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3,094,274

ARTIFICIAL RESPIRATOR APPARATUS

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2 Sheets-Sheet 1

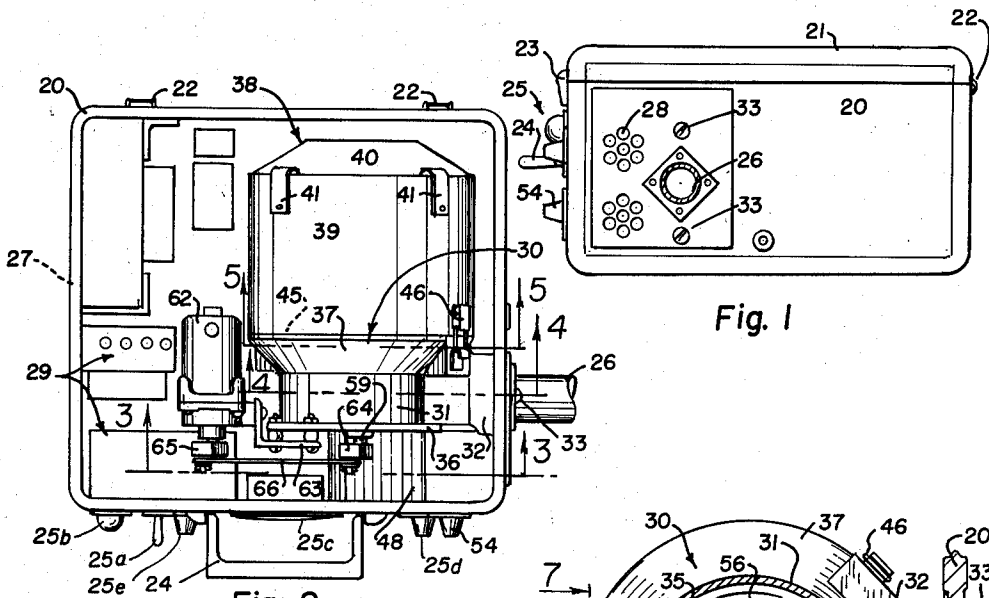


Fig. 1

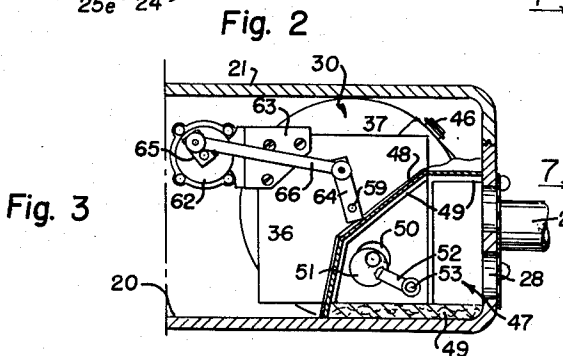
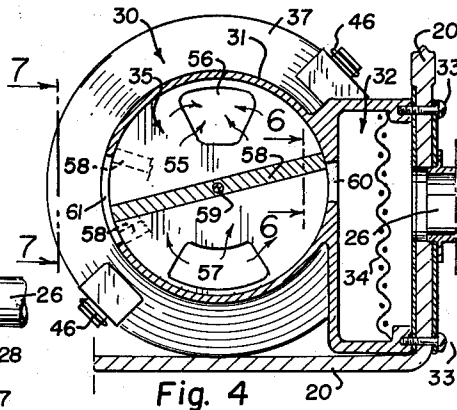


