Aug. 19, 1969 C. E. BARKALOW ET AL 3,461,861

CARDIAC COMPRESSOR AND VENTILATION MEANS

Filed Oct. 5, 1966 5 Sheets-Sheet 1

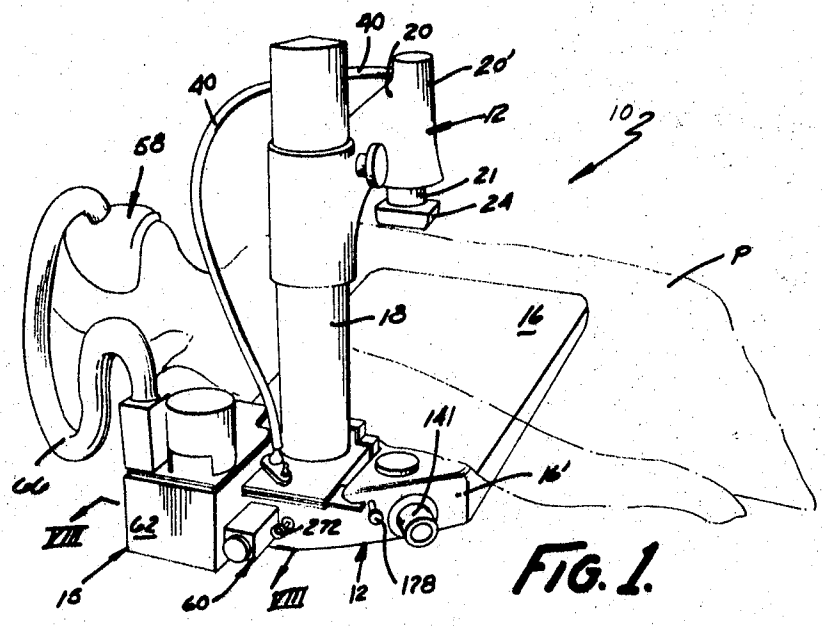


FIG. 1.

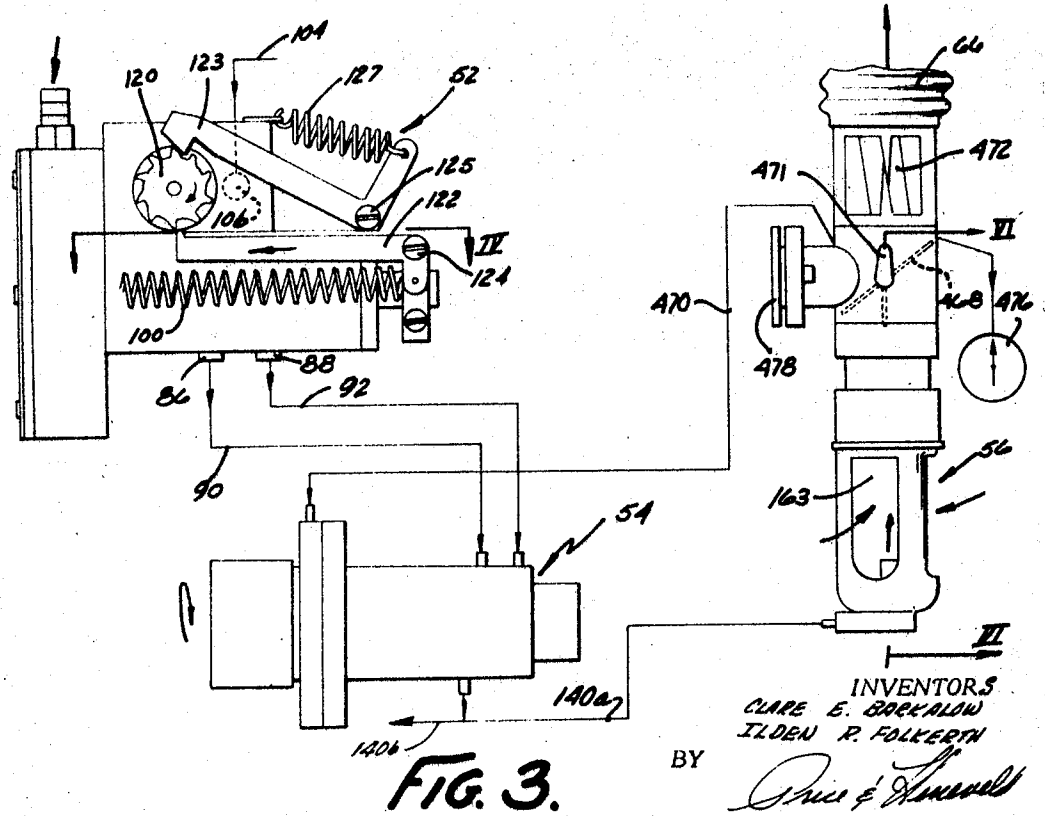


FIG. 3.

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CARDIAC COMPRESSOR AND VENTILATION MEANS

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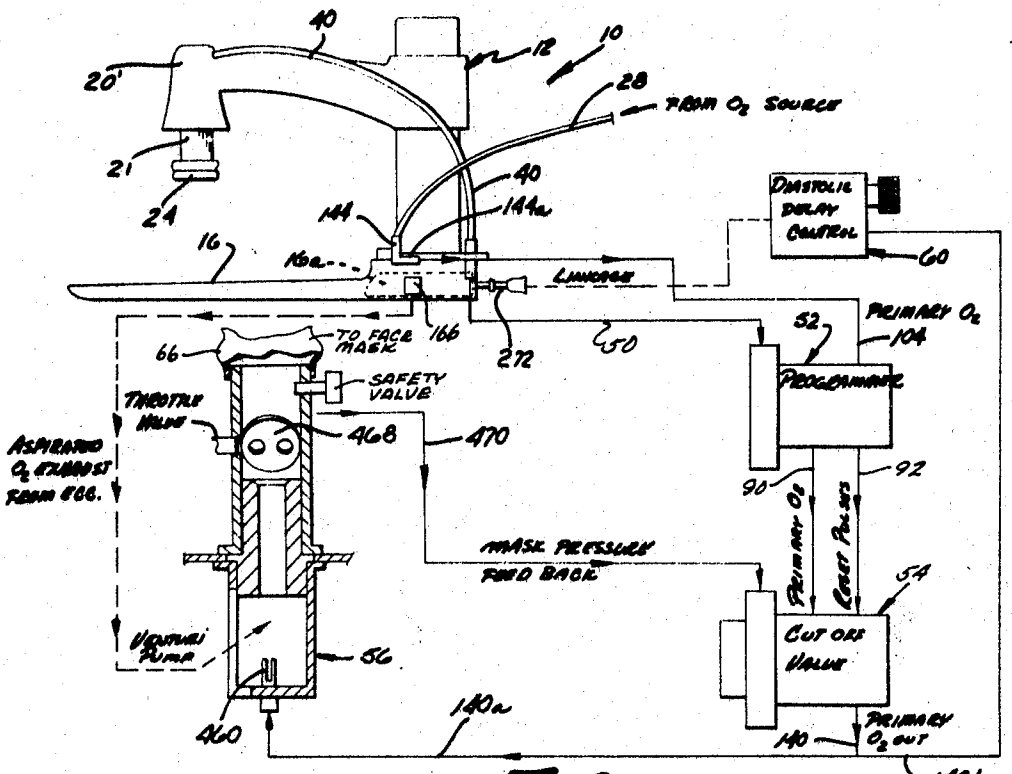


FIG. 2.

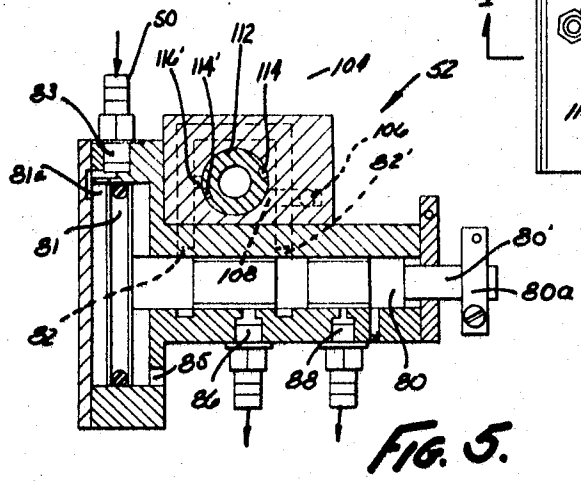


FIG. 5.

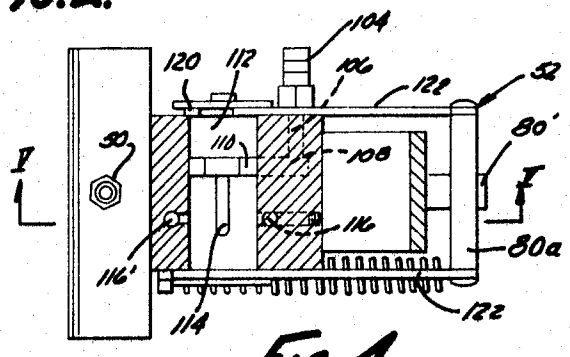


FIG. 4.

