

Jan. 17, 1967

A. LATHAM, JR
ATRAUMATIC FLUID PUMP

3,298,320

Filed May 17, 1965

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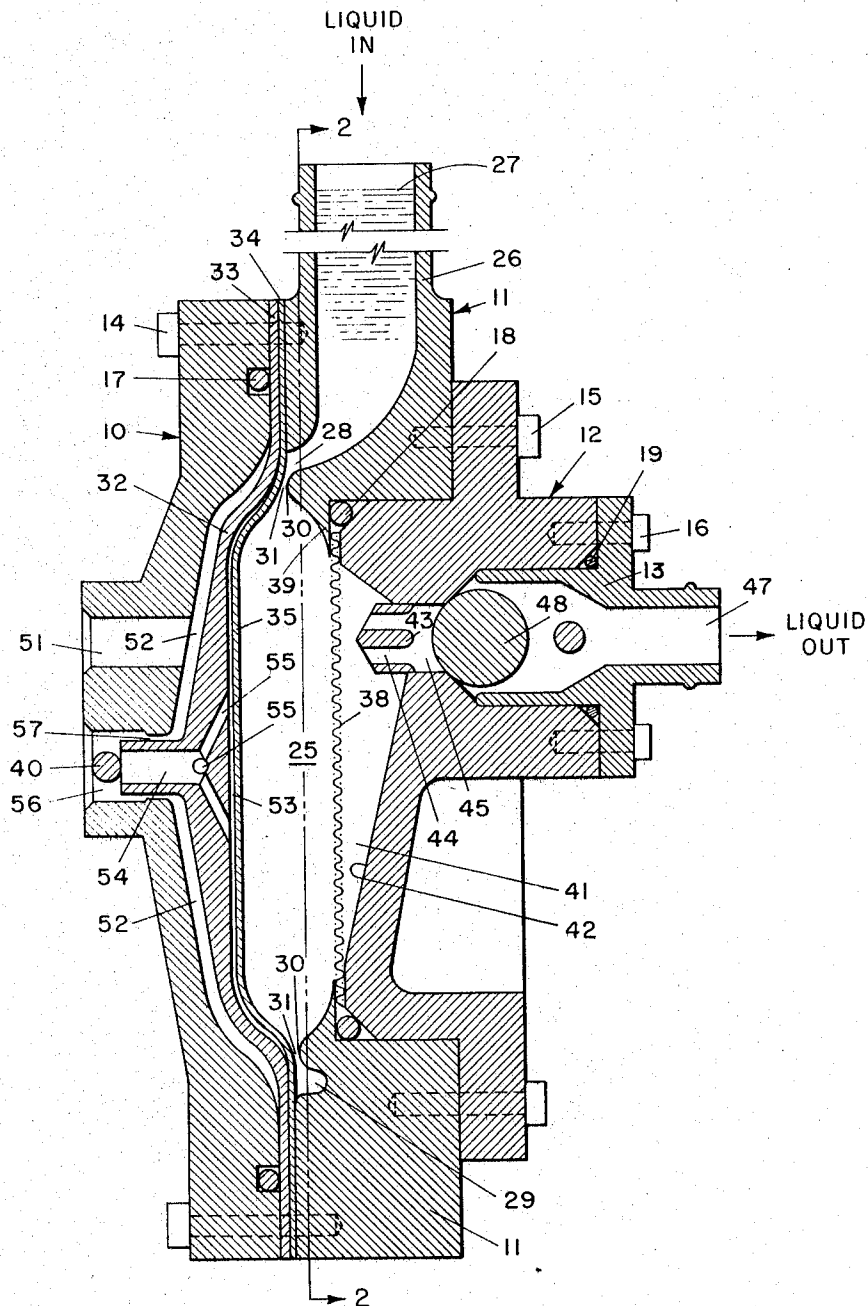