Fig. 2

Fig. 3



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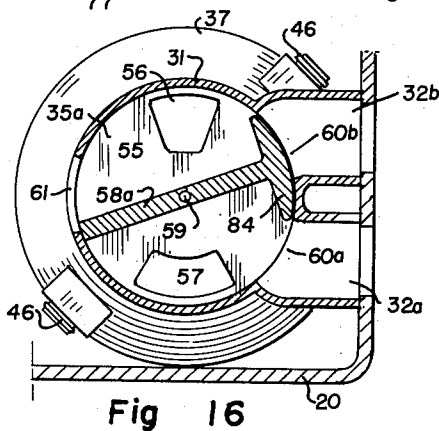
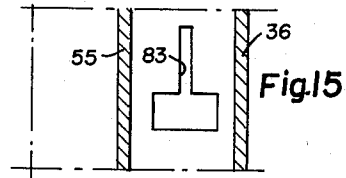
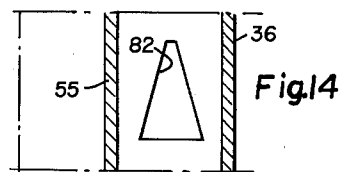
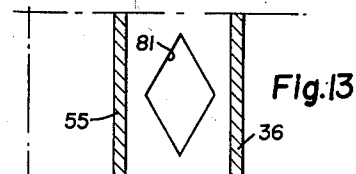
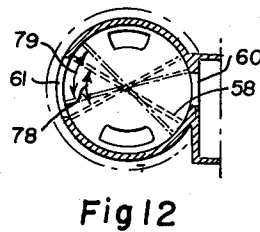
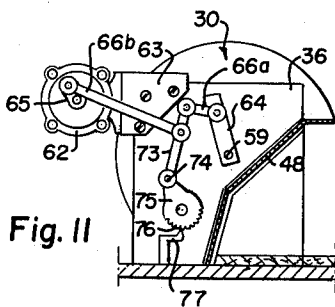
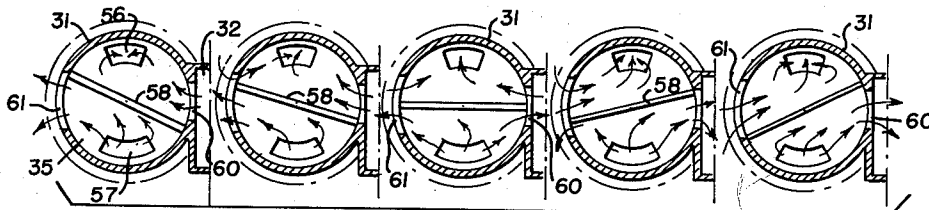
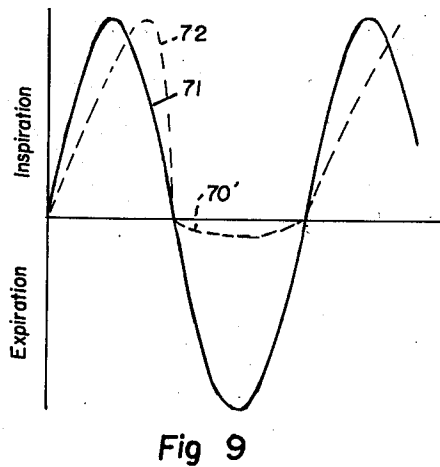
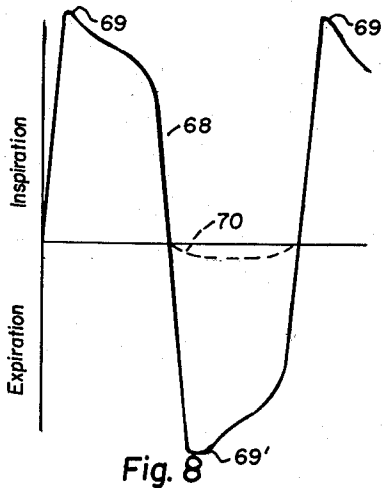
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ARTIFICIAL RESPIRATOR APPARATUS

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2 Sheets-Sheet 2



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ARTIFICIAL RESPIRATOR APPARATUS

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10 Claims. (Cl. 230-224)

This invention relates to pulsating pumping equipment for artificial respiration apparatus, and more particularly to pulsating pumping equipment of a type which employs a continuously operating blower as its prime element with the pressure and suction effect of the blower being cyclically directed to and/or from a patient through respiratory apparatus being worn by a patient. As such, the invention will be hereinafter referred to as a blower-type pulsator pump for artificial respiration apparatus or simply as a blower pump for artificial respiration apparatus in contrast with the more commonly known types which employ bellows or pistons.