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CARDIAC COMPRESSOR AND VENTILATION MEANS

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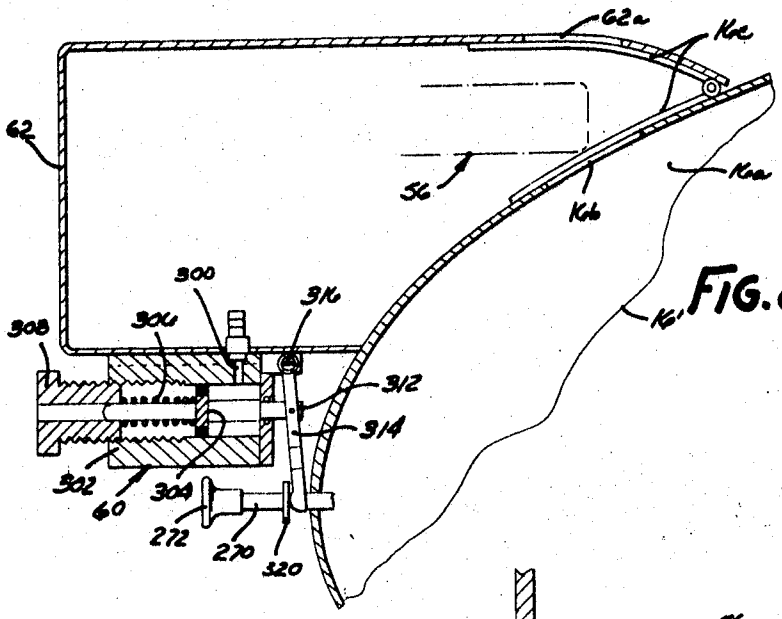


FIG. 8.

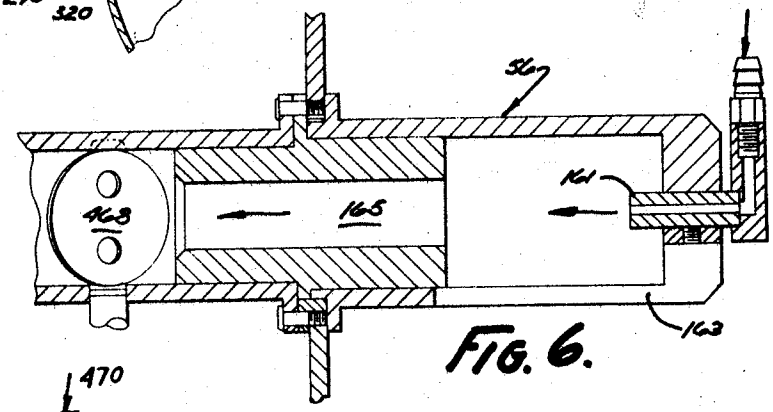


FIG. 6.

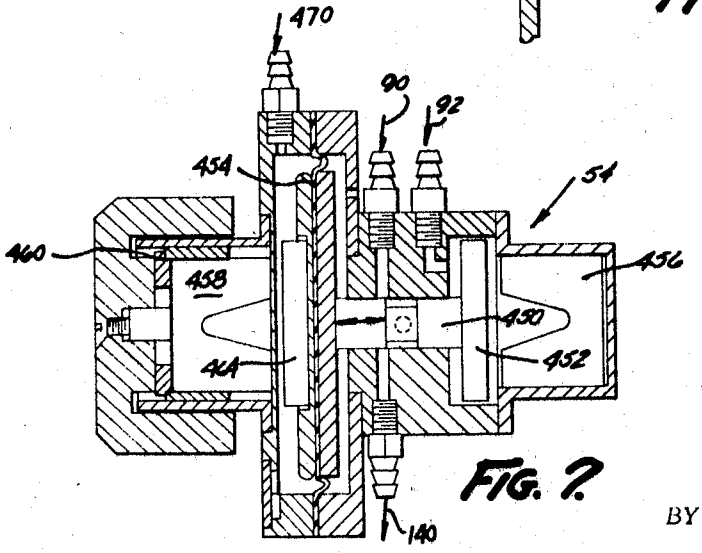


FIG. 7.

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CARDIAC COMPRESSOR AND VENTILATION MEANS

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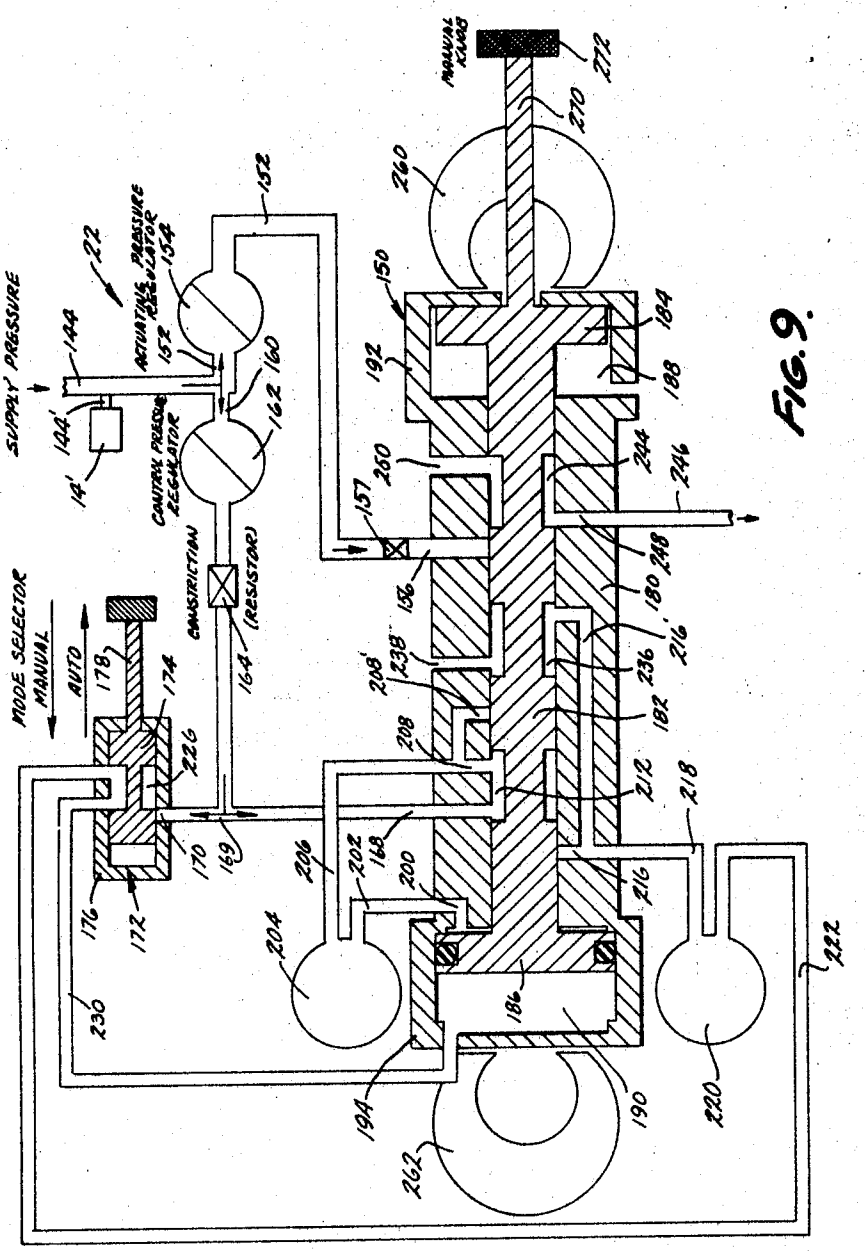


FIG. 9.

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# CARDIAC COMPRESSOR AND VENTILATION MEANS

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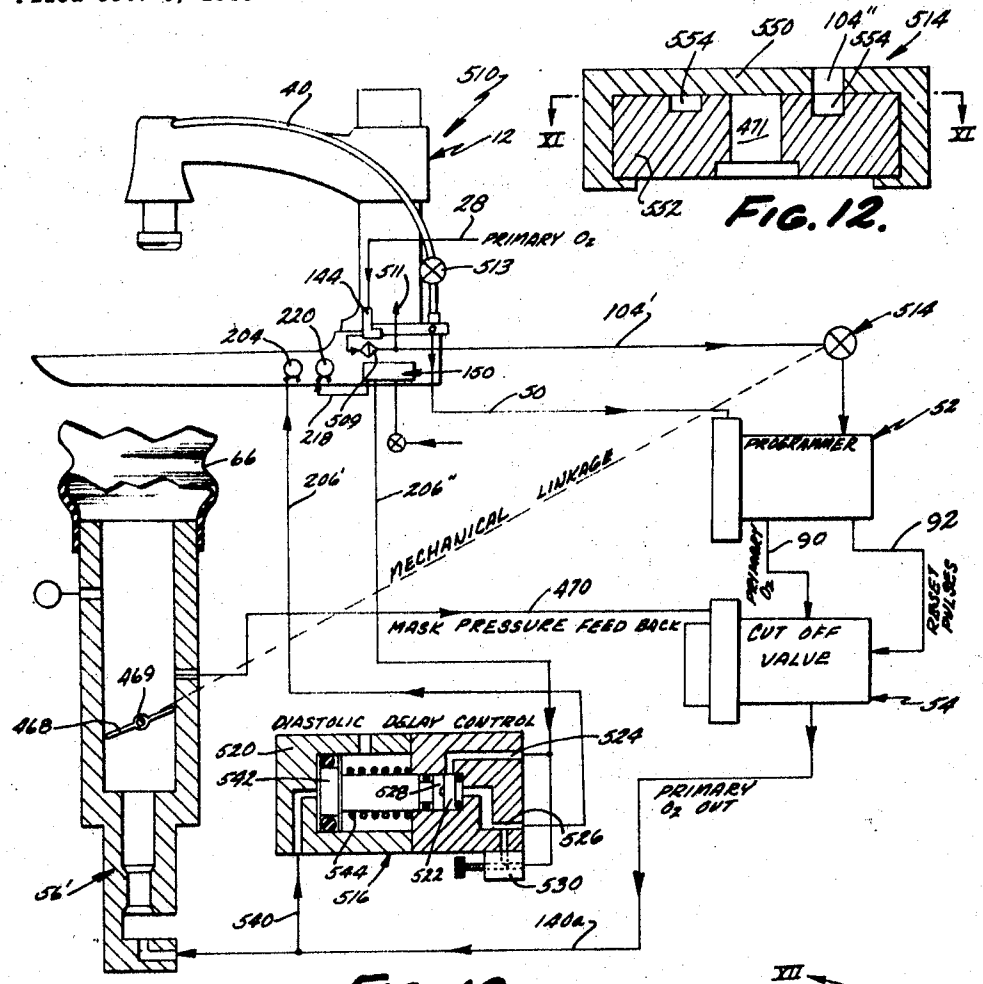


FIG. 10.