Fig. 1

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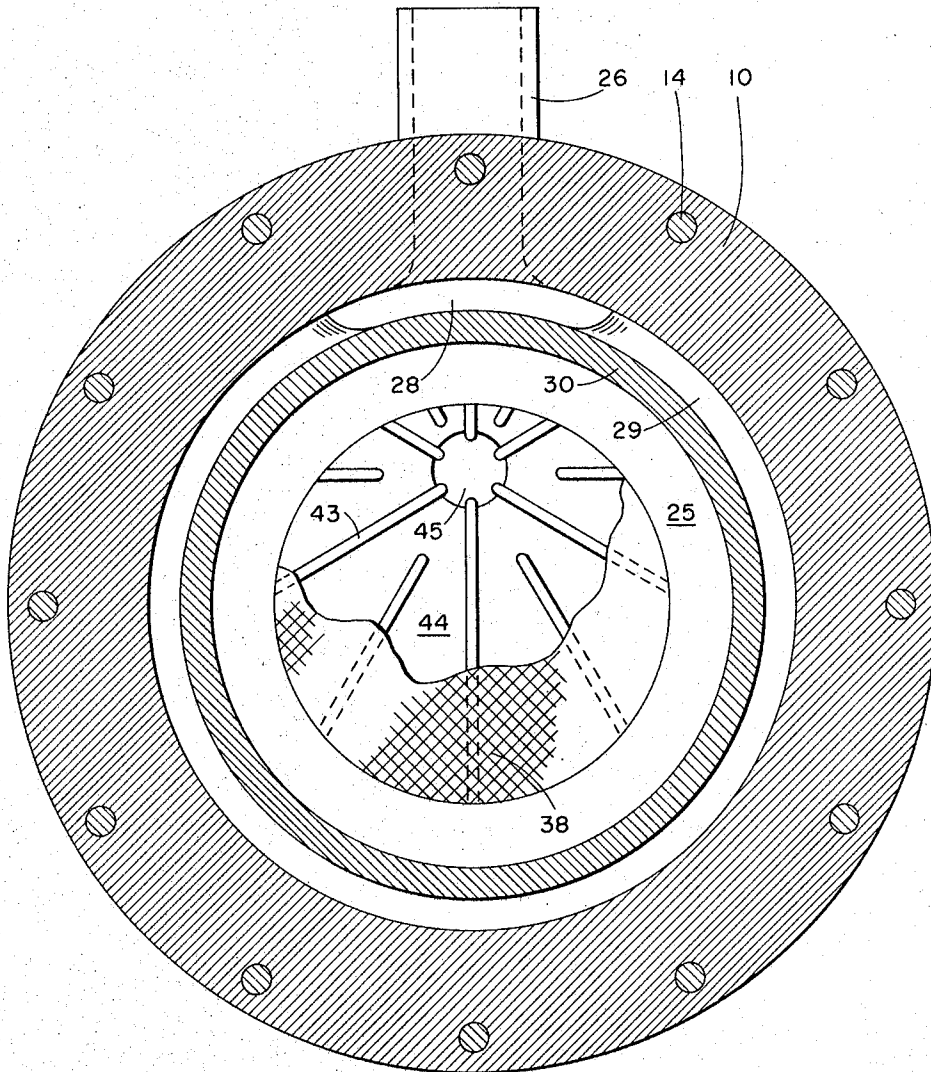