An object of the invention is to provide a novel and improved blower pump for artificial respiration apparatus which includes a cyclic valve-shifting arrangement and other controls which are adapted to provide for pulsating air movement to and from the respiratory apparatus being used or worn by a patient and with the air movement being varied in frequency, pressure intensity and in a cyclic pattern most suitable to the needs of a patient.

Another object of the invention is to provide a novel and improved pulsating blower pump which will operate with positive pressure breathing as through a patient's mouth where the forced portion of the patient's breathing cycle is a pulse of positive pressure, or will operate equally well with respiratory apparatus of a type which encases a patient and where the forced portion of the patient's breathing cycle may be a pulse of negative pressure.

Another object of the invention is to provide in a blower pump for artificial respiration apparatus, a novel and improved cyclic, valve shifting means adapted to pulsate the air flow to and/or from respiratory apparatus in a manner which avoids sudden pressure changes or air flow shock effects which are commonly associated with the opening and closing of line valves to shut off a steady flow as from a blower pump.

Another object of the invention is to provide in a blower pump for artificial respiration apparatus, a novel and improved cyclic valve shifting means which permits the pulsating air flow to follow any given time-pressure relationship throughout each cycle of operation.

Other objects of the invention are to provide an improved blower-type pulsator pump for artificial respiration apparatus, which include improved valving and controls therefor, and which is an exceedingly compact, low-cost, neat-appearing, versatile, rugged and durable unit.

With the foregoing and other objects in view, all of which more fully hereinafter appear, my invention comprises certain novel and improved constructions, combinations and arrangements of parts and elements as herein-after described, defined in the appended claims and illustrated in preferred embodiment in the accompanying drawing, in which:

FIGURE 1 is a side elevation view, looking towards blowing and venting ports, of a case containing a blower-type pulsator pump constructed according to the principles of my invention.

FIGURE 2 is a plan view of the case with the lid

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removed to illustrate the pumping apparatus, as taken substantially from the indicated line 2-2 at FIG. 1.

FIGURE 3 is a fragmentary sectional detail of the case interior illustrating certain components of the blower unit controls, as taken from the indicated line 3-3 at FIG. 2.

FIGURE 4 is a fragmentary sectional detail of the case interior illustrating blower unit valving elements, as taken from the indicated line 4-4 at FIG. 2 but on an enlarged scale.

FIGURE 5 is a fragmentary sectional detail of the case interior illustrating the air flow passages in the blower unit, as taken from the indicated line 5-5 at FIG. 2 but on an enlarged scale.

FIGURE 6 is a fragmentary sectional detail of a blower valve port as viewed from the indicated line 6-6 at FIG. 4 but on an enlarged scale.

FIGURE 7 is a fragmentary sectional detail of a relief valve port as viewed from the indicated line 7-7 at FIG. 4 but on an enlarged scale.

FIGURE 8 is a graphic showing of representative cyclic operations of the air movement with a conventionally ported valving arrangement in the apparatus.

FIGURE 9 is a graphic showing of representative cyclic operations of the air movement using modified ported valving arrangements in accordance with the principles of the invention.

FIGURE 10 is a series of diagrammatic fragmentary sectional details, each similar to FIG. 4 and illustrating certain movements of the valve vane and air flow direction during a cycle of operation, in accordance with the principles of the invention.

FIGURE 11 is a fragmentary sectional detail, illustrating a portion of the showing at FIG. 3 but with the elements thereof including an adjusting means.

FIGURE 12 is a fragmentary diagrammatic sectional detail similar to one of the series of FIG. 10 but showing in broken lines modifications in positioning of the valving elements therein by use of the adjusting means shown at the valve port.

FIGURES 13, 14 and 15 are fragmentary sectional details similar to FIG. 6 but showing further modifications of the valve port.

FIGURE 16 is a fragmentary sectional detail similar to FIG. 4 but showing an alternate construction of the valving and conduit arrangements.

