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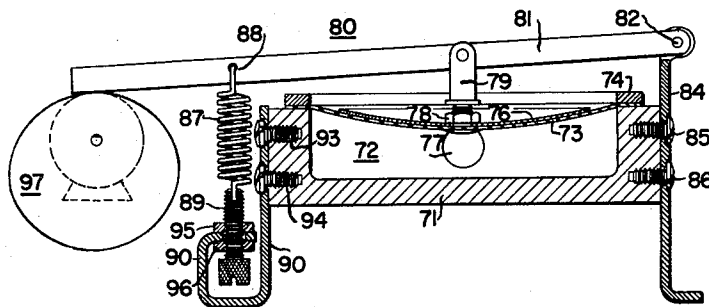
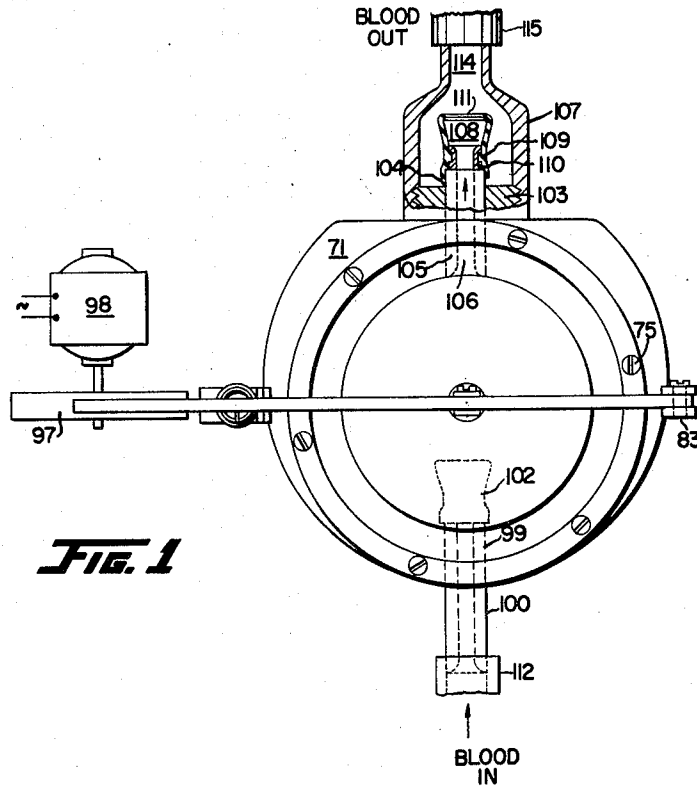
R. E. DI VETTE