FIG. 12.

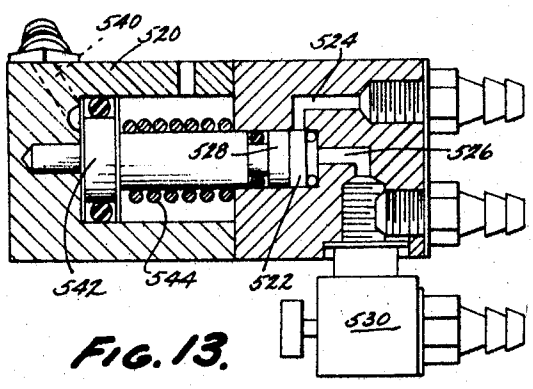

FIG. 13.

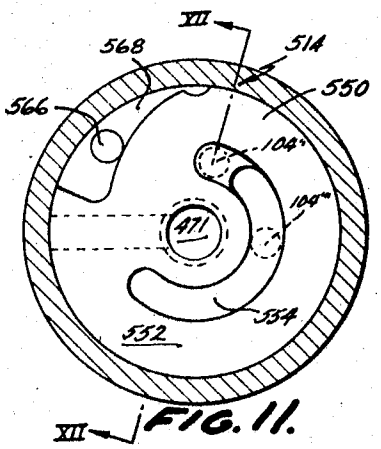

FIG. 11.

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United States Patent Office 3,461,861 Patented Aug. 19, 1969



3,461,861

# CARDIAC COMPRESSOR AND VENTILATION MEANS

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Continuation-in-part of application Ser. No. 409,634, Nov. 9, 1964. This application Oct. 5, 1966, Ser. No. 584,402

Int. Cl. A61h 7/00

U.S. Cl. 128—53 17 Claims

## ABSTRACT OF THE DISCLOSURE

A combined cardiopulmonary apparatus having a pneumatically operable, reciprocatable, cardiac compressor and a lung ventilation means. A pneumatically operated control system operates the cardiac compressor and the ventilation system such that the ventilation cycle is synchronized with the cardiac compression cycle, although the ventilation cycle is slower than the cardiac compression cycle. Means are provided to operate the cardiac compressor or the ventilation system in the absence of the other. These means are so contructed so as to permit the discontinuance of one of the cardiac compressor or the ventilation system for a short period of time, and commencing the stopped unit automatically in the same synchronized relationship. Means are further provided to delay the cardiac compression cycle in the event of a restricted passage in the patient's ventilation system. Means are also provided to control the gaseous flow rate and gaseous pressure to the patient's lungs.

This is a continuation-in-part application of copending application entitled Cardiac Compressor, Ser. No. 409,634, filed Nov. 9, 1964, now Patent No. 3,364,924.

This invention relates to cardiopulmonary resuscitation apparatus, and more particularly to a combination cardiac compressor and lung ventilation apparatus, and to a ventilation adjunct for use in combination with an external cardiac compressor.

External cardiac compression can be effectively employed for obtaining perfusion by causing forced pumping of blood from a temporarily stopped heart. This is achieved by constant cyclic external compression of the heart (systole) for a short time period, followed by pressure release to allow heart expansion (diastole) for a short time period. To achieve proper heart compression by external force, the breastbone is forced toward the backbone while the back is rigidly supported.

Although forced pumping of the blood is essential for a patient whose heart has failed, this is only part of the continuous treatment necessary since, when the heart fails, breathing normally fails also. Hence, when an external cardiac compressor is presently employed, simultaneous sustained cyclic mouth-to-mouth ventilation is also important to cyclically inflate the lungs for oxygenation of the blood. According to accepted medical practice, the lungs are inflated during certain diastole periods. In spite of its importance however, proper mouth-to-mouth ventilation may not be given in many circumstances due to a lack of knowledge of the technique by persons in the vicinity, or the fact that persons may be loathe to directly contact certain other persons in mouth-to-mouth fashion, or the fact that an attendant may tire from the ventilation process, or several other reasons.

Hence, it has been conceived to combine an external cardiac compressor with a ventilation adjunct for synchronized cardiopulmonary resuscitation. However, many problems are immediately raised by this combination, and



many criteria must be met. The cyclic ventilation process must be synchronized in a specific manner with the cardiac compressor. Further, the ventilation process timing must be conducted in a differently regulated fashion from the cardiac compressor. Specifically, the time cycle for ventilation is several times that of the cardiac compression, and yet the lungs should be completely inflated as quickly as possible during the "off" period of cardiac compression, preferably within one normal diastolic period, according to presently accepted teachings. Also, there are definite medically acceptable limits on the pressures that can be applied to the lung system of the patient. Yet, there are certain minimum flow rates and transfer volumes which can be used for lung inflation in order to meet the time criterion noted above. Until presently, in fact, only with mouth-to-mouth ventilation has it been possible to meet the medically acceptable flow rate and transfer volume criteria to safely fill the patient's lungs sufficiently rapidly to complete lung inflation before the next cardiac compression, and yet to fill them under acceptable pressures. The problem becomes more complex if the patient has some sort of windpipe restriction. In fact, there are many such variables which immediately arise from patient to patient.

It is an object of this invention to provide cardiopulmonary resuscitation apparatus that combines a cardiac compressor and a lung ventilator in a unique inter-related fashion so that the equipment can be operated in synchronism, yet each portion having its own time cycle and each being capable of controlled regulation to operate on parameters which effect safe but optimum constant cyclic lung ventilation and cardiac compression.

Another object of this invention is to provide combined cardiopulmonary resuscitation apparatus completely operable without electrical power supply means. It is completely pneumo-mechanical both in operation and in control, so that the apparatus can be effectively operated simply from a standard oxygen supply tank or other source, rather than requiring an electrical supply outlet. The pneumatic supply effects controlled timing regulation for the cardiac compressor, controlled timing for the ventilation unit, controlled force for the cardiac compression, and controlled gaseous flow rate and pressures for lung ventilation.

Another object of this invention is to provide cardiopulmonary apparatus having complete regulation flexibility for independent regulation of lung ventilation and cardiac compression, enabling its accommodation to the particular size of the patient, lung capacity, rib cage size and strength, position of breastbone, ventilation flow rate, and other variable factors.

Another object of this invention is to provide a unique cardiopulmonary apparatus having synchronized lung ventilation and cardiac compression, but capable of immediate discontinuance of either the compressor or the ventilator, and yet capable of instant reactivation of either at any selected time, in exact synchronism with the other. This is very important, for example in order to achieve defibrillation at the optimum time and conditions by controlling the cardiac compressor, while allowing the lung ventilator to operate continuously.

Another object of this invention is to provide a unique cardiopulmonary apparatus having a potentially large ventilation gas flow rate because of a unique pumping arrangement. Moreover, the controlled rate of flow has a controlled variable oxygen enrichment content so that the ventilating gas can range anywhere from an oxygen content of about 35%, to highly oxygen enriched gas of approximately 90%.

Another object of this invention is to provide a cardiopulmonary apparatus that not only can employ a stand-

ard oxygen supply for all of the operations and regulation of the equipment, but also enables conservation of the primary oxygen used to operate the cardiac compressor by allowing it to be re-employed subsequently for ventilation.

Another object of this invention is to provide a cardiopulmonary apparatus that enables cyclic ventilation of persons having an obstructed air way, and therefore capable for receiving only reduced flow rates into the lungs for ventilation and also requiring increased time for the ventilation, yet with the ventilation apparatus still being completely synchronized with the more rapid cycle of the cardiac compressor.

Another object of this invention is to provide cardiopulmonary apparatus having unique ventilation pressure control with a feed-back operation from the face mask to a bistable valve which limits the pressure applied to the patient's mouth and air ways to only that which a patient can safely handle. The pulmonary pressure is limited to medically acceptable limits by positive means which is sufficiently fast acting and failure free to make safe high flow rates capable of filling the lungs in one-half second. The apparatus is designed to operate at optimum parameters such that highly efficient patient ventilation is available without compromise of cardiac compression and perfusion, and vice versa.