A pulsator pump for artificial respiratory apparatus must be designed to fit the needs of a patient using the apparatus. Usually a patient will require only forced inspiration of air for expiration will be a natural reflex action, although in some instances, forced expiration may also be necessary. Other factors which also depend upon an individual patient include the period of the breathing cycle and the comparative suddenness or slowness of inspiration and expiration. Ordinarily, a patient will require the breathing apparatus to operate with smooth regularity but the requirements of some individuals may be otherwise. For example, it may be desirable to provide comparatively slow inspiration but sudden expiration. In any event the rate of pressure change as the apparatus commences inspiration or expiration is important. In the final analysis, the establishment of an operative cycle of a pulsator pump to supplement a patient's breathing action will be a problem for the doctor and the

formation of a desired operative cycle of a pulsator pump may consider a number of variables. It thus follows that a pulsator pump must be versatile in its operation. Also, it should be adapted to effect inspiration of a patient either by suction as where body case type respirator is used or by positive pressure as where the forced breathing is through a patient's mouth.

Conventional bellows or piston types of respiratory pumps often lack this desired versatility of operation and cannot always be easily switched from suction pumping to positive pressure pumping. Moreover such conventional apparatus is also bulky and expensive and it has been suggested that blower-type respirators which use a steady flow of air and operate by a continuously shifting valve arrangement would be more simple. However, it has been found that conventional valves of a type which permit a continuous air flow to shift direction in a cyclic pulsating pattern, to correspond with breathing action, are not satisfactory. A continual changing of the direction of air flow is usually accompanied by undesirable rapid pressure changes such as elastic shock-waves resulting from the inertia of air within the conduit.

With such factors in view the present invention was conceived and developed and comprises, in essence, a blower-type pulsator pump of a simple compact design. The invention incorporates in such a pump a rugged construction of a continuously operating blower an improved valve construction, along with other necessary controls which permits a regulated pulsating action of air movement for artificial respiration according to any selected pattern of breathing desired by a patient.

Referring more particularly to the drawing, my respirator pump may be suitably enclosed in a rigid box-like case 20 of a construction similar to a neat appearing suitcase. A top lid 21 is affixed to the body of the case by hinges 22 at the back side and latches 23 at the front side thereof. The interior of the case is thus accessible by removal of the top lid 21 as illustrated at FIG. 2. A handle 24 may be located at the front wall of the case and suitable controls, collectively designated at 25 and hereinafter further described, may also be mounted upon this front face of the unit. The respiratory blower pipe 26, which extends to respiratory apparatus, not shown, is suitably mounted in an opening at a side wall of the unit. A primary vent 27, shown in broken lines at FIG. 2, and an auxiliary vent 28 are likewise formed in the side walls of the body to permit air movement into and out of the apparatus. The primary vent 27 is preferably formed in the sidewall opposite to the pumping elements to permit an air movement across other elements of the apparatus and so provide necessary cooling action therefor.

The electrical circuits, and controls are contained in housings 29, and the circuits which drive and control the pulsating pumping unit 30 will be hereinafter further described.

This pumping unit 30 includes a valve head 31 which carries other elements of the unit as hereinafter described and this head includes a side-port chamber 32 which abuts against the side wall of the case 20. The head 31 is secured to the case as by suitable mounting screws 33. The conduit 26 extends into this chamber 32 and a protective screen 34, or even a filter, may be mounted in this chamber in front of the entrance of the conduit 26.

The valve head 31 includes a short cylindrical valve chamber 35, hereinafter described, which is closed at the front end by a face plate 36. This head is outwardly flared at the opposite side to form a blower-retainer section 37 with the outer edge forming a circular seating ring to hold the edge of a cylindrical blower 38. The blower unit 38 which effects a movement through the apparatus is mounted upon the seating ring of this retainer section 37 and is generally formed as a cup shaped unit having a cylindrical body shell 39, and a rear end cap 40 attached to the shell as by clips 41.