Fig. 2

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4 Sheets-Sheet 3

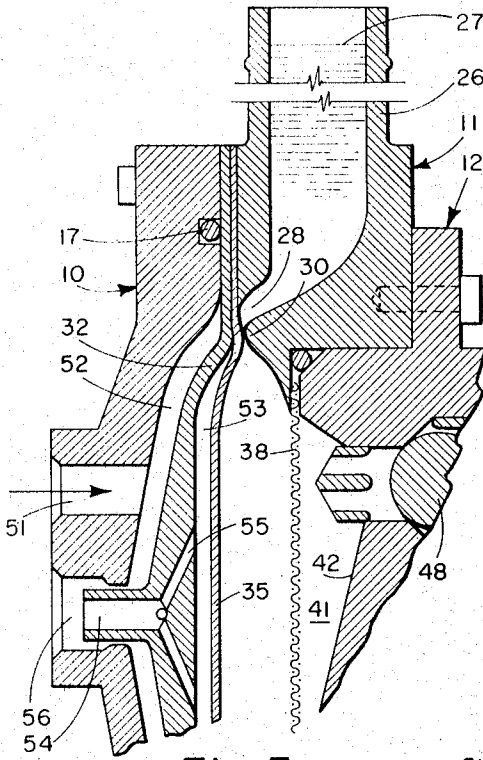


Fig. 3

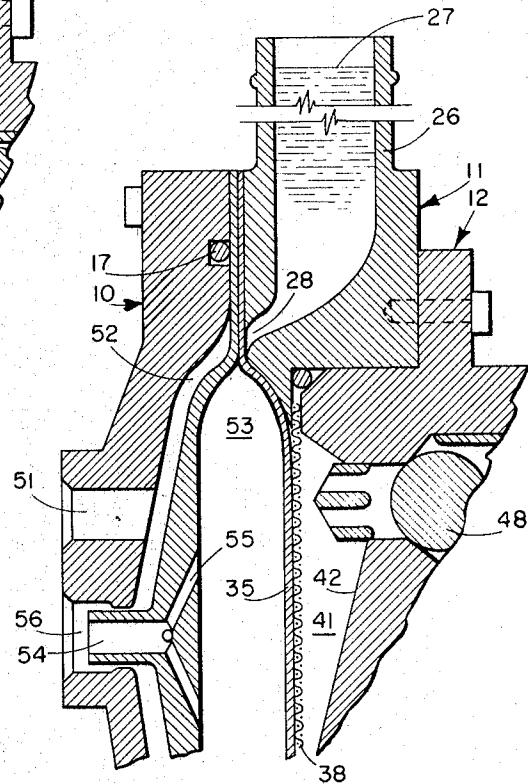


Fig. 4

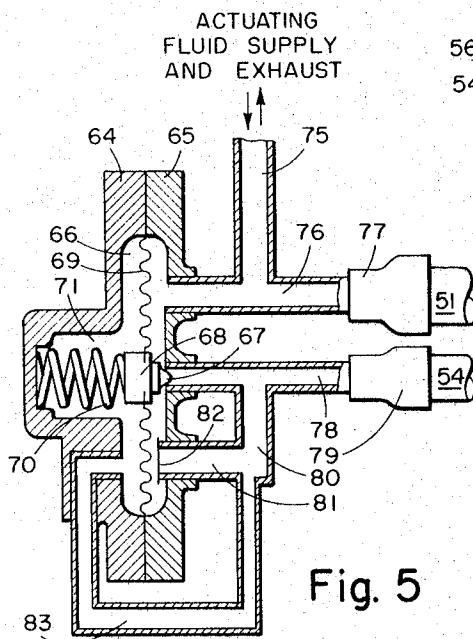


Fig. 5

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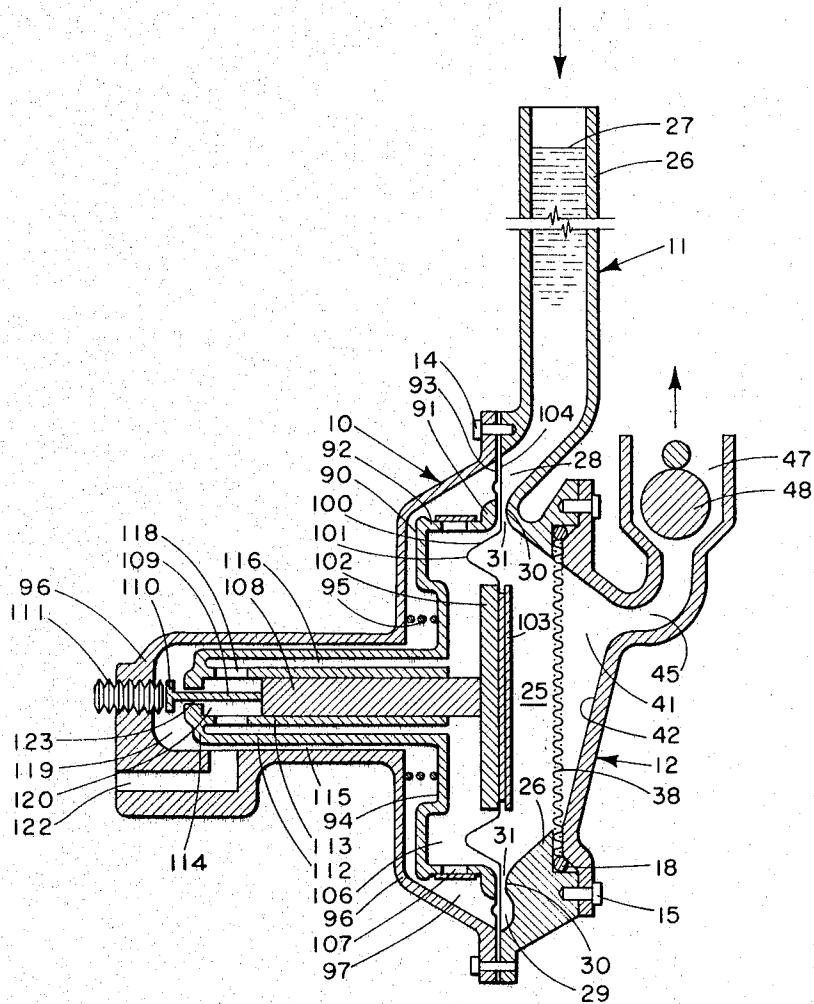


Fig. 6

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3,298,320

ATRAUMATIC FLUID PUMP

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9 Claims. (Cl. 103—152)

This invention relates to an apparatus for pumping fluids which are subject to traumatic effects and more particularly to an apparatus which is capable of pumping blood for extracorporeal circulation.

The description of the apparatus of this invention is presented in terms of the problem of pumping or circulating blood; but it is to be understood that the apparatus has application in other related fields.

Although the concept of artificial extracorporeal circulation has long been a part of medical thinking, it has only been recently that it has been an important technique in medical practice. The concept of extracorporeal circulation as an aid to cardiac surgery originated in 1937, and although much work has been done on the techniques involved, there is much more work to be done to make it routine. However, extracorporeal circulation need not be limited to cardiac surgery and the term is generally now employed to refer to any artificial system by which all or a part of the circulated blood is transported outside the body. It covers procedures as different from cardiac surgery as the perfusion of isolated organs and the connection of a living organism to any kind of artificial device so long as the blood taken from the organism is eventually returned to it.

If the extracorporeal circulation is to replace all or part of the heart-lung system, then it is necessary to combine a blood pump with an oxygenator which is a gas exchange device to replace the gas exchange function of the lungs. Such a system then becomes a pump-oxygenator and the apparatus of this invention is suitable for incorporation into such a system. As an example of the use of such apparatus there may be cited the cases involving chemotherapy where it is desired to treat an isolated area of the body with a chemical which can be transported in the blood but which may be harmful to certain organs. Under these circumstances it is possible to use the blood pump of this invention along with an oxygenator for partial perfusion of the blood through the isolated area without danger of poisoning the rest of the system. There are also, however, circumstances in which the blood pump may be used without an oxygenator such as when endogenous oxygenation is employed. Finally, in the case of severe injury or shock it may be desirable to supplement the heart action for a short period of time.

The fluid pump of this invention is intended to be used in any of the roles described above or in any application where it is necessary to pump fluids which are subject to the infliction of trauma thereon.

Many mechanical devices have been designed for pumping blood and several of these are in operation. However, all of the mechanical blood pumps developed up to the present time require as an integral component some form of control means to prevent the pumping of gas in the event of insufficient blood supply to the pump inlet. Such control means now range from float valves to complex and expensive electronic systems. All of these control means at present constitute an inherent source of concern over their absolute dependability. This concern for dependability is grounded on the fact that in any pumping system, such as a heart-lung system, wherein the pump draws blood from a reservoir with a liquid level involving direct contact of the blood with gas and forces blood into the arterial system of the patient, it is

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absolutely necessary to prevent the pumping of free gas into the arterial system. Inclusion of large bubbles in the arterial blood is likely to be quickly fatal. It is therefore desirable, if not mandatory, that a blood pump provide absolute assurance against drawing the gas-blood interface into its pumping chamber. The blood pump of this invention has this assurance as an inherent characteristic.