These and several other objects of this invention will become apparent upon studying the following specification in conjunction with the drawings in which:

FIG. 1 is a perspective view of the cardiopulmonary resuscitation apparatus shown employed on a patient;

FIG. 2 is a schematic view of the components in the first form of the apparatus of FIG. 1;

FIG. 3 is an enlarged exploded view of three of the cooperative components in the lung ventilation subassembly of the assembly in FIGS. 1 and 2;

FIG. 4 is a partially sectional view of the programmer forming one of the components in FIG. 3, and taken on plane IV—IV of FIG. 3;

FIG. 5 is a sectional view of the programmer, taken on the vertical plane V—V of FIG. 4;

FIG. 6 is a sectional view of the special Venturi pump unit shown as one of the three components in FIG. 3, and taken on plane VI—VI of FIG. 3;

FIG. 7 is a sectional view of the pressure cut-off valve shown as one of the three components in FIG. 3;

FIG. 8 is a fragmentary sectional view through a portion of the complete apparatus in FIG. 1, taken on plane VIII—VIII of FIG. 1;

FIG. 9 is a sectional view of the cardiac compressor control mechanism which cooperates with the lung ventilation apparatus, and forms part of the assembly in FIG. 1;

FIG. 10 is a schematic view of a second form of the system;

FIG. 11 is an end view of the main portion of a control valve in the system of FIG. 10 taken along lines XI—XI of FIG. 12;

FIG. 12 is a sectional view taken on plane XII—XII of FIG. 11; and

FIG. 13 is a side elevational sectional view of a diastolic delay control unit in the system of FIG. 10.

Referring now specifically to the drawings, particularly FIGS. 1–9, the first form of the cardiopulmonary resuscitation apparatus or system **10** is basically composed of a cardiac compressor subassembly **12** and a lung ventilation subassembly **15**.

The cardiac compressor subassembly **12** is basically like that shown in co-pending patent application Ser. No. 409,634, now Patent No. 3,364,924, filed Nov. 9, 1964 by one of the inventors herein and entitled Cardiac Compressor. It includes a platform **16** for supporting the back of the patient P, shown in outline phantom form in FIG. 1, a removable upstanding columnar support **18**, an overhanging arm **20** mounted to support **18** and having on one end thereof a cylinder **20'** with shiftable extending plunger piston **21** and pad **24** pneumatically operable to compress the breastbone and thus the heart of the patient. Platform **16** has a thick hollow protruding end **16'** to which support **18** is mounted. This end has a hollow chamber **16***a* therein enclosing a control valve assembly **22** (FIG. 9).

This control valve assembly includes fluid valve means **150**, shown in detail in FIG. 9 and the operation of which will be described hereinafter, manual mode selector unit **172** (FIG. 9) and other cooperative elements shown in FIG. 9 and described in detail hereinafter. Valve assembly **150** includes a shaft **270** having a manual control knob **272** protruding therefrom and protruding from the end of the housing (FIG. 1). Likewise, manual selector means **172** includes a selector device **178** protruding from the housing (FIG. 1).

All of the components of the entire apparatus **10** are pneumo-mechanical, being completely independent of electrical power source means.

The pneumatic pressure for the cardiac compressor subassembly **12** is supplied through an inlet line **28** (FIG. 2) from an oxygen source, normally at about 40–60 p.s.i. to a T connector **144** which connects to the valve system in FIG. 9, and has a branch outlet **144***a* to the programmer components **52** of the subassembly **15**. The pressurized gas introduced through connector **144** is released from the assembly in FIG. 9 in controlled pulses in a manner to be described hereinafter, through line **246** (FIG. 9) which communicates through the subassembly apparatus **12** and specifically through its base, to a hose or tube **40** (FIGS. 1 and 2). Hose **40** communicates to the upper end of cylinder **20'** for downwardly extending plunger piston **21** under controlled pressure, for cardiac compression. The pulsing pneumatic fluid which communicates with tube **40** also communicates through a line **50** which branches from hose **40**, to programmer subassembly **52**.

This programmer subassembly **52** cooperates with a pressure cut-off valve subassembly **54**, which in turn cooperates with a special Venturi pump subassembly **56** that supplies controlled lung ventilating, oxygen-containing gas to face mask subassembly **58** (FIG. 1). Valve subassembly **54** also cooperates with a special diastolic delay control subassembly **60**.

Preferably, programmer subassembly **52**, pressure cut-off valve subassembly **54**, Venturi pump subassembly **56**, and the interconnecting lines therebetween are all mounted in a small housing **62** (FIG. 1) attached to enlarged end **16'** of the platform base **16** alongside chamber **162** (FIG. 2). Diastolic delay control means **60** is attached alongside housing **62**. Flexible extensible conduit **66** leading to face mask subassembly **58** extends from the housing as shown in FIG. 1.

Programmer subassembly **52** is basically a pneumo-mechanical device which serves to open a passageway for flow of oxygen through it at regular intervals (whole number of compression cycles) of cardiac compressor subassembly **12**. Its control input **50** is the pulsatile pressure to the cardiac compressor cylinder (line **40** in FIG. 2). The programmer can be set to provide the open passageway at regular multiple intervals, usually 1 out of 5, of the cardiac compressor actuation because the lungs should be ventilated only once every multiple of cardiac compressions. It is normally set to open during cardiac diastole (compressor cylinder pressure of 0), but may be set to open during cardiac systole if the latter is preferred. The output of primary oxygen-containing gas from the programmer flows into the pressure cut off valve subassembly **54**.

Referring more specifically to the programmer subassembly **52** and its particular construction (FIGS. 2 and 5), it includes a spool valve **80** having a pair of inlet passageways **82** and **82'** communicant with the spaces between the lands of the spool valve. Also communicant with the spaces between the lands is a pair of outlet

content of the output of the Venturi pump has been shown to be about 35%. Hence an increase in oxygen content of about 75% over that of normal air is achieved.

The Venturi pump actually includes a very simple construction, having a nozzle outlet **161** from line **140***a*, surrounded by ambient air inlets **163** (FIGS. 2, 3 and 6) into the discharge conduit **165** (FIG. 6). This housing also includes a controllable throttle butterfly valve **468** having a manual actuator **471** for regulating output of the pump to flexible conduit **66**. Preferably, a volume indicator **472**, of the typical forced tidal volume type is mounted adjacent the output to conduit **66**, as well as a pulmonary pressure gauge **476** downstream of throttle valve **468**, and a supplemental or secondary pressure relief valve **478**, also downstream of the throttle valve **468**. The pressure is actually controlled independent of this valve **478** as will be explained immediately hereinafter, but this safety valve is another precautionary factor rendering the device completely safe from a medical standpoint.

The Venturi pump thus provides for high flow amount yet under low acceptable and safe pressure to enable the lungs to be filled within ½ second or so. Previously, this was possible only with mouth-to-mouth resuscitation techniques. The Venturi pump also provides oxygen enrichment as noted above. With the novel apparatus, it is possible to provide greatly enriched oxygen containing gas to the face mask by reason of the apparatus shown in FIGS. 1 and 8. More specifically, the discharge gas from the cardiac compression unit is exhausted into the generally enclosed chamber **16***a* in larger end **16'** of platform base **16**. As shown in phantom lines in FIG. 8, the Venturi pump subassembly **56** is mounted with its intake end within an enclosure which communicates through a port **16***b* from chamber **16***a* into the interior of housing **62**. Over this port is a pivotal control flap **16***c* which can be used to close port **16***b*, or alternatively to close port **62***a* between the interior housing **62** and the atmosphere. If flapper **16***c* is over port **16***b*, Venturi pump **56** draws its ambient supply from the atmosphere through port **62***a*. If on the other hand, greater oxygen enrichment is desired, flap **16***c* is pivoted over opening **62***a* to thereby open port **16***b* to chamber **16***a*. Since the chamber **16***a* contains greatly enriched oxygen content, of normally about 90%, due to the exhaust of the straight oxygen gas from the cardiac compressor into this chamber, the percentage of oxygen which passes from the Venturi pump to the flexible hose and mask can be enriched up to a value of about 83% of oxygen content. This represents an increase of about 315% oxygen content over that of normal air. If desired, the pivotal gate can be positioned somewhere between so that both of openings **16** and **62***a* can be open to have some intermediate oxygen content between the low and high maximum.

The pressure output to the lungs is actually controlled by the regulating action of pressure cut-off valve **54**. Particularly, when the pulmonary pressure in the lungs, and thus in face mask **58**, conduit **66**, and throttle valve **468**, reaches a certain value because of the lungs being inflated to a specific predetermined amount, this pressure is transmitted through a feed back conduit **470** to control diaphragm **454** (FIGS. 3 and 7) of pressure cut-off valve assembly **54**, to shift spool valve **450** to the right and therefore shut off any further pressure to primary oxygen line **140** and **140***a* to the pump.