The cylindrical blower motor 42 is axially and con-

centrically mounted within the cup-shaped shell 39 to form an annular space between the body of the blower 42 and the shell 39. This blower motor is of a common and conventional type having an electrical motor within it, whose rotatable elements are associated with blower vanes. A central suction intake 43 which is located at the end of the motor adjacent to the blower retainer section and the discharge from the motor is expelled from the annular space 44 between the body of the blower motor 42 and the shell 39. It follows that when the motor is operating, a continuous air flow occurs, into the intake 43 and from the discharge ring 44 as in the direction of the indicated arrows at FIG. 5. This type of motor-blower moves a continuous flow of air through it and in doing so advantageously and automatically air-cools the unit, so that it may operate continuously over a long period of time without overheating. To direct this air flow through the several ports and the valve, the retainer section is divided into two ported chambers, as hereinafter described.

The blower unit is connected to the retainer section 37 by affixing the end of the shell 39 in a suitable annular rabbeted groove 45 in the retainer section 37, as shown in broken lines at FIG. 2, and by locking it in position by latches 46.

The auxiliary vent 28 is suitably located alongside the conduit 26 to open to a chamber 47 adjacent to front side of the face plate 36. This chamber 47 is defined by a portion of the face plate and the wall of the side port chamber 32, a portion of the case wall and a hood 48 which extends between the face plate and the front wall from an edge of the side wall to the bottom of the unit as illustrated at FIG. 3. Suitable packing 49 of felt or sponge rubber is placed at the various joining edges of the hood 48 against the other elements to substantially seal off the several chambers from each other against the moderate air pressure encountered in operation of the apparatus.

The portion of the face plate 31 within the chamber 47 includes a relief orifice 50 which permits a by-pass of air flow from the valve chamber 35. A regulating cover plate 51 is adapted to move over this orifice to cut off or to adjust the air flow therethrough and the plate 51 is mounted upon a control arm 52 which, in turn is swingably connected to a shaft 53. The shaft 53 extends to a face-control knob 54 on the front wall of the case 20. It follows that air flow may be diverted from the valve chamber 35 by opening this orifice 50 to permit the flow to pass therethrough and through the auxiliary vent 28 as hereinafter described.

The valve chamber 35 is defined a short cylindrical portion within the valve head 31, the face plate 36 at one side thereof and a transverse wall 55 parallel to face plate which separates the chamber from the blower unit 38. This wall 55 includes an intake port 56 as shown at the top thereof and an exhaust port 57 at the bottom thereof. A transversely disposed vane 58, which oscillates from a nominal horizontal position is mounted within this chamber 35 upon a central axial shaft 59. The vane 58 thus divides the valve chamber into an intake or suction section above the vane and an exhaust or pressure section below it in correlation with the action of the respective ports on the wall 55. The vane 58 oscillates on its shaft from each side of the horizontal position through a selected arc to permit air to flow into and out of an operating port 60 at the side of the chamber which communicates with the side port chamber 32. The vane also opens and closes a supply port 61 at the opposite side of the valve chamber, and the vane thus operates to permit pulsating air flow in the conduit 26 as in the manner hereinafter described in detail.

The vane 58 is oscillated by a drive motor 62 which is mounted upon a suitable bracket 63 affixed to the side of the face plate 36. The shaft 59 of the vane extends through the face plate 36 and carries a crank arm 64.

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The drive motor 62 has a much shorter crank arm 65 mounted upon its shaft and the crank arms are interconnected by a link 66. The rotation of the short crank arm 65 will produce oscillation of the longer crank arm 64 through a desired angular sweep depending upon the respective lengths of the crank arms, and a corresponding sweep movement of the vane 58 will occur, the desirable sweep angle of the vane being indicated in broken lines at FIG. 4.

In order to effectively direct the air flow into the intake port 56 to the blower motor 42 and therefrom and through the exhaust port 57, the connective retainer section 37 of the valve head 31 is divided into an outer chamber and an inner chamber of an eccentric circular wall 67 which abuts against the end face of the blower motor 42 and the intake orifice 43 and intake port 56 are within the confines of this circular wall 67. The abutting edge of the wall 67 may also include suitable packing 49' to prevent air leaks.