Some of the blood pumps of the prior art possess, among other drawbacks, another very serious disadvantage, that is of inflicting trauma to the blood. For example the infliction of trauma will hemolyze the red blood cells and then organs such as the kidneys are overburdened with free hemoglobin and other waste matter all arising from the trauma.

Specifications for the ideal blood pump can be established; and Galletti and Brecher in their book "Heart-Lung By-Pass—Principles and Techniques of Extracorporeal Circulation" (Grune and Stratton, New York, 1962) have listed the desirable features of a blood pump. Among these features are the ability to move blood volumes up to 5 liters per minute against pressures up to 180 mm. of mercury, and the ability to handle the blood at low velocities of flow. The ideal blood pump should, in addition to providing absolute assurance against drawing the gas-blood interface into its pumping chamber, have all smooth internal surfaces while being free of all dead spaces and recesses to eliminate any opportunity for stagnation or turbulence, or for the formation of bubbles, foam or clots. It should be able to be readily dismantled, cleaned and sterilized with the blood-handling components being disposable. The ideal pump should be amenable to rapid and reliable calibration, and should be able to be automatically controlled in normal use and manually operated in an emergency. Finally, it should have an adjustable stroke volume with a controllable pulse rate. The extent to which the blood pump of this invention approaches the attainment of these ideals will become apparent in the following detailed description.

It is therefore a primary object of this invention to provide an improved mechanical pump, particularly one suitable for pumping blood. It is another primary object to provide a blood pump which by its very design and construction assures that the gas-blood interface can never enter the pumping chamber to give rise to the introduction of fatal bubbles into arterial blood. It is an additional object to provide a blood pump of the character described which is atraumatic with respect to the fluid being pumped. It is another primary object of this invention to provide a blood pump which is capable of moving blood volumes up to 5 liters per minute against pressures up to 180 mm. of mercury without inflicting trauma upon the blood. It is a further object of this invention to provide a mechanical pump of the character described which is flexible in its use, with or without an oxygenator, and is adaptable for applications which require total or partial perfusion. It is a still further object to provide such a pump which is portable, does not require a source of electric power, and is adaptable as a supplement to or a temporary replacement for the heart in conditions of severe shock or injury. It is another object of this invention to provide such a pump which is easily assembled and disassembled and which can be so constructed that it is entirely disposable, thus simplifying and minimizing problems of sterilization and assembly. It is another object of this invention to provide a blood pump which can be controlled either automatically or manually and which can be adjusted for a controllable pulse rate. Other objects of the invention will in part be obvious and will in part be apparent hereinafter.

The invention accordingly comprises the features of

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construction, combination of elements and arrangement of parts which will be exemplified in the construction hereinafter set forth, and the scope of the invention will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention reference should be had to the following detailed description taken in connection with the accompanying drawings in which

FIG. 1 is a longitudinal cross-section of one embodiment of the pump of this invention;

FIG. 2 is a cross-section of the pump of FIG. 1 along line 2—2 of FIG. 1;

FIGS. 3 and 4 are fragmentary cross-sections of the pump as in FIG. 1 showing the movement of the diaphragms during the operation of the pump;

FIG. 5 is an embodiment of one form of a valve system used to control the flow of pressurizing fluids for driving the pump of FIG. 1; and

FIG. 6 is a longitudinal cross-section of another embodiment of the pump of this invention.

The blood pump of this invention is basically a diaphragm pump; but the flexible pumping diaphragm made of a soft material such as silicone rubber, serves the dual functions of fluid displacement and inlet valve actuation. The region of the diaphragm toward the center serves for fluid displacement, while the region near the rim, by seating against a rounded shoulder in the pump body between an inlet passage and the displacement zone, serves as a very low impedance inlet valve. At the end of its pumping stroke the diaphragm is confined by the smooth interval contour of the pumping chamber and a smooth perforated plate or screen which is set into the chamber at the entrance to the discharge valve region. The discharge valve itself may be a simple ball valve or any of the recently developed valves for this type of service. The extreme position of the diaphragm during the intake stroke is set by adjustment of a stop.

The blood pump of this invention may be driven entirely by a pressurized fluid and may therefore be independent of any electric power supply. This means that it may be connected to the pressurized oxygen cylinders which are always available in an ambulance or in a hospital and may therefore become an integral part of first-aid equipment. It is of course not limited to pressurized oxygen as a driving fluid and it may be connected to any suitable source of a pressurized fluid including a pump and the like. In a typical operating situation the pump is actuated by either air or oxygen at approximately 10 p.s.i. with venting to atmospheric pressure. Thus, the venting pressure is the same pressure as that on the gas-blood interface at the liquid level of the blood in the system. The pump diaphragm and inlet valve actuator assembly are preferably so arranged as to have a soft but positive spring constant which will hold the inlet valve portion of the diaphragm against the inlet valve shoulder at all times except when the hydrostatic head of blood over the pump inlet exceeds the pressure of gas in the actuating side of the diaphragm chamber. Thus, the inlet stroke can be accomplished only by the pressure of blood displacing the diaphragm and expelling the actuating gas through the vent passages. If for any reason the supply of blood is insufficient to displace the diaphragm full stroke, the inlet flow stops through lack of sufficient hydrostatic head before the gas-blood interface has dropped to the pump inlet. Normally, when the inlet stroke is carried to completion the intake volume is established by the setting of the stroke adjusting stop. Thus, in normal operation, the volume pumped per stroke will remain constant for any given setting.