As stated previously, branch line **140***b* from output **140** of primary oxygen communicates with inlet **300** (FIG. 8) of diastolic delay control means **60** (FIG. 2). Diastolic delay control **60** includes a housing **302** (FIG. 8) containing a small piston **304** responsive to input pressure from passage **300** to shift to the left (as viewed in FIG. 8), but normally biased in the opposite direction by a compression spring **306** to an inactive position. The amount of biasing force by this spring on the piston can be regulated by rotation and thus axial threaded insertion or extension of knob **308** to compress the spring a controlled amount. A shaft **312** extending from piston **304** connects pivotally to a link **314** intermediate the ends of the link. One end of the link is pivotally fixed at **316** adjacent housing **62**. The opposite end is in abutment with an annular shoulder **320** affixed around reciprocable shaft **270** for the cardiac compressor control valve assembly (see also FIG. 9). Normally, spring **306** has a sufficient biasing force when knob **308** is adjusted inwardly to overcome any pneumatic pressure applied periodically through line **140***b* and inlet passage **300** to piston **304**. Hence, the diastolic delay control structure is normally in the inactive position shown in FIG. 8. In fact, its use is only initiated when encountering restricted airway problems in a particular type of patient. For example, patients with high resistance airways caused by asthma, emphysema, laryngospasm, choking or the like create a need for an operating difference since normally high flow rates are not feasible. More specifically, it has been found that with normal airways the average flow rate, utilizing the Venturi pump, can be made high enough so that it is possible to safely transfer a full lung volume of gas into the patient's lungs during the normal ½ second diastole period of cardiac compression. However, this may require the transfer of up to 2.0 liters of gas in approximately ½ second, requiring flow rates of the order of 200 liters per minute into the lungs. With patients having restricted airways, this is not possible. If the device were used as normally, therefore, the back pressure caused by the airway restriction would cause the pressure cut-off valve **54** to stop flow after the lungs were only partialy filled. By adjusting throttle valve **468** (FIG. 6) adjacent the Venturi pump, the flow rate can be regulated down to a smaller amount that will not increase the back pressure to an amount sufficiently rapidly to immediately shut off the supply of oxygen by the pressure cut-off valve. However, when throttling valve **468** is regulated to lessen the flow rate for patients having restricted airways, it will be realized that it takes more than the normal ½ second to fill the patient's lungs a satisfactory amount. Hence, if the lungs are to be filled before the cardiac compressor again compresses the lower portion of the chest, then the cardiac compression step must be delayed a controlled amount. This delay is conveniently achieved with the novel apparatus shown in FIG. 8, merely by adjusting threaded member **308**. The member is turned enough to relax the bias of compression spring **306** a regulated amount sufficiently to delay the time period by causing the air inlet through passageway **300** to shift piston **304** against the compression of the spring, and thereby pull the linkage **314** against actuator **270** to hold the actuator. This provides a holding force on the reciprocating valve means **150** in FIG. 9 that otherwise automatically reciprocates repeatedly under pneumatic influence to cause the cardiac compression step (as explained hereinafter), thus extending the normal off period by a controlled amount. After the lungs then fill up to a satisfactory extent, and the pressure in the lungs or pulmonary pressure has increased to the amount necessary to trip the pressure cut-off valve, the supply of oxygen through line **140***b* to diastolic control **60** is shut off, causing spring **306** to again take over and shift linkage **314** back to its inactive position. This allows manual lever **270** (FIG. 8) of the valve means **150** (FIG. 9) to release its holding force on the cardiac compressor control mechanism, and thereby enable it to go through its next pulsing stage. Under this type of operation, the pulmonary pressure is still the control factor therefor, and the lungs will fill to the preset pressure still, but at a reduced and tolerable rate and without the need for excessive mask, tracheal, and bronchial pressures. The ventilation will cease, however, and the cardiac compressor resume at some maximum time interval, even if the lungs have not completely filled (e.g. if there were a face mask leak). Therefore, the unit will not undesirably keep delaying cardiac compression indefinitely in case of leakage or

passages 86 and 88 (FIGS. 3 and 5) to pass pressurized gas through lines 90 and 92 respectively to shut off valve subassembly 54 when the gas is allowed to pass the spool valve from passageways 82 and 82'. Spool valve 80 is operated in one direction by piston 81 in chamber 81a, because one side of the piston communicates with a passageway 83 to pulsing pressure supply line 50 (FIGS. 5 and 2). The other side communicates with an exhaust outlet 85. Pressure pulses through line 50 therefore shift the spool valve to the right (as viewed in FIG. 5), against the bias of tension spring 100 (FIG. 3). The spring returns the spool valve upon release of the pressure pulse. This pulsing and consequent shifting of spool valve 80 occurs with each cycle of the cardiac compressor i.e. about once every second. However, the pressurized gas from passageways 82 and 82' enter the spool valve chambers only once every multiple cardiac compressor cycles because of a sequencing feature of this subassembly 52.

More specifically, the pressurized oxygen is introduced to subassembly 52 in a constant pressure condition through conduit 104 (FIG. 2) from leg 144a of connector 144, and thence to an inlet port 106 to the programmer or sequencing valve. This passage inlet 106 communicates with a passageway 108 (FIG. 5) to an annular groove 110 (FIG. 4) around a rotational programming valve 112. Groove 110 communicates with a pair of oppositely positioned, axially elongated, slot type passages 114 and 114' (FIGS. 4 and 5) in valve 112. When this cylinder 112 is rotated, slots 114 and 114' align, after the predetermined multiple of cardiac compressor cycles, with outlet passages 116 and 116' to then allow flow therethrough. Passages 116 and 116' communicate with outlets 82 and 82' to spool valve 80.

To control the multiple of compressor cycles between each of these flow periods, control cylinder 112 is rotated in angular increments by a ratchet connection. This includes a pair of ratchet wheels 120 on opposite ends thereof, and a pair of ratchet levers 122 (FIGS. 3 and 4). Ratchet levers 122 are mounted to the protruding end 80' of spool valve 80 by a connector 80a. Levers 122, by being mounted on pivot axis 124, ride over the teeth of ratchet wheels 120 when the spool valve 80 extends its end 80' to the right (FIG. 5). Retraction of the spool valve to the left, with release of pressure on piston 81, causes ratchet lever 122 to rotate ratchet wheels 120 and thus cylinder 112 a controlled arcuate amount. To prevent the ratchet wheel from reversing in direction with movement of ratchet levers 122 to the right, a pair of ratchet brake arms 123 engage the teeth. These are pivotally mounted on pivot axis 125, being biased toward the ratchet teeth by tension springs 127.

Briefly therefore, although the pneumatic pulses from the cardiac compressor cylinder and thus line 50 to piston 81 occur about once every second, since cylinder 112 is controllably rotated by the ratchet element only a small fraction of a revolution with each pressure pulse of the cardiac compressor cylinder, the alignment of slots 114 and 114' only occur with their respective outlets 116 and 116' only once every five cardiac compressor strokes (or other multiple preset), to allow pressurized air to the spool valve and possible exhaust therefrom through the outlets 86 and 88.

The pressurized oxygen from outlet 86 through line 90 (FIG. 2) is eventually used in a special manner to supply oxygen enriched air to ventilate the lungs in a manner to be described. This gas through line 92 is used to reset the pressure cut-off valve subassembly 54 in a manner to be described hereinafter.

The pressure cut-off valve subassembly 54 is a bistable device which in the on position, provides an open passageway for the flow of primary oxygen-containing air, and which closes this passageway in the alternate position. Actuation from on to off is via feed-back pressure from the hose leading to the face mask and therefore representing endotracheal pressure. Actuation from off to on is via pressure reset pulses passing intermittently from programmer 52 through tube 92. The pressure cut-off serves to stop the flow of primary oxygen when pulmonary mask pressure has reached some safe preset value (e.g. about ten inches of water or i.e. about 0.35 p.s.i.). Thus it serves as a device to limit pulmonary pressures to within safe limits and to conserve the use of primary oxygen.

The specific construction of the pressure cut-off valve subassembly 54 is shown particularly in FIG. 7. It includes a spool valve 450 which has an annular groove between its spaced lands to allow controlled penumatic flow through the valve from inlet line 90 to outlet line 140. On one end of spool valve 450 is a reset valve actuating piston 452 to shift the valve to "on" or flow position. On the opposite end of the spool valve is a diaphragm pressure responsive actuator 454 to shut the valve off. The device is bistable by having a permanent magnet 456 mounted in one end to hold the valve in its off position until overcome by a greater force, and by having a second permanent magnet 458 mounted adjacent its opposite end to hold the valve in its on position until overcome by a greater force. At least one of the magnets, e.g. 458, is manually adjustable by a rotational setting member 460, to enable its axial spacing with respect to the spool valve assembly to be varied. Piston 452 is magnetically responsive to cooperate with magnet 456, and a piston 464 adjacent diaphragm 454 is magnetically responsive to cooperate with magnet 458. Each pulse from line 92 to piston member 452 shifts spool valve 450 to an on or flow position (to the left as illustrated in FIG. 7), since the facial area on the outer end of piston 452 is acted on by the application of primary oxygen pressure. Shifting the structure to the left therefore causes magnet 458 to attract inset 454 and thus hold the valve in the open position. Oxygen will then flow from passageway 90 to line 140 to the Venturi pump 56 and also to the diastolic delay control 60 until a pressure from line 470, communicates with the flexible conduit 66 to the face mask, is sufficient to shift diaphragm 454 to the right and thereby close off the spool valve passage. This thereby shifts magnetically responsive piston 452 close to magnet 450 to retain the valve in this off position. The oxygen flows through line 140 and line 140a to the Venturi pump subassembly 56 for a controlled period of time determined by the pressure to the lungs from pump 56, or, if this cut-off pressure is not reached, by the maximum period of time allowed by the diastolic delay control unit 60.