When the operating port 60 and the supply port 61 are formed in a conventional manner, either square or circular, the pressure of the pulsating air movement from the blower will change in a sudden manner, somewhat as illustrated by the curve 68 illustrated at FIG. 8. This curve 68 shows a cycle of operation where the ordinate may represent the pressure of air flow during inspiration and expiration and the abscissa represents time, the curve 68 showing slightly more than a complete cycle of inspiration and expiration. It is to be noted that inspiration may be with suction, that is negative pressure, or with positive pressure depending upon the type of respiration equipment being used.

It may be observed that with conventional valve ports the pressure rise of the curve 68 at the beginning of inspiration is quite sudden and may rise to a peak 69 as the port opens. After reaching the peak, the pressure effect will remain near the maximum value during a substantial portion of the inspiration cycle and then drop quite suddenly as the expiration cycle is about to begin. The pressure effect then drops to a minimum peak 69' to remain near the minimum value during a substantial portion of the expiration cycle, and finally, to again suddenly reverse. If such operation were to be used for artificial respiration, the relief orifice 50 or a check valve in the conduit 26, not shown, would ordinarily be used to cut off the pressure action during the expiration portion of the cycle, as indicated by the broken line 70 of the curve. However, a pressure action which changes suddenly as in the manner illustrated by the curve 68 is unsatisfactory for artificial respiration.

A more desirable inspiration-expiration 71 is illustrated at FIG. 9 which is accomplished by both modifying the operative port 60 and supply port 61 as hereinafter described. This curve 71 will be shaped according to the needs of a patient, not only as far as timing of the cyclic period is concerned, but also, as to the suddenness or gradualness of the changes during inspiration and expiration. The sine-shaped curve illustrated is typical of that which is desired for an average patient. Since expiration will not ordinarily be needed, a check valve in the conduit 26, or the like, may be used to cut off that portion of the cycle as indicated at 70'. Other portions of the curve 71 may also be modified. With some patients it is desirable to permit a pressure effect forcing inhalation to increase gradually to a peak and then drop suddenly at the end of the inspiration cycle, and such may be indicated by the skewed curve 72 shown in broken lines at FIG. 9.

One manner of obtaining improved operation is by increasing the operative extent of the supply port 61 over that of the operating port 60. This is to permit air to flow through the supply port and the operating port simultaneously during those phases of operation where inspiration ceases and expiration commences, and vice versa, with the by-pass action through the supply port eliminating sudden pressure changes. Accordingly, the supply port

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61 extends over a substantial arc in the valve body 31 which may be equal to the arc of sweep of the vane 58, while the operating port 60 is at a substantially smaller arc. Such action is illustrated graphically at FIG. 10 where the vane is at different sequential positions during a half-cycle of operation. At the first illustrated position, at FIG. 10, the vane permits all positive pressure air to by-pass out of the supply port 61 while all suction flow into the intake port 56 is from the conduit 26. Where suction effects inspiration, as with a body case, this position of the vane would represent a condition at or near the top of the curve 71 illustrated at FIG. 9.

As the vane 58 moves to the second position the supply port 61 is partially divided by the vane. The lower portion of the port 61 still permits exhaust of positive pressure but the upper portion permits inflow to reduce the suction effect in the conduit 26 as shown by the indicated arrows representing air flow. In the next position the vane 58 reaches a neutral, horizontal position where there will be neither suction nor pressure in the conduit 26. This position on the curve 71 is where inspiration commences and expiration ceases. Subsequently, at a further movement of the vane and with the vane still dividing the supply port 61, there is both exhaust of pressure and suction intake through the port 61 but with pressure also in the conduit 26. As a final phase of the half cycle the full pressure flow is into the conduit 26 while the suction flow is relieved by air flow through the supply port 61.

It may be desirable to change the shape of the curve 71 by obtaining skewness or by even changing the time lapse of the inspiration cycle with respect to the expiration cycle. One manner of effecting such a change is to relocate the position through which the vane 58 sweeps and such relocation may be accomplished in a simple manner by changing the length of the link 66. This may be done by substitution of a link or by using an adjustable link mechanism such as that illustrated at FIG. 11. The compound link is formed of two segments 66a and 66b with the portion 66a being connected to the crank arm 64 and the portion 66b being connected to the crank arm 65. The link portions are also pivotally interconnected, at spaced-apart positions, to a transverse lever arm 73. This lever arm is pivotally connected to a normally-fixed anchor point 74 to permit the link 73 to swing back and forth to permit rotation of the crank arm 65 to oscillate the crank arm 64 as hereinbefore described. However, the anchor point 74 is on the arm of an adjusting head 75 which is pivotally mounted upon the face plate 36, and thus the point may be shifted back and forth to change the position of the arm 73 with respect to the link members and accordingly, the relative distance between the link portions which connect with the crank arms 64 and 65. A rack 76 on the head and a detent 77 affixed to the case 20 act to hold the anchor point 74 at any of a number of selected positions.