The discharge stroke is accomplished by pressurization of the gas in the actuating chamber. By providing a continuous or cyclic positive difference in the fluid pressure in the valve actuator chamber and in the displacement region of the diaphragm the inlet valve will be tightly closed before the discharge stroke actually com-

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mences and will remain closed throughout the duration of the stroke. Upon completion of the stroke, the pressure in the actuation chamber is vented and a low-impedance lightly sprung system of valves permits free discharge of the gas from the displacement section of the actuation chamber into the vent passages.

Two embodiments of the blood pump incorporating these basic operational principles are illustrated in FIGS. 1 and 6. These two embodiments differ primarily in the details of design of the diaphragms and the arrangement of the pneumatic means by which they are driven. However, both pumps use the hydrostatic head of the blood to open the inlet valve mechanism and hence both provide absolute protection against bubble formation in the blood. FIG. 2 further illustrates the annular ring opening into the pumping chamber and the associated annular valve seat, an arrangement common to both embodiments. FIGS. 3 and 4, which are fragmentary cross-sections, when examined with FIG. 1, illustrate the manner in which the blood pump operates. FIG. 5 is a detail of a valving system suitable for use with the blood pump of FIG. 1.

As will be seen in FIG. 1 the pump is formed of three separable sections. From left to right in FIG. 1 these comprise the valve and diaphragm driving section 10, the central fluid supply and fluid volume section 11, and the discharge section 12 which has associated with it a discharge valve body 13. By means of suitable screws 14, 15 and 16 these sections can be readily assembled and disassembled; and in assembly are made fluid-tight through the use of suitable sealing rings 17, 18 and 19. The three pump sections define internally a displacement fluid volume 25 which is in effect the pumping chamber. Admission of blood into this displacement fluid volume 25 is by way of blood inlet conduit 26 which is of sufficient height (typically about 12 inches) to impart to the blood entering the pump a hydrostatic head of sufficient magnitude to activate the intake stroke of the pump. Thus the displacement volume 25 is filled provided there is a sufficient supply of blood in inlet conduit 26. When the supply of blood in conduit 26 is insufficient to generate the necessary hydrostatic head, the valve mechanism into displacement volume 25 is not actuated which in turn means that the gas-blood interface 27 never enters the pump and there is therefore absolute assurance that no gas bubble will be present in the blood being pumped.

Admission of the blood from conduit 26 into volume 25 is by way of passageway 28 which opens into annular passage 29 (see FIG. 2) which in turn serves to introduce the blood into the displacement volume 25 around the entire periphery of the chamber. The central section 11 of the pump is provided with an annular rounded shoulder 30 which serves as a valve seat against which diaphragms can be contacted. When the diaphragms are not contacting the shoulder 30, they define with it an annular ring opening 31 which provides fluid communication between annular passage 29 and displacement volume 25.

Admission of the blood into displacement volume 25 at a suitable flow rate under the driving force of the small hydrostatic head in inlet conduit 26 is made possible by the low "spring constant" and flow impedance of the diaphragm and inlet section assembly. Rigid diaphragm casing 32 has a thin flexible rim 33 extending around it. Rim 33 acts on a matching flexible rim 34 of a flexible pumping diaphragm 35 to serve as an inlet valve by seating against annular rounded shoulder 30. The seating of the two flexible rims 33 and 34 on the rounded shoulder 30 forms a barrier between annular passage 29 and displacement volume 25, thus closing ring opening 31.

The movement of the blood within and through the pump is controlled by the movement of flexible pumping diaphragm 35. A restraining member 38 which is foraminous (e.g., a screen) is provided to limit the forward motion of the flexible pumping diaphragm 35 and is held

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in place by being clamped between a flange section 39 of section 11 and the discharge section 12. When flexible rims 33 and 34 are seated against shoulder 30 any back flow of blood into the inlet passage system is prevented during the discharge stroke as flexible pumping diaphragm 35 moves forward. Displacement fluid volume 25 can be adjusted by positioning stop 40 for any desired volume between zero and 100 percent of full capacity of the pump.

The displacement fluid volume 25 is defined by the flexible pumping diaphragm 35 on one side and the foraminous restraining member 38 and the surrounding casing of section 11 on the other. The volume 41 which is defined between the foraminous restraining member 38 and inclined wall 42 remains constant and within it are located splines 43 (FIG. 2) which define between them flow channels 44 which in turn communicate with the port 45 through which the blood passes into discharge conduit 13 which contains a discharge valve 47 in accordance with accepted valve design for blood pumps.

