internal volume or capacity of the flexible breathing chamber means 60 is above, and the remainder below the centroid plane 36. With the individual breathing bags 60a and 60b being of equal capacity, the aforementioned relationship of volume distribution around the centroid plane will be true for any diver orientation. When inflated, the breathing chamber means may typically contain 8 liters of breathing gas distributed, as governed by diver orientation, between the toroidal bags 60a and 60b.

Examining for a moment just the interconnected breathing bags by themselves, if a quantity of gas is placed into the breathing system such that the collapse plane 46 is coincident with the centroid plane 36, then for any conceivable orientation of the breathing bags in the water, that same quantity of gas is afforded a potential volume and the collapse plane remains coincident with the centroid plane. There are other factors however to be considered; gas is being supplied and used by the diver, and valves 83 and 84 are relieving the pressure within the system. The apparatus does however maintain the collapse plane 46 very close to the centroid plane 36 for all diver orientations.

If, in FIG. 10, the distance between valves 83 and 84 is D and the lung centroid 34 is approximately positioned at $D/2$, then the valves 83 and 84 should be set

to a value of $D/4$ for maximum diver comfort. If the valves are otherwise positioned an appropriate setting is chosen. By way of example if the diver's dimension from his chest to his back along line 90 is 22 cm and valves 83 and 84 are each 1 cm away from the diver than the distance D would be 24 cm and each of the valves 83 and 84 may be set to a value of 6 cm. That is, with the valves 83 and 84 having a construction and operation as previously described, the spring setting S would be 6 cm and the valve would open when the system pressure reached a pressure of 6 cm of water greater than the ambient pressure at the valve.

FIG. 11A illustrates the relationship of the collapse plane 46 to the centroid plane 36 with the diver in an upright position and with a valve setting of 6 cm. The vertical distance between the two planes is 6 cm and the system pressure is determined by the location of the collapse plane. FIG. 11A and subsequent FIGS. 11B and 11C portray the collapse plane just at the end of exhalation and at the beginning of inhalation.

If the diver in FIG. 11A rotates 180° he will be in an orientation illustrated in FIG. 11B. The two valves 83 and 84 with their respective 6 cm setting define the collapse plane 46, 6 cm below the centroid plane 36. Since the valves 83 and 84 are in the same horizontal plane in both FIGS. 11A and 11B, one or both of these valves will be operable to exhaust gas if the system pressure tries to exceed the pressure at the collapse plane. For all other diver orientations, the valve closest to the surface of the water will always be the controlling valve. By way of example, in FIG. 11C the diver is in a prone position with valve 84 directly above the centroid 34 and valve 83 directly below it. Let it be assumed that the ambient pressure at the upper valve is P_1 and the ambient pressure at the lower valve is P_2 . Since the lower valve is at a greater depth, P_2 is always greater than P_1 . The upper valve will open when the pressure within the system reaches $P_1 + S$ and the lower valve will open if the system pressure reaches $P_2 + S$. However, P_1 is less than P_2 and system pressure never reaches $P_2 + S$ since the upper valve opens when the system pressure reaches the lesser pressure $P_1 + S$ to thereby maintain a system pressure of $P_1 + S$. With a valve setting of 6 cm, in FIG. 11C the collapse plane 46 is 6 cm below valve 84 and is situated above the centroid plane 36.

In FIGS. 12, 13 and 14 there is plotted, for the preferred embodiment of the present invention, the difference between collapse plane pressure and centroid plane pressure as a function of diver rotation. The vertical and horizontal scales are the same for all three curves and are identical to those illustrated in FIGS. 5, 6 and 7.

In position A of FIG. 12, the diver is in an upright orientation and with both valves 83 and 84 set to 6 cm the collapse plane 46 is established 6 cm below the centroid plane 36. As the diver rotates forwardly about the centroid 34, valve 84 is brought to a position closer to the surface than valve 83 bringing the collapse plane 46 to a position a few centimeters above the centroid plane 36 at a diver position B. At position C the diver experiences maximum negative pressure breathing, however only to the extent of 6 cm, within the tolerable range. Continued diver rotation brings the curve back down to a positive pressure breathing situation in position E whereupon the curve is repeated for the diver rotating from the up-side-down position E to the verti-

cal position which occurs at 360°. Whereas in the prior art apparatus a maximum pressure difference of 44 cm was encountered, for the same rotation, the apparatus of the present invention allows a maximum excursion of only 6 cm.