The Venturi pump is powered by this primary oxygen but its output is composed largely of ambient gas which is drawn into the reduced pressure area produced within the Venturi by the jet of oxygen containing gas to line 140a. Hence its input is generally of low volume and high pressure, but its output is generally of high volume and low pressure. It is especially designed to most effectively and efficiently encompass the optimal characteristics for pulmonary ventilation. Typical characteristics include an input pressure of about 50 p.s.i. and flow of about 50.0 liters per minute (stp.) with an output pressure of about 0.2 p.s.i. and output flow of about 200 liters per minute (stp.). Thus, the pump is said to have a net flow gain as compared to direct ventilation using only the gas containing primary oxygen. By so doing the pressure applied to the pulmonary system is safe, and the volume is sufficient to inflate the lungs rapidly. As noted from the above example, the gain is normally in the area of about 4.0. The ambient gases serve to dilute the primary oxygen which serves as the main gas in line 140 and 140a. Thus, in the above example, if the ambient gas is ordinary air, the output will contain oxygen higher than that in normal air, but lower than the pure oxygen flowing through line 140a. This results in an oxygen enrichment condition. Typically, if air is drawn in as the ambient gas, based upon the 5.5 ratio noted above, the oxygen

other factors preventing the lungs from completely filling. It should be realized that at present, it is believed medically advisable that ventilation should be performed without concurrent chest compression by the cardiac compressor. In fact, currently this is the only acceptable medical technique. An advantage of ventilation during diastole is the ability to judge the level of lung inflation by observing the chest rise.

Thus, for the restricted airway patient some compromise between ventilation and blood perfusion is required. This unique diastolic delay control, combined with the throttle valve makes this compromise possible with good control and repeatability and with minimum sacrifice of blood perfusion.

It has been found with actual experimentation that this diastolic delay control can be widely adjusted merely by turning threaded member **308** from the position where it is fully in, with maximum spring compression so that no delay will be provided, to a fully out position so that the diastolic time can be increased from the normal 0.5 second to over 2.0 seconds.

If desired, the maximum delay period may be preset to a fixed amount, say 1½ seconds. Then if the patient's airway can tolerate a high flow rate, negligible or zero delay will be encountered, since the lungs will fill quickly to cause pressure cutoff. If less flow is required, the needed delay of up to 1½ seconds will be automatically provided without further adjustment.

The assembly **22** in FIG. 9 allows pneumatic control of the pneumatically powered operation of the cardiac compressor. This system is supplied by pressurized oxygen from a pressurized oxygen supply, i.e. tank or line (not shown), in a conventional ambulance, emergency room, or the like. The oxygen supplied through connector **144** communicates to reservoir **14'** inside the column support **18** through branch line **144'**, and then separates into pressure lines **152** and **160**. Line **152** includes manually adjustable actuating pressure regulator **154** operated by knob **141** (FIG. 1). This line **152** communicates with the basic control valve **150** through an inlet port **156**. The second branch conduit **160** from the supply line communicates through a control pressure regulator **162** and through a controlled constriction **164** such as an orifice plate or needle valve, through branch conduit **169**, to inlet port **168** of valve **150**, and also to inlet port **170** of the automatic on-off pneumatic switch **172**. This pneumatic switch includes a valve spool **174** inside housing **176**, operable by extending shiftable manual knob **272** which may have a rigid push-pull connection extending from the housing base as shown in FIG. 1.

Control valve **150** includes a basic housing construction **180** having a valve spool **182** inside the valve box. Magnetically responsive armatures **184** and **186** are attached to opposite ends of the spool and are located in chambers **188** and **190** respectively. These chambers are closed by suitable end cap assemblies **192** and **194**. Armature **186** is also a piston having a peripheral seal (herewith an O-ring) to the periphery of chamber **190**. The portion of chamber **190** adjacent the inner face of piston **186** communicates through a port **200** and a conduit **202** to a small gas reservoir chamber **204** which may be simply a hollow cylindrical vessel for example. This reservoir also communicates through conduit **206** to another port **208** in valve body **180**. Both of these ports are interconnected pneumatically through an annular recess passage **212** around spool **182** when the spool is at the far right position as illustrated in FIG. 9. At the left position of the spool, relative to the drawings, port **168** is communicant with passage **216** in the valve spool body which is in communication through conduit **218** to a second reservoir chamber **220**. This reservoir chamber also communicates through another conduit **222** back to spool **174** of manual switch **172**, and specifically with annular recess **226** therearound.

In one position of this spool **174** it therefore is in operative communication with conduit **230** that communicates with the side of chamber **190** adjacent the outer face of piston **186**. In the other position of spool **174**, conduit **230** is in operative communication with conduit **169** which communicates with port **168** in valve body **180**.

Spool **182** also includes an annular recess **236** intermediate its end, communicating with an exhaust outlet port **238** in the valve body and also with a branch passage **216'** interconnecting with passage **216**. In another position, recess **236** interconnects with exhaust port **238** to passage **208'** branched from passage **208** in the valve body.

A third annular recess **244** in valve spool **182** is communicable in its first position (to the right) with port **248** and output pressure conduit **246** and also exhaust port **250** to allow flow therebetween. In its second position (to the left), it interconnects port **156** of conduit **152** with outlet port **248** to conduit **246**. This outlet conduit **246** interconnects with hose **40** to supply pressurized gas on a controlled basis to the top end of the plunger cylinder.

As noted previously, pistons **184** and **186** are magnetically responsive. Mounted adjacent the pistons is a pair of magnets **260** and **262** for the respective pistons **184** and **186**. By positioning these magnets at a controlled distance with respect to the outer faces of the pistons, the bias necessary to overcome the magnetic attraction of each piston to its own magnet and shift the spool in the opposite direction is controlled. This enables adjustment of the pressure necessary to build up in the alternate reservoir capacitor chambers **204** and **220** to shift the valve spool in one direction or the other. This controls the time interval of valve shifting. A fixed rod extension **270** is attached to piston **184** and extends through one magnet **260** out of the housing to terminate in a manual knob **272**. This manual knob extends from the end of the base **16** to be manually operable for actuating the valve manually, or to enable the diastolic delay control means **60** to hold the cardiac compressor for lung inflation on patients with restricted airways.

## Operation

In order to employ the novel apparatus with a patient requiring cardiac compression for blood perfusion, and lung ventilation for blood oxygenation, the patient is placed in the illustrated position (FIG. 1) with his back on platform **16**, and the cardiac compressor is adjusted so that pad **24** is immediately over the lower breastbone. Arm **20** of the cardiac compressor is vertically adjusted on column support **18** so that pad **24** contacts the breastbone or sternum when the pad and plunger are in the raised position. Then a gas supply hose **28** as from a conventional oxygen tank is connected. This is done when knob **272** is in a closed position to prevent premature air flow and compression.

Initially, the cardiac compressor equipment is actuated and after this is adjusted, the lung ventilation subassembly **15** is actuated. It will be realized that the pressurized gas acts as the actuating means for the cardiac compressor and as the controlling means for the cardiac compressor, and then subsequently acts as the actuating means for the lung ventilation, and as the controlling means for the lung ventilation, and further is used to provide increased oxygen enrichment.

In actuating the cardiac compressor, since valve **150** is closed, no gas is supplied to the compressing mechanism. When valve knob **272** is slowly opened, the compressed oxygen will pass from reservoir **14'** in the column to apply an operating pressure, controlled by regulator **154**, through conduit **152** and restriction **157** to port **156** in valve body **150** (FIG. 9). When the spool of the valve assembly **150** is in the position to the right, conduit line **246** which supplies pressurized gas to the top of the compressor cylinder is open to exhaust ports **250** (to the atmosphere). The gas flowing through conduit **160** and regulator **162** (which is previously adjusted for a particu-

lar time interval) flows through constriction 164 to manual switch 172 and to port 168 of the control valve. Switch 172 may be placed in the position illustrated in FIG. 9 for its automatic cycling control, and can be placed in its second position to cause communication between conduits 169 and 230 if valve 150 is to be operated manually. Assuming automatic operation being desired, gas passing through conduit 169, port 168, recess 212 in spool valve 182, port 208, conduit 206, to reservoir chamber 204, causes a steadily increasing pressure in chamber 204. Pressure increase is gradual due to restriction 164. At the same time, chamber 220 is exhausted to atmosphere by flow through conduits 218 and 216', recess 236, and port 238. As soon as the pressure in chamber 204 reaches a predetermined amount, to apply a sufficient pressure to piston 186 to overcome the magnetic attraction between magnet 260 and piston 184, it will shift piston 186 to the left as illustrated in FIG. 9, toward magnet 262. When it does this, conduit 152, port 156 and recess 244 will allow flow of pressurized actuating gas from conduit 152, through cavity 244 in spool 182, through port 248 and conduit 246, and thence to the upper end of the compressor cylinder. This forces the plunger down to compress the chest and squeeze the heart (systole) for perfusion. The actual time of piston extension and compression, prior to its release for retraction, is determined by filling of the second reservoir chamber 220 (FIG. 9).

As soon as spool valve 182 is shifted to the second position from that illustrated in FIG. 9, compressed oxygen passes from conduit 169 through port 168, recess 212, port 216, conduit 218, to fill reservoir chamber 220. Pressure in chamber 220 is also exerted on the outer face of piston 186 due to the connection through conduits 222 and 230 through the selector switch valve 172. Therefore, as soon as the pressure in this chamber has built up sufficiently to overcome the magnetic attraction of magnet 262 to piston 186, the bistable valve shifts back in the opposite direction. Meanwhile, pressure in chamber 204 will be bled to chamber 16*a* beneath the base of the cardiac compressor assembly. As soon as this valve shifts back to its initial position, the pressurized air exerted on the cardiac compressor plunger is released so that the natural resilience of the chest to expand causes it to do so and thereby allows the heart to expand and be filled with blood (diastole). Once the regulatory action is obtained to cause this cardiac compressor valve to reciprocate back and forth on a controlled basis, normally of about ½ second time interval for diastole and about ½ second time interval or slightly more for systole, attention is then paid to ventilation of the lungs through subassembly 15.