Actuation of the rigid diaphragm casing 32 and the flexible diaphragm 35 is effected through the application of fluid pressure. A pressurized fluid (e.g., oxygen) to actuate the rigid diaphragm casing 32 serving as a means to prevent back flow of blood into the inlet conduit, is introduced into the pump by way of conduit 51. This fluid conduit communicates with a circular force-applying chamber 52. The rigid diaphragm casing 32 is moved toward the right by the introduction of the force-applying fluid into chamber 52 to close off the flow of blood into displacement fluid volume 25. (Rigid diaphragm casing 32 is moved to the left (valve opened) by the hydrostatic pressure of the blood entering the pump when the pressurizing fluid is vented to the atmosphere and the pressures in the pneumatic driving system and at the gas-blood interface 27 are equal.) During the discharge stroke of the pump a positive differential pressure of the driving fluid is maintained between chamber 52 and chamber 53, the latter being the fluid driving chamber which actuates the flexible pumping diaphragm 35. This maintaining of a differential pressure serves to hold the inlet valve section of the diaphragm structure tightly sealed. The pressure-applying fluid is introduced into chamber 53 through fluid conduit 54 and radial conduits 55. Because fluid conduit 54 and radial conduits 55 are located within the moving rigid diaphragm casing 32, provision is made for the extension of the rigid diaphragm which defines conduit 54 to move back and forth in recess 56 and to make a sliding fit over the area generally indicated by the numeral 57.

A suitable fluid valving means must be provided to control the flow of the driving fluid in and out of chambers 52 and 53. One embodiment of such a valving means is illustrated in cross-section in FIG. 5. This valving means requires a source of fluid which is controlled with respect to fluid pressure and flow direction. Such a source is not part of this invention.

The fluid control valve means of FIG. 5 is designed to first pressurize the rigid diaphragm casing 32 to close the annular ring opening or passage 30 and then to move the flexible pumping diaphragm 35. The valve embodiment of FIG. 5 will be seen to be comprised of two valve body portions 64 and 65, which define internally a valve chamber 66. In order to direct the pressurized driving fluid first into chamber 52 and then into chamber 53 (FIG. 1) there is included in the valve a suitable mechanism to establish a pressure differential in these chambers. This comprises the needle 67, its support 68, and the flexible diaphragm 69 which is held in position between portions 64 and 65 of the valve body. A spring 70 located in recess 71, is associated with this needle valve to hold the pressure in driving chamber 52, and hence on the rigid diaphragm casing 32, about 2 p.s.i. higher than on the flexible pumping diaphragm 35 thus making the rigid diaphragm casing 32 engage the valve

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seat prior to and during the actuation of the flexible pumping diaphragm 35.

The pressurized driving fluid, e.g., oxygen, is introduced and withdrawn through conduit 75 which in turn is directly connected through conduit 76 to conduit 51 and is affixed thereto by suitable sealing means such as flexible tubing 77. Fluid communication with conduit 54 is made by way of the valve chamber 66 and conduit 78 when needle valve 67 is open. Conduit 78 in turn can readily be connected to conduit 54 of the pump through a suitable sealing means such as flexible tubing 79. Branching off from conduit 78 is a conduit 80 which in turn has a branch conduit 81 terminating in vent valve 82 and a circuitous branch conduit 83 which terminates in the valve chamber 66. The purpose of these latter branch conduits is to permit equalization of fluid pressure when that is required as explained below.

Turning now to FIGS. 1, 3, 4 and 5 it will be possible to describe the working of the pump of this invention. When the pump is in the condition illustrated in FIG. 1 the fluid to be pumped, e.g., blood is introduced into conduit 26 which is of sufficient height to develop a hydrostatic head in the fluid of such a magnitude to force the fluid through passageway 28 into the annular ring opening 31 over the rounded shoulder 30 which forms the inlet valve seat and into the displacement volume chamber 25. There is at this time sufficient fluid back pressure exerted through conduit 47 to maintain the ball valve 48 in its closed position. At this point the pressurized driving fluid is introduced into conduit 75 of the valve means of FIG. 5, and by way of valve conduit 76 it passes into the pump through conduit 51 into the force applying chamber 52. With the build-up of fluid pressure in this chamber the rigid diaphragm casing 32 is moved forward to the position shown in FIG. 3 thus closing the annular passage 31 and halting the flow of fluid between the inlet passage and volume 25. The valve shown in FIG. 5 is so designed that the spring maintains the needle in the valve seat until about 2 p.s.i.g. pressure has built up in chamber 53. At this point the pressure entering the valve chamber 66 is sufficiently great to open the needle valve 67 by actuating the flexible diaphragm 69 to the left and thus open conduit 78 to the passage of driving fluid into chamber 53 by way of the conduit system previously described. Discharge of blood from the pump begins when the pressure in the chamber 53 slightly exceeds the pressure then existing in the blood discharge connection 47. With the attainment of this pressure the flexible pumping diaphragm 35 moves to the right forcing the fluid in the pump ahead of it through the foraminous member 38 and then by way of channels 44 into port 45 and through the discharge valve by way of conduit 47 to the arterial cannula not shown. At the end of the discharge stroke of the pump the flexible pumping diaphragm 35 occupies a position in contact with the foraminous restraining member 38 as seen in FIG. 4.

The supply of pressurized driving fluid is then cut off, the hydrostatic head of the blood in conduit 26 forces the flexible pumping diaphragm 35 and the rigid diaphragm casing 32 back towards the left and opens the annular passage 31 thus permitting another quantity of blood to enter the pump. Vent valve 82 is incorporated in the valving means of FIG. 5 to insure that the driving fluid can easily be expelled from chamber 53 during the intake stroke.

FIG. 6 illustrates another embodiment of the pump of this invention. Like the pump of FIG. 1, it is divided into three sections, namely, the valve diaphragm driving section 10, the central fluid volume section 11 and the discharge section 12. However, in the embodiment of FIG. 6 the actual driving mechanism and discharge valve are integral parts of sections 10 and 12, respectively. In FIGS. 1 and 6 like elements of the pump are identified by like reference numerals.