In FIG. 13 illustrating diver rotation as described in FIG. 6, both the front and rear mounted valves remain in the same horizontal centroid plane and since the valves are set at 6 cm, the collapse plane is established 6 cm below the centroid plane for all 360° of diver rotation. For the prior art apparatus illustrated in FIG. 6, there was experienced a maximum positive pressure breathing situation to the extent of 47 or 48 cm. FIG. 13 shows the substantial improvement obtained with the present invention.

Diver rotation in FIG. 7 produced, with prior art apparatus, a maximum pressure difference of approximately 34 cm at the 90° position. FIG. 14 illustrating the same rotation with the apparatus of the present invention results in a curve with a maximum excursion of 6 cm.

The flexible breathing chamber means of the present invention extends above and below the centroid plane so that the available volume above the centroid plane is approximately equal to the available volume below it. When breathable gas is admitted to the system, there is always an inflated portion of the breathing chamber means above the centroid plane and a deflated portion below it. The junction between the inflated and deflated portions, as defined by the collapse plane, may vary from 6 cm below the centroid plane to 6 cm above it, representing approximately a range of 60 to 40 percent inflation respectively. By incorporating one or more valve means which varies its setting in accordance with positional orientation, the collapse plane may be substantially coincident with the centroid plane for all diver orientations. One such type of valving means is described and claimed in copending application Ser. No. 832,671 filed June 12, 1969, now U.S. Pat. No. 3,841,348, and assigned to the same assignee as the present invention.

The deflated portion of the breathing chamber means for one orientation may be the inflated portion for another orientation. In other words for varying diver positions there is always a place for the gas to go, other than out the exhaust valve or valves. This arrangement minimizes buoyancy changes for various changes in diver orientation. By way of example, and with reference to FIG. 7, in the 90° diver position C both bags are fully inflated. Rotation of the diver to the 270° position G would substantially deflate the lowermost breathing bag and contribute to an undesirable net buoyancy change. With the present apparatus and with reference to FIG. 14, in the 90° diver position C substantially only the uppermost breathing bag is inflated, this situation remaining unchanged in the 270° position G.

By way of further example and with reference to FIG. 6, in diver position A the breathing bags are almost entirely inflated and rotation to the 270° position G would substantially deflate the lower breathing bag. By comparison, in FIG. 13, the same amount of gas is present in the breathing chamber means in diver position A as in diver position G.

With the diver in an upright orientation the two valves 83 and 84 of FIG. 10 are on the same horizontal plane, and with equal valve settings, either one or both of the valves will exhaust. To eliminate bubbles in front

of the diver's face, the valve 84 on the diver's back may be set to a slightly lower setting than valve 83 to insure that it will open before valve 83. For equal valve settings valve 84 on the back of the diver may be made to exhaust first when the diver is in an upright orientation by means of the arrangement illustrated in FIG. 15. With equal valve settings, valve 84 is placed at a position in the water closer to the surface and therefore at a lesser ambient pressure than valve 83. The valves however still remain on line 90 which passes through the centroid 34.

The breathing bags 60a and 60b have been shown by way of example to be interconnected but independent. FIGS. 16A and 16B show a variation wherein the flexible breathing chamber means 98 includes interconnected first and second sections 98a and 98b, however they are joined as a single entity.

There has been provided therefore an underwater breathing apparatus which minimizes the difference between desired pressure and actual pressure of the breathing gas supplied, for all conceivable diver orientations in the water. In addition, the arrangement insures that the flexible breathing chamber means remains inflated to within a certain range, thus minimizing buoyancy variations and reducing diver moment problems.

Although the present invention has been described with a certain degree of particularly, it should be understood that the present disclosure has been made by way of example and that modifications and variations of the present invention are made possible in the light of the above teachings.