As noted previously, the constant supply of pressurized oxygen at about 40–60 p.s.i. from input conduit 28 through connector 144 and its branch 144*a*, to line 104, and to programmer subassembly 52, causes a constant pressure to be put into assembly 52 up to rotational cylinder 112 (FIG. 4 and 5). Also, with each compression stroke of cardiac compressor subassembly 12, a pressure pulse is applied through line 50 branching off line 40 to the compressor, to inlet passageway 83 and to piston 81 of the programmer. Thus, with each compression stroke of the cardiac compressor, piston 81 shifts to the right (as illustrated in FIG. 5) to back up ratchet levers 122 for taking another bite on ratchet wheels 120. With each release of the cardiac compressor, the valve shifts back to the left, to cause spring 100 to shift the ratchet wheels through an angle to rotate cylinder 112 a controlled amount. After a multiple of these reciprocations, and angular rotations, preferably every fifth cardiac compression reciprocation, slot passages 114 and 114' on cylinder 112 line up with outlet passages 116 and 116' to apply oxygen pressure through outlets 82 and 82' to spool valve 80. When this valve is shifted by piston 81 during that one stroke, the pressurized oxygen flows out outlet passages 86 and 88. The pressurized oxygen therefore flows through lines 90 and 92 down to the pressure cut off valve subassembly 54. Pressure in line 92 actuates piston 452 (FIG. 7) to the left to open spool valve 450. When spool valve 450 (FIG. 7) is open, oxygen flows from line 90 to line 140 and hence to nozzle 460 of Venturi pump 56 (FIG. 6). It then picks up the ambient gas, either air or oxygen enriched air, depending upon whether flapper valve 16*c* (FIG. 8) is one position or the other, and discharges it through passage 165, past throttle valve 468, to flexible hose 66 and to face mask 58.

As soon as the pressure in the lungs, i.e. pulmonary pressure, has built up to a predetermined value, it applies a back pressure through line 470 (FIG. 3) to diaphragm 454 (FIG. 7) to shift valve 450 to its closed position to shut off the oxygen flow to line 140 and thus to the lungs. Upon release of the pressure to the patient, the patient exhales automatically, as usual, through discharge valves (not shown) in mask 58. Exhaling is assured when the cardiac compressor then goes through its compression portion of the cycle, to depress the sternum.

One of the many novel features is very important for optimum regulation of ventilation and cardiac compression independently as well as synchronously. Specifically, either the ventilation or the compression portions of the system can be started independently of the other, can be stopped independently of the other, and can be re-started independently of the other, while both are automatically synchronized whenever operating simultaneously. During initial start up, therefore, for example, the cardiac compressor can be initiated and regulated, and subsequently, when the ventilator is initiated and regulated, it is instantly synchronized. Also, as another important example, if the heart is in fibrillation, it has been medically determined that defibrillation is best attempted after the heart has been compressed for a period until it is a more receptive condition. Thus, when this condition is detected, as by electrical probes, the compressor may be temporarily stopped while ventilation continues, or both may be stopped, the typical defibrillating medical injections and electrical shock treatment are made, and then the compressor is reactivated, automatically in synchronism with the ventilator, until the heart can take over by itself. Moreover, the compressor can be temporarily stopped at any desired time to check on the heart action, without disrupting the ventilation action. Such features greatly aid the attending physician in his efforts.

If the patient has a restricted airway, throttle valve 471 is manually adjusted to a lower rate of flow of oxygen containing air to the patient, and the pre-adjusted diastolic delay control 60 will automatically produce a delay during that particular period of diastole that is used to fill the lungs. This is accomplished as follows: The air pulse from the pneumatic cut-off valve through lines 140 and 140*b* (FIGS. 2 and 3) causes a shift of piston 304 (FIG. 8) to the left and thereby actuates linkage 314 to pull shaft 270 of valve 150 (FIG. 9). This puts a temporary holding force on this valve 150 that controls the cardiac compressor rate. The cardiac compressor will therefore be held in its noncompressing elevated position until the pressure in the lungs increases to the predetermined amount, at the slower flow rate, until it applies back pressure through line 470 (FIG. 3) sufficient to actuate the pressure cut-off valve to its off position, or until a maximum, preset, time has elapsed. This releases the flow of oxygen through lines 140*a* and 140*b*, so that the actuating pressure on diastolic delay control 60 is relaxed, enabling the pneumatic pressure on the valve mechanism 150 (FIG. 9) to shift it again to its cardiac compression activating position (i.e. to the left as viewed in FIG. 9).

Briefly therefore, the cardiopulmonary apparatus broadly is a combination of the pneumatically operable cardiac compressor 12 which has pneumatically operable compression cycling control valve means 150 (FIG. 9), and lung ventilation means including pumping means 56 in housing 62 and receiving a controlled amount of enrich-

ment oxygen from compressor exhaust chamber **16***a*, tube conduit **66** and face mask **58**, and ventilation cycling control means cooperable with the compressor supply and the compressor control means, and including programmer **52**, flow cut-off valve **54** operable with a feed back pressure in conduit **470**, and compressor delay control **60** cooperable with throttle **468**. Each of these components in the combination has special operational features as set forth above.

It will be obvious from the foregoing description that the combination is particularly unique in several respects. The device has been repeatedly operated on an experimental basis and used on patients and found to operate extremely well and dependably. It has been found to be safe, easily controlled, highly variable to suit the size, age and condition of patients. It can be readily operated by one person, obtaining controlled lung ventilation and cardiac compression in controlled synchronized fashion, and enabling complete lung inflation without reliance upon conventional mouth-to-mouth techniques.

Second form

In the system **510** shown in FIG. 10, the cardiac compressor assembly **12** basically has the same construction as that illustrated in FIG. 2. Also, programmer **52** and cut-off valve **54** are the same as that previously described with regard to the first embodiment. The Venturi pump **56'** is slightly different from the previously disclosed pump **56**, due to an improved air flow relationship. It connects with hose **66** to the face mask as previously. Its throttle valve **468** is also preferably interlinked mechanically with a novel valve unit **514** described in detail hereinafter.

Probably the most important difference in the system in FIG. 10 from that in FIG. 2 is the use of a pneumatic diastolic delay control **516** instead of the mechanical arrangement **60** in the first form of the device. This novel diastolic delay control unit **516** is interconnected pneumatically with cycling valve assembly **150** (FIG. 9) and pneumatic capacitors **204** and **220**, specifically capacitor **204**. This is done by inserting unit **516** in line **206** so that the flow rate from valve assembly **150** to air capacitor **204** is controlled. It will be understood that by reducing the flow rate of oxygen to the capacitor, the time required to build up to a predetermined pressure in capacitor **204** sufficient to overcome the magnetic attraction of magnet **260** (FIG. 9) and shift the valve unit in assembly **150** to the left (as viewed in FIG. 9) can be delayed a controlled amount.

Referring specifically to FIG. 10, unit **516** includes a housing **520** interconnected in line **206**, the branch lines of which are hereby designated as **206'** and **206''** for convenience. The housing forms a first chamber **522** to which lines **206'** and **206''** openly communicate through passageways **524** and **526**. In chamber **522** is a small piston member **528** (FIG. 13) which can close off the connection between these two passageways when shifted to the right (as viewed in FIGS. 10 and 13). In parallel with the through passage through this housing is a passage connection from line **206''** through a variable needle valve assembly **530**, hence passage **526** to the conduit **206'**. Thus, when the through passage through the diastolic delay control housing is closed, the rate of flow from valve assembly **150** to capacitor **204** can be regulated by adjusting this needle valve device **530**. This of course then controls the rate of pressure buildup in capacitor **204**, to thereby control the time duration before valve unit **150** is shifted in the opposite direction to shift the assembly from a diastolic (non-compressing) condition to a systolic (chest compressing) condition.

The control over whether or not the through passageway in the diastolic delay control housing is open or closed is achieved by tapping a line off the main pressure line **140***a* through which the primary oxygen flows from the cut-off valve assembly **54** to the venturi pump **56'**. Specifically, this lead off pneumatic line **540** communicates to housing **520** to one end of an enlarged actuating piston **542** which is interconnected with smaller piston **528**, and which is normally biased by spring **544** to a position allowing the through passageway to be open. It will be realized therefore that the diastolic delay control valve unit is closed, to cause throttle flow through needle valve **530**, only when pressure is applied to the primary oxygen line **140***a* from the cut-off valve to the Venturi pump **56'**. Thus, if the entire ventilation system is shut off while the cardiac compressor system is operating, there will be unhindered air flow to the diastolic pressure build up capacitor **204** as well as the systolic pressure build up capacitor **220**. Thus, the cardiac compressor will operate at its normal preset rate. When the ventilation adjunct is activated, the diastolic delay control is activated so that the pressure on piston **542** closes this through passage through the control housing, and requires all air to be passed through the needle valve **530** capable of throttling the passage. If the patient has no windpipe obstructions or the like, then full flow rate may be used, and the patient's lungs will quickly fill until pressure cut-off of the respirator occurs, and little or no delay will be needed. However, if the patient exhibits windpipe restrictions or the like of the type for example set forth specifically with regard to the first form of the invention, then reduced flow rate would be utilized, and the previous adjustment of needle valve **530** will cause the diastolic time period during the non-compression step of the chest to be delayed a controlled amount, to enable the proper amount of air to be introduced into the patient's lungs for proper ventilation.