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DIAPHRAGM PUMP

Filed Nov. 8, 1957

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

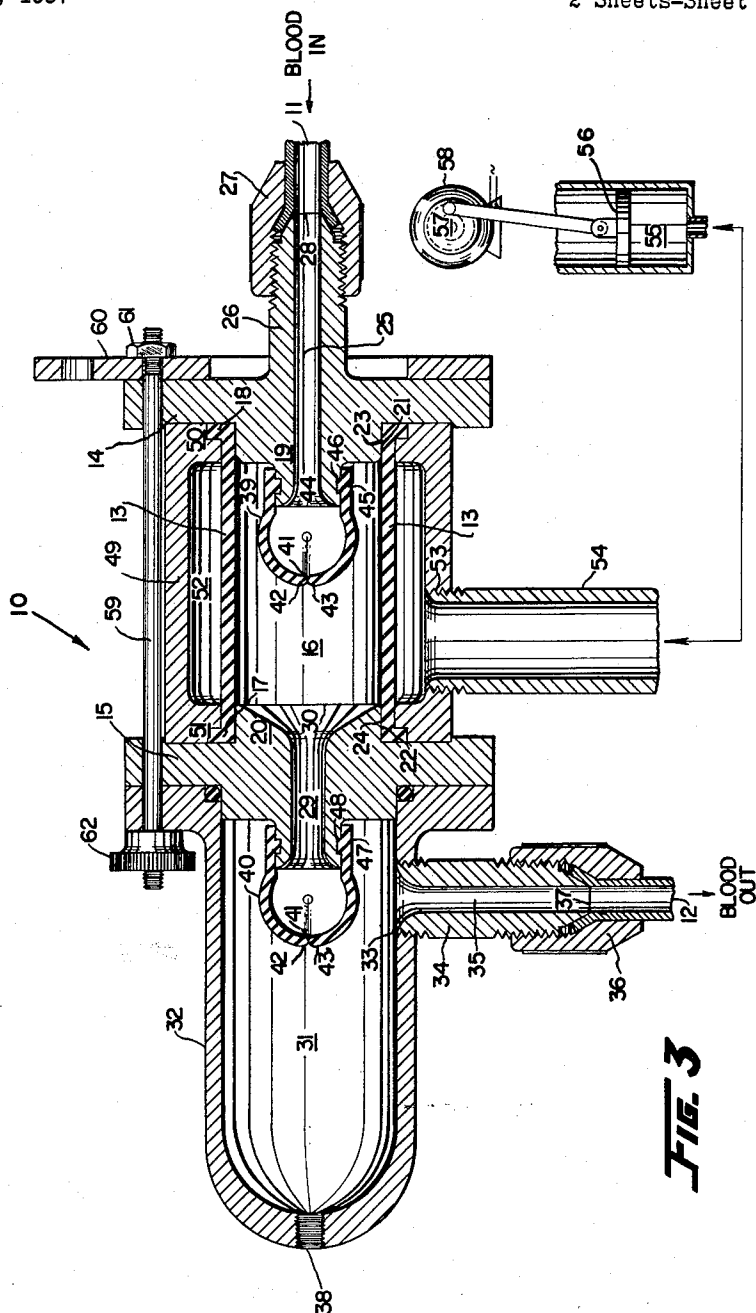


FIG. 3

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DIAPHRAGM PUMP

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1 Claim. (Cl. 103—44)

My invention relates to a diaphragm pump which is specially adapted to the handling of sensitive liquids by the use of soft pliant valve members. It is particularly directed to a device suitable to control and maintain blood flow without the destruction of blood through subjection to impact, touching or pinching by movable metallic parts or surfaces.

Among the objectives of the present invention the following may be considered illustrative:

To provide a device for controlling liquid flow whereby liquids known to deteriorate upon harsh handling may be pumped with the effective elimination of the deleterious effects encountered in the use of pumps having moving metallic parts.

To provide a diaphragm pump in which the valving and driving members are made of soft pliant material to prevent the deleterious effect of the liquid being pumped against hard metallic surfaces.

To provide a pump for the control of blood flow wherein soft pliant valve members are made to function in response to flexure of the main body of the device to cause blood to flow therethrough.

To provide a diaphragm pump for the control of blood flow in which soft pliant valve members have slits defining lips which open or close in response to predetermined pressure differentials to cause flow therethrough in response to flexure of said diaphragm.

My invention is most directly concerned with the problem of proper handling of human blood. With the development of surgical methods for the correction of irregularities in the heart, a need has been evident for some means by which blood flow through the heart could be curtailed while still providing the necessary blood to the body. The surgical work on the heart could be greatly facilitated if the heart could be relieved of its pumping function for the time needed to manipulate the heart tissues. However, it is known that the circulation of blood to the body tissues can be cut off for only short periods of time before harm results to the tissues through a lack of blood, in the case of brain tissues, for only a matter of seconds. It becomes apparent that to give the heart a safe opportunity to rest from its normal function, an auxiliary pumping means is needed to continue blood flow through the body. However, the handling of blood entails some difficulties which are not easily resolved by the conventional liquid pump.

In particular, when human blood is pulsed or struck against metallic surfaces, pinched by metallic pieces, such as valve parts, or in any other way subjected to extreme localized pressures, it is known to suffer a breakdown of its red corpuscles. If such harsh treatment continues for an extended period of time and the breakdown of the blood continues, a condition of red corpuscle deficiency known as hemolysis or pernicious anemia develops. The present invention seeks to reduce or eliminate this blood deterioration by the exclusion of moving metallic parts and surfaces from the line of blood flow within the present pump. To advance this purpose the present device