I claim as my invention:

1. Underwater breathing apparatus for a diver, comprising:
 - A. flexible breathing chamber means;
 - B. gas inlet means for supplying a breathable gas to said breathing chamber means;
 - C. exhaust valve means connected to said flexible breathing chamber means;
 - D. said flexible breathing chamber means being constructed and arranged, and said exhaust valve means being operably positioned so that there is always an inflated portion and a deflated portion of said flexible breathing chamber means for every diver orientation in the water; and
 - E. said inflated portion occupying approximately 40-60 percent of the total available breathing chamber means volume.
2. Underwater breathing apparatus for a diver, comprising:
 - A. flexible breathing chamber means adapted to be worn by a diver;
 - B. gas inlet means for supplying a breathable gas to said flexible breathing means;
 - C. passageway means for communicating said flexible breathing chamber means with said diver;
 - D. said flexible breathing chamber means having a front volumetric portion and a back volumetric portion for said gas,
 - E. said front and back volumetric portions being communicative with one another and being approximately equal and being approximately equal above and below the diver's pressure centroid plane.
3. Apparatus according to claim 2 which includes;

11

12

- A. first and second pressure exhaust valves located diametrically opposed on said breathing chamber means whereby the pressure of said breathing chamber will be equal to that of the diver's internal pressure centroid. 5
4. Underwater breathing apparatus for a diver, comprising:
- A. flexible breathing chamber means having first and second interconnected sections;
- B. each said section substantially in the form of a closed loop; 10
- C. gas inlet means for supplying a breathable gas to said flexible breathing chamber means;
- D. passageway means connected to said flexible breathing chamber means for communication with said diver; 15
- E. first and second exhaust valves connected to said flexible breathing chamber means and positioned on a line adapted to pass through the diver in the vicinity of the diver's pressure centroid. 20
5. Apparatus according to claim 4 wherein:
- A. each section of the flexible breathing chamber means is adapted to be looped over a respective shoulder of the diver.
6. Apparatus according to claim 5 wherein: 25
- A. each section of the flexible breathing chamber means is adapted to extend down to approximately the diver's waist area.
7. Apparatus according to claim 4 wherein: 30
- A. the first and second exhaust valves are connected to the same section of the flexible breathing chamber means.
8. Apparatus according to claim 4 wherein: 35
- A. each exhaust valve is settable to retain a certain pressure over ambient; and
- B. both exhaust valves are set to substantially the same setting.
9. Apparatus according to claim 4 wherein: 40
- A. each exhaust valve is settable to retain a certain pressure over ambient; and
- B. the first exhaust is adapted to be positioned on the front of the diver,
- C. the second valve is adapted to be positioned on the back of the diver; and wherein 45
- D. the first exhaust valve has a higher setting than the second exhaust valve to eliminate exhaust bubbles in front of the diver's face when in an upright orientation in the water.
10. Apparatus according to claim 4 wherein:
- A. each exhaust valve is settable to retain a certain pressure over ambient; and
- B. the first exhaust valve is positioned in front of the diver;
- C. the second valve is adapted to be positioned on back of the diver; and
- D. the first exhaust valve is at a position lower than the second exhaust valve when the diver is in an upright orientation. 50
11. Underwater breathing apparatus for a diver, comprising:
- A. a jacket for placement on said diver and having closure means on the front side thereof;
- B. a first flexible breathing bag connected to said jacket and extending continuously in a closed loop around the front and back of said jacket on one side of said closure means;
- C. a second flexible breathing bag connected to said jacket and extending continuously in a closed loop around the front and back of said jacket on the other side of said closure means;
- D means for interconnecting said first and second flexible breathing bags;
- E. means for admitting a breathable gas to at least one of said flexible breathing bags; and
- F. means connected to said flexible breathing bags for communication with said diver.
12. Flexible breathing chamber means for an under water breathing apparatus, comprising:
- A. a first section of flexible material construction defining an enclosed volume which extends around in a closed loop;
- B. a second section of flexible material construction defining an enclosed volume which extends around in a closed loop; and
- C. means for interconnecting said first and second sections. 55
- * * * * *

45

50

55

60

65