The valve actuating means of the embodiment of FIG. 6 is different in construction from that of FIG. 1, but is, along with the pump, operated on the same principle. In the apparatus of FIG. 6, the rigid diaphragm casing is replaced by rigid ring 90 which is joined to an annular ring 91 through a cylindrical section 92. The annular ring 91 is sized and positioned to engage rounded shoulder 31 through a flexible rim 93 which is, like rim 33 of FIG. 1, adapted to be held between pump sections 10 and 11. Rigid ring 90 has recessed section 94 adapted to contain a spring 95 between it and main housing 96. Between ring 90 and main housing 96 there is defined a fluid chamber 97 into which a pressurized driving fluid is introduced to actuate ring 90 and hence to actuate the valve mechanism.

The flexible pumping diaphragm 35 of FIG. 1 is replaced in the apparatus of FIG. 6 by a convoluted diaphragm 100 with convolutions 101 of sufficient depth to permit the diaphragm 100 to be moved forward as the pumping diaphragm drives the fluid toward the discharge end. This pumping diaphragm is formed into two sections, i.e., the back plate 102 and the forward plate 103 between which the flexible convoluted diaphragm 100 is held. Convoluted diaphragm 100 terminates in a flexible rim 104 which with rim 93 is fastened between pump sections 10 and 11. A driving chamber 106 adapted to contain the driving fluid which acts upon the convoluted and pumping diaphragms is defined between the rigid ring 90 and these diaphragms. Fluid communication between chambers 97 and 106 is through check valves 107.

The pumping diaphragm sections 102 and 103 are supported on a reciprocating shaft 108 which through pin 109 terminates in a stop 110 designed to contact adjustable screw 111 in main housing 96. By adjusting screw 111 the stroke of the pump is varied so that any desired volume, from zero to 100 percent of the full capacity of the pump, may be handled. Concentric cylindrical members 112 and 113 along with an end plate 114 define annular fluid passages 115 and 116 which communicate with chambers 97 and 106, respectively. These annular passages are connected through ports 118. Fluid cushioning chambers 119 and 120 provide for pressure equalization within the actuating mechanism and the driving fluid is introduced and withdrawn from the actuating mechanism by means of inlet conduit 122.

The basic principle of operation of the pump of FIG. 6 is essentially the same as that of the pump of FIG. 1 with the exceptions noted. In the pump of FIG. 6, pressurized driving fluid, e.g., oxygen, enters inlet conduit 122 and by way of passage 115 reaches chamber 97, applying sufficient pressure to overcome the fluid pressure generated by the hydrostatic head of the fluid in inlet conduit 26. This fluid pressure moves the rigid ring 90 forward thus forcing the annular ring 91 to contact shoulder 30 through flexible rims 93 and 104. This cuts off flow of blood between the displacement fluid volume 25 and inlet passage 29. Annular passage 123 is proportioned to serve as a flow-constricting orifice so that the pressure in chamber 106 will be enough less than that in chamber 97 during the pumping stroke of diaphragm 101 to hold the inlet valve closed. Thus the pump of FIG. 6 will continue to operate so long as there is a flow of gas into chamber 106 for this creates the necessary difference in chamber pressures. This differs in operation from the apparatus in FIG. 5, since in the apparatus of FIGS. 1 and 5, a greater pressure is continuously maintained in chamber 52, associated with the driving of rigid diaphragm casing 32, than is maintained in chamber 53, associated with the pumping diaphragm. Moreover, the external source of pressurizing fluid is not controlled by conditions existing in the pump. However, in both pumps the pressure differential is maintained only during the pumping stroke.

In the operation of the pump of FIG. 6 at the end of the pumping stroke, the actuating fluid pressure is released through passage 122. Check valves 107 allow free

venting of chamber 106 into 97 and the hydrostatic fluid pressure of the blood in inlet conduit 26 is sufficient to overcome the inertia of the diaphragms and the force exerted by the lightly loaded spring 95 to open the annular ring opening and cause blood to again enter the displacement volume 25.

Because of the nature of blood and the need to prevent the entrapment of gas bubbles in it prior to its introduction into the pump of this invention it is contemplated that some suitable means will be provided to introduce the blood at a moderate velocity into the inlet conduit. One such suitable means, which is not part of this invention, may be an inclined plane designed to be in fluid communication with the inlet conduit.

Sterilization of the pump of this invention may readily be effected by putting the entire device in an autoclave and flushing the blood handling circuit with saturated steam at 15 p.s.i.g., 250° F. After sterilization the pump is connected to the blood circuit. The pneumatic control system for the pump need not be sterilized and is conveniently located remote from the pump with a single actuation fluid hose connection.

It is of course, necessary to construct a blood pump so that those surfaces which contact the blood are of a material compatible with the blood. A number of such materials are known and include polytetrafluoroethylene, polyphenyleneoxide and certain acrylic resins. The blood pump of this invention is of such a design that it lends itself readily to being molded in sections of synthetic resin materials. This technique of construction makes it relatively inexpensive to construct and offers the possibility of providing disposable pumps, thus eliminating the work of disassembling, reassembling and resterilizing.