The primary oxygen for the entire apparatus is introduced through line **28** as previously. It passes through connector **144** and thence preferably through a filter **509** from whence it flows to the cardiac compressor unit through the support assembly as in the first form of the invention and in a manner generally represented in FIG. 10 by the pneumatic line **511**. It also passes through line **104'** to the programmer **52** through an added ventilation adjunct control valve **514**. The main function of control valve **514** is an on-off function to enable the operator to start or stop the operation of the ventilation portion of the system. (In this form of the apparatus an on-off valve **513** has been added to pneumatic line **40** on the cardiac compressor, to enable the operator to turn the cardiac compressor portion of the system on or off.)

This valve **514** includes, for example, a mechanism having a stationary member **550** (FIG. 12) and a rotary member **552**. The stationary member includes an oxygen inlet port **104''** communicating with line **104'**, and a nearby outlet **104'''**, such inlet and outlet ports being arranged with respect to the rotor as shown in phantom in FIG. 11. These ports are arranged in an arcuate path, to correspond selectively with arcuate passage **554** in rotor member **552**. This arcuate passage preferably has a gradually varying depth as shown in FIG. 12 so that it will act not only in an "on-off" manner selective communication and non-communication between ports **104''** and **104'''**, but also, when in communication with both of these ports, can regulate the rate of flow therethrough by the depth of the particular arcuate portion of the passage **554** placed in communication therewith. Thus, valve assembly **514** can act not only as an on-off means but as a "primary" throttling means on the oxygen pressure being passed to the ventilation adjunct portion of the system. It will be realized that the butterfly type throttle valve **468** shown in the Venturi pump **56'** acts as a volume flow control for the air passed to the patient through the face mask. This valve **468** does not normally vary the limiting pressure of the flow to the face mask significantly, but mainly varies the volume flow rate. (Throttling of the "primary" flow, however, will reduce the maximum output pressure from the Venturi pump.) By utilizing valve **514** as a pressure flow control of the oxygen to the programmer **52**, the result is that unit **514** can serve as a primary throttling means, while valve unit **468** serves as a secondary throttling means. The primary throttling means is desirable in order to conserve the amount of oxygen used when, for

example, a relatively smaller flow rate might be desired from the Venturi pump. However, it normally is not desirable to throttle the primary flow down to too low a value, since the resulting maximum output pressure might not be sufficient to fill the patient's lungs to a necessary amount. Thus, these valves are set to predetermined optimum operating characteristics. The valves are preferably mechanically linked as indicated, as by being mounted on the same rotary shaft. This is done by extending shaft **469** into the central receiving cavity **471** in the valve unit **514**.

In FIG. 11, valve unit **514** is also shown to have a ball and detent connection, specifically ball **566** and slot **568**, to enable the operator to have optimum feel of the valve condition during its rotary actuation, to render the assembly bi-stable between "off" and "on" positions and to provide holding friction at various "on" settings.

The operation of this second form of the invention is basically the same as that in the first form of the invention, except that the connection between novel valve **514** and throttle **468** provides an added control, and except that the diastolic delay control is achieved by adjusting needle valve **530** rather than adjusting member **308** in the diastolic delay control **60** shown in FIG. 8.

It will be obvious to those having ordinary skill in this art that the details of construction of this particular preferred embodiment may be modified in a great many ways without departing from the unique concepts presented. It is therefore intended that the invention is to be limited only by the scope of the appended claims rather than to any of the particular details of construction shown, except as specifically stated in the claims.

We claim:

**1.** A combined cardiopulmonary apparatus comprising: a reciprocatable cardiac compressor means and cycling control means therefor; lung ventilation means including Venturi pumping means having nozzle means, said nozzle means having pressurized oxygen inlet means, said pumping means having supplemental air inlet means adjacent said nozzle means, whereby said pumping means can employ high pressure, low volume intake for causing low pressure, high volume output for ventilation, lung ventilation control means operably connected to said compressor cycling control means, and throttle means operably connected to said lung ventilation means to vary the output rate from said lung ventilation means.

**2.** The apparatus of claim **1**, wherein said cardiac compressor means employs oxygen and has an oxygen exhaust, which exhaust is connected to said supplemental air inlet means for oxygen enrichment of the ventilation gas.

**3.** A combined cardiopulmonary apparatus comprising: a pneumatically operable, reciprocatable, cardiac compressor means; pneumatically operable compression cycling control valve means operably associated with said compressor means to supply pneumatic pulses thereto; lung ventilation means including gaseous inlet means and pneumatically operable, ventilation cycling control means; a programmer valve operably associated with said cycling compression control valve to receive pneumatic pulses therefrom to actuate said programmer valve synchronously with said cardiac compressor cycle control valve to periodically allow a gaseous flow therethrough only once every predetermined multiple of said pulses; and said ventilation cycling control means being operably associated with said programmer valve to cause ventilation in controlled synchronism with said cardiac compressor means.

**4.** The apparatus in claim **3** wherein said programmer valve means is actuated by said pulses to stop said flow at the next succeeding pulse after said predetermined multiple of pulses, to limit lung ventilation to a time period of one compressor cycle.

**5.** The apparatus in claim **3** wherein said programmer valve means is responsive to allow said flow only upon termination of the last pulse of said multiple of pulses, to cause ventilation flow during the diastole period of the cardiac compression.

**6.** The apparatus in claim **3** wherein said ventilation means includes pumping means, a face mask, and flow conduit means allowing flow from said pumping means to said face mask; and said ventilation cycling control means includes pressure responsive flow cut off means have a pressure feedback conduit communicant with said face mask and said flow conduit means, to stop said air flow after a predetermined pulmonary pressure occurs in said face mask.

**7.** The apparatus in claim **6** including throttle means to variably throttle flow from said pumping means to said face mask to accommodate restricted patient air ways, and including pneumatically operated compressor delay control means operably associated with said flow cut off means and said compression cycling control valve means to controllably delay the succeeding cardiac compression cycle during throttle flow inflation of the lungs of a patient with restricted airways.

**8.** The apparatus in claim **7** wherein said delay control means comprises a holding means for temporarily holding the pneumatically operable compression cycling control valve means with a predetermined holding force, and being actuable only during the lung ventilation cycle after each of said predetermined multiple of pulses.

**9.** The apparatus in claim **6** including pneumatically operated compressor delay control means operably associated with said flow cut off means and said compression cycling control valve means to controllably delay the succeeding cardiac compression cycle during throttle flow inflation of the lungs of a patient with restricted airways.

**10.** The apparatus in claim **9** wherein said delay control means comprises mechanical holding means for temporarily holding the pneumatically operable compression cycling control valve means with a predetermined holding force, and being actuable only during the lung ventilation cycle after each of said predetermined multiple of pulses.

**11.** The apparatus in claim **9** wherein said delay control means comprises pneumatically actuated flow restrictor means pneumatically associated with said compression cycling control valve means to delay the operation thereof and thereby to controllably delay the succeeding cardiac compression cycle during throttle flow inflation of the lungs of a patient with restricted airways.

**12.** The apparatus in claim **3** wherein said compression cycling control valve means and said ventilation cycling control means include respective on-off control means capable of deactivating either of the respective cardiac compressor means and lung ventilation means while allowing the other to operate normally, and of reactivating the deactivated means in synchronism therewith.

**13.** The apparatus in claim **3** wherein said ventilation cycling control means includes primary throttling pressure control valve means for said lung ventilation means, and includes secondary throttling flow control valve means for said lung ventilation means, said primary and secondary throttling pressure control valves being interconnected such that a reduction in the flow rate through the first pressure control valve will produce a reduction in flow rate through the second pressure control valve.

**14.** Combined cardiopulmonary apparatus, comprising: pneumatically operable, reciprocable cardiac compressor means having inlet means for connection to a pressurized oxygen supply and having cycling control means therefor; lung ventilation means and cycling control means therefor said lung ventilation control means operably connected to said cycling control means for said cardiac compressor and synchronized therewith; said lung ventilation means including Venturi pumping means having a nozzle with pressurized oxygen inlet means thereto; said pumping means having supplemental gas inlet means adjacent said nozzle; said cardiac compressor means having exhaust means for exhausting the oxygen used for compressing; and enclosure means for said exhaust means and said

supplemental gas inlet means, to enable further oxygen enrichment for ventilation.

15. The apparatus in claim 14 including flow control means from said exhaust means to said supplemental gas inlet means for control of oxygen enrichment.

16. A combined cardiopulmonary apparatus comprising: a pneumatically operable, reciprocatable, cardiac compressor means; a pneumatically operable, compression cycling control valve means operably associated with said compressor means to supply pneumatic pulses thereto; lung ventilation means including gaseous inlet means and pneumatically operable ventilation cycling control means, said lung ventilation means including Venturi pumping means having a nozzle with pressurized oxygen inlet means thereto; said pumping means having supplemental gas inlet means adjacent said nozzle; said cardiac compressor means having exhaust means for exhausting the oxygen used for compressing; an enclosure means for said oxygen means and said supplemental gas inlet means to enable further oxygen enrichment for ventilation; and said ventilation cycling control means being operably associated with said cardiac compressor cycling control valve means



to cause ventilation in controlled synchronism with said cardiac compressor means.

17. The apparatus in claim 16 including flow control means from said exhaust means to said supplemental gas inlet means for control of oxygen enrichment.


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