The effect of changing the length of link 66 is illustrated at FIG. 12 where the normal sweep of the vane 58 is represented by the arc 78 and where a modified sweep of the vane 58 is represented by the arc 79. It becomes immediately obvious that operation with the arc 79 creates a somewhat longer and more intense suction portion of the cyclic operation with release of pressure flow from the port 61 at all times.

Further shaping of the curve 71 may be accomplished by changing the shape of the operating port 60 in the illustration at FIG. 6. This port 60 is generally triangular in form with the base thereof being at the wall 55 and with the side edges 80 sloping from this wall to a curved apex portion 81. In operation the vane 58 moves first across the sloping side edges 80 to commence opening and closing of the port in a more gradual manner than would be otherwise possible.

Other forms of ports include a diamond shape 82 illustrated at FIG. 13 which shapes the curve 71 in a generally symmetrical manner with a peak of short dura-

tion. The tapered shape 82', as illustrated at FIG. 14, permits a gradual application of pressure but in an unbalanced manner as illustrated by the skewed curve 72. The notched form illustrated at FIG. 15 also provides an unbalanced action with sudden increase of pressure effect after a portion of the cycle has been completed.

An alternate construction where only suction or pressure is desired is illustrated at FIG. 16 where the circular valve chamber 35a includes two operating ports, a positive pressure port 60a and a negative pressure port 60b, and a modified vane 58a which is formed with the widened head 84 adapted to close off each port 60a or 60b, individually. The supply port 61 is extended over a substantial portion of the arc of swing of the vane as hereinafter described to provide for a relief of air pressure as the vane is shifting from one position to another so that a portion of the air flow will be released during the shifting phase of the cycle to prevent any sudden undesirable build up of pressure.

In this FIG. 16 construction certain other arrangements of conduit connections are possible from an arrangement which provides only suction or pressure. The positive pressure port 60a and the negative pressure port 60b may be interconnected to a single outlet to that operation will include both positive pressure and negative pressure cycles. Yet another mode of interconnecting this unit is to reverse the arrangement and use the supply port 61 for connection with the conduit 26 by forming a chamber such as 32 beyond the supply port 61 to facilitate interconnection with the conduit.

The controls to operate the apparatus include a starting switch 25a, an indicator light 25b which burns to indicate that the apparatus is properly operating, a pressure gauge 25c to register the pressure in the conduit 26, a rheostat 25d to vary the speed of the motor 42, and thereby to vary the effective operating pressure, and a rheostat 25e to vary the speed of the drive motor 62 to thereby vary the breathing period of the patient. The circuits to the motors and the rheostats by which their speed is controlled are conventional and circuits of a type which may ordinarily be used to control the operation of such motors, hence, such need not be elaborated in detail.

The operation of this unit is substantially as heretofore described in part. The conduit 26 extends to respiration apparatus, not shown, the drive motor 62 is then operated at a rate corresponding with the desired breathing period of the patient. The air blast through the pumping unit 30 provides suction in port 56 and exhaust in port 57 and the air flow from this suction and exhaust is cyclically moved through the operating port 60 according to a selected pattern determined by the form of the operating port 60 and extent of the supply port 61 as well as by the sweep position of the vane 58 as hereinbefore described.

While I have described my invention in considerable detail it is obvious that others skilled in the art can devise and build alternate and equivalent constructions which are within the sphere and scope of my invention, hence I desire that my invention be limited, not by the illustrations and constructions described, but only by the proper scope of the appended claims.