It will be seen from the description of the operation of this pump that it requires only a periodic flow of pressurized driving fluid to operate it. Inasmuch as such control can readily be maintained and adjusted, it meets the requirement of an ideal blood pump for automatic or hand controlled operation. Moreover by proper choice of design parameters it is amenable to rapid and reliable calibration and can be constructed to move any predetermined volume against a desired pressure. By controlling the rate at which the pressurized driving fluid is introduced, the duration of the discharge stroke can be controlled over a wide range. By controlling the volume of blood in the return side of the system, and hence the height of the liquid level in the liquid inlet conduit the duration of the intake stroke can be controlled. Finally, it will be apparent from the design of the pump that it presents only smooth surfaces, it eliminates dead spaces and recesses, and most important of all it eliminates the possibility of the intake of gas bubbles during the liquid intake stroke. The pump can be readily dismantled, cleaned and then sterilized. Moreover, it should be pointed out that the pump is of a relatively simple design which means that the various sections can be readily cast in suitable plastic material. Its construction is therefore sufficiently economical to permit it to be used as a one-time disposable pump. It is also relatively small in size and hence it is adaptable for carrying in ambulances and other first-aid equipment.

It will thus be seen that the objects set forth above, among those made apparent from the preceding description, are efficiently attained and, since certain changes may be made in the above construction without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described and all statements of the scope of the invention which, as a matter of language, might be said to fall therebetween.

I claim:

1. A pump suitable for pumping a liquid subject to infliction of trauma, comprising in combination

- (a) a displacement fluid volume internal of said pump and having valve-controlled liquid discharge means; 5
- (b) a fluid passage surrounding said displacement volume and separated therefrom by a contoured shoulder;
- (c) a liquid intake conduit in fluid communication with said fluid passage and of a height such that liquid contained therein can develop a small predetermined hydrostatic head; 10
- (d) a first substantially rigid diaphragm member actuatable by fluid pressure and having a contoured portion engageable with said contoured shoulder thereby forming with said shoulder an inlet valve adapted to control the intake of liquid into said displacement volume; 15
- (e) a second flexible diaphragm member actuatable by fluid pressure movable within said displacement volume and adapted to effect discharge of liquid from said pump; 20
- (f) a foraminous member within said displacement volume adapted to limit the forward movement of said second diaphragm member; and 25
- (g) fluid pressure driving means adapted to actuate said first diaphragm member to close said inlet valve and then to move said second diaphragm member to its forward position, said fluid pressure means being vented to the atmosphere after liquid discharge from said pump and in conjunction with said diaphragm members having an impedance which can be overcome by said hydrostatic head of said liquid in said liquid intake conduit whereby said inlet valve is opened if and only if said hydrostatic head is sufficient to overcome said impedance. 30 35

2. A pump in accordance with claim 1 wherein said driving means comprise a first pressurized-fluid actuating means associated with said first diaphragm member and a second pressurized-fluid actuating means associated with said second diaphragm member, said first and second actuating means being in fluid communication through regulating valve means whereby the fluid in said first actuating means is maintained during the actuation of said diaphragm members at a higher pressure level than the fluid in said second actuating means. 40 45

3. A pump in accordance with claim 1 wherein said foraminous member is a screen.

4. A pump in accordance with the claim 1 further characterized by having stroke controlling means adapted to limit the travel of said second flexible pumping diaphragm member and hence to predetermine the displacement volume of said pump. 50

5. A pump in accordance with claim 1 further characterized by having spring means associated with said first diaphragm member and adapted to develop at least a portion of said impedance. 55

6. A pump in accordance with claim 1 further characterized by having fluid channel means forward of said foraminous member and adapted to direct the flow of said fluid during discharge into said discharge means. 60

7. A pump suitable for pumping a liquid subject to infliction of trauma, comprising in combination

- (a) first, second and third housing sections capable of being assembled as a unit and defining within their combined internal structure a displacement fluid volume;
- (b) valve-controlled discharge means associated with said third section;
- (c) a fluid passage surrounding said displacement volume and separated therefrom by a contoured shoulder;
- (d) a liquid intake conduit in fluid communication with said fluid passage and of a height such that liquid contained therein can develop a small predetermined hydrostatic head;
- (e) a first substantially rigid diaphragm member having a flexible rim held between said first and second sections, actuatable by fluid pressure, and having a contoured portion engageable with said contoured shoulder thereby forming with said shoulder an inlet valve adapted to control the intake of fluid into said displacement volume;
- (f) a second flexible pumping diaphragm having a flexible rim held between said first and second sections, actuatable by fluid pressure, and movable within said displacement volume thereby to effect the discharge of liquid from said pump;
- (g) a foraminous member within said displacement volume adapted to limit the forward movement of said second diaphragm member; and
- (h) fluid pressure driving means adapted to actuate said first diaphragm member to close said inlet valve and then to move said second diaphragm member to its forward position, said fluid pressure means being vented to the atmosphere after liquid discharge from said pump and in conjunction with said diaphragm members having an impedance which can be overcome by said hydrostatic head of said liquid in said liquid intake conduit whereby said inlet valve is opened if and only if said hydrostatic head is sufficient to overcome said impedance.

8. A pump in accordance with claim 7 wherein said driving means comprise a first pressurized-fluid actuating means associated with said first diaphragm member and a second pressurized-fluid actuating means associated with said second diaphragm member, said first and second actuating means being in fluid communication through orifice flow construction means whereby the fluid in said first actuating means is maintained during the actuation of said diaphragm members at a higher pressure level than the fluid in said second actuating means.

9. A pump in accordance with claim 7 further characterized by having stroke controlling means adapted to limit the travel of said second flexible pumping diaphragm member and hence to predetermine the displacement volume of said pump.

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