I claim:

1. A respiratory pumping unit having a conduit extending therefrom for connection with artificial respiratory apparatus and comprising:

- (1) a valve case having a generally cylindrical chamber,
- (2) an axially-centered shaft-mounted vane arms provided with sweep faces in the chamber dividing the chamber into two compartments with the shaft thereof extending through a wall of the case,
- (3) a motor-driven oscillating means connecting with the shaft and being adapted to oscillate the shaft and vane connected thereto through a selected sweep-arc

of movement of less than approximately 90 degrees and at a frequency corresponding with a person's selected breathing frequency.

- (4) a continuous-flow air pump having a suction intake branch extending to one compartment of the valve chamber and the pressure discharge branch extending to the other compartment of the valve chamber,
- (5) a supply port in the valve communicating from the valve to the atmosphere and being positioned at the side of the valve and within the sweep-arc of one arm of the vane,
- (6) an operating port in the valve substantially diametrically opposite to the supply port and being within the sweep of the other arm of the vane and communicating from the valve to the respiratory conduit, and,
- (7) wherein the openings of the said ports at the valve interior are substantially wider than the sweep faces of the vane arms, whereby to open the ports to both compartments of the valve chamber when the arms are moving across the ports and thereby permit a continuous air flow in the pump when the air flow in the conduit ceases as when reversing in direction, and thereby eliminate pressure and inertial effects in changing the direction of air flow in the conduit.

2. In the unit defined in claim 1, said operating port being generally step-shaped with a narrow slot-shaped portion at one end of the vane sweep and a wider opening at the opposite end of the vane sweep.

3. In the pumping unit defined in claim 1, wherein said oscillating means includes a motor having a shaft adapted to rotate at a selected rate, a crank arm on the motor shaft, a second crank arm on the vane-supporting shaft and a link interconnecting the two arms, and wherein the vane-shaft crank arm is longer than the motor shaft crank arm whereby to effect oscillation of the vane-shaft crank arm by rotation of the motor shaft crank arm.

4. In the unit defined in claim 3, wherein said link includes a length-adjusting means adapted to permit a shift in position of the oscillation-sweep of the vane-shaft crank arm with respect to the position of the motor shaft.

5. In the unit defined in claim 1, said operating port being generally diamond-shaped.

6. In the unit defined in claim 1, said operating port being generally trapezoidal-shaped with a narrow apex edge being substantially at one end of the vane sweep and a wider base edge being substantially at the opposite end of the vane sweep.

7. In combination with a continuous flow air pump having an intake and an exhaust, and a conduit extending from the pump, an oscillating valve between the pump and the conduit adapted to cyclically shift the intake flow and exhaust flow of the pump into the conduit to oscillate the air movement therewithin in a pattern analogous to respiratory breathing, said valve comprising a cylindrical end-closed chamber having an axial shaft therethrough, a vane mounted upon the shaft diametrically dividing the chamber into two portions, means for cyclically oscillating the shaft and vane attached thereto through a minor portion of a full revolution, said air pump intake communicating with one portion of the valve chamber, the air pump exhaust communicating with the other portion of the valve chamber, an operating port in the peripheral cylindrical wall of the valve communicating with the conduit and a supply port communicating with the atmosphere diametrically opposite to the operating port said vane being adapted to move across and from one side to the other side of operating and supply ports during its oscillation movement and wherein the arcuate reach of at least one of the ports is substantially greater than the width of the vane, whereby to permit a continuous flow of air through the intake and exhaust of the pump as the vane sweeps over the ports to change the direction of air flow in the operating port.

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8. In the combination defined in claim 7, wherein the arcuate reach of the specified greater-than-the-vane width port is step-shaped to provide a selected variation of pressure within the chamber as the vane moves across said port.

9. In the combination defined in claim 7, wherein the arcuate reach of the specified greater-than-the-vane width port is generally trapezoidal shaped with a narrow apex edge being substantially at one end of the vane sweep and the wider base edge being substantially at the opposite end of the vane sweep.

10. In the combination defined in claim 7, wherein

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the arcuate reach of the specified greater-than-the-vane width port is diamond shaped.

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