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includes a main portion composed substantially of a flexible diaphragm with valve members positioned in the inlet and outlet portions or passages also made of soft pliable material. The valve members each have a slit therethrough defining lips which will normally be closed but which will open on a predetermined pressure differential, and close on the reverse differential. The valves are oriented such that when the first valve is open to permit blood to enter the pump from the body's circulatory system, the second valve will close to obstruct flow until the pump is substantially full of blood. The pump will then function upon the flexure of the diaphragm in the main portion to cause the blood to be forced through the second valve from said main portion. Operation of the diaphragm flexing means will give continued cyclical operation of the pump and maintain flow in the system. The pump may be connected in parallel with the heart during an operation and all or part of the blood caused to cycle through the present device. As the breakdown of the red corpuscles within the auxiliary pumping means is reduced, the period of time for which flow through the heart may be curtailed can be extended. Other needs of the blood, such as oxygen, may be supplied to the blood stream by other equipment provided independent of the present invention.

Other objectives and advantages of the present invention will be obvious from the detailed description and claims hereinafter set forth.

In the drawings:

Figure 1 is a top view of a second embodiment of my invention.

Figure 2 shows in sectional elevation the second embodiment of my invention with motor-actuated lever driving means.

Figure 3 represents, in sectional elevation, the improved diaphragm pump and valving members pursuant to the present invention and illustrates schematically a second pumping member utilized in this embodiment to contribute the necessary driving pressure for my pump.

Referring to Figure 3, I have illustrated therein a pump 10 which is adapted for use as a blood pump for heart by-pass purposes. Blood will be received from the circulatory system of the human body through a tubing 11 and be returned to the body through a like tubing 12. The pump controls the flow within the circulatory system and contributes a driving pressure to maintain that flow. The pump may be of such size as is needed to pass the necessary quantity of blood and maintain the pressure desired.

Within pump 10 itself a flexible diaphragm 13 is positioned between two end walls 14 and 15 to define a chamber 16. In the present embodiment said diaphragm is made of rubber and is generally cylindrical in shape, with ends 17 and 18 flanged for mounting purposes. Diaphragm 13 is fitted over shoulders 19 and 20 of end walls 14 and 15 to provide a liquid-tight seal on the mating of surfaces 21 and 22 of diaphragm 13 with surfaces 23 and 24 of the end walls. A bore or passage 25 in end wall 14 serves as an inlet port for chamber 16. Said passage extends through an extension 26 of end wall 14 which is threaded to receive a collar 27 securing tubing 11 across an opening 28 of passage 25. Blood from tubing 11 will then be free to enter chamber 16 through passage 25. End wall 15 is provided with a similar bore or passage therethrough at 29; said passage being expanded at its inner end 30 to give a streamlined path for the flow of blood. Passage 29 serves as an outlet port for chamber 16 and opens into a secondary chamber or outlet reservoir 31 defined by a bell-shaped housing 32. Blood having entered chamber 16 by inlet passage 25 may flow through outlet passage 29 to the outlet reservoir 31. An adapter 34 having a bore 35 therethrough is re-

ceived by a threaded aperture 33 in housing 32. Said adapter is itself threaded to receive a collar 36 holding tubing 12 in place at opening 37 of bore 35. Blood passes through bore 35 into tubing 12 to return to the circulatory system of the body.

Blood received in tubing 11 enters passage 25 and passes through end wall 14 to chamber 16. The blood in chamber 16 reaches the outlet reservoir 31 by means of passage 29 from which it is free to enter bore 35 and return to the body through tubing 12. Provision may be made external to the pump for the introduction of oxygen or other necessary elements to the blood stream but in addition to providing a means for bleeding the system and evacuating the pump of air prior to its being inserted in the blood stream, opening 38 in housing 32 may also be used to receive equipment supplying these other needs of the blood. The opening is shown threaded to receive means to maintain the system closed under normal operating conditions.

Valve members 39 and 40 are included across the line of blood flow to control the flow through the course described. Each of said valve members resemble a teat, having a globular bulb with a slit 41 therein extending through substantially one-half of a circumference of the globe in a plane along the longitudinal axis of the valve. The valve is made of a soft pliant material, in this instance rubber, and slit 41 defines a set of lips 42 and 43 in said valve which will normally be closed but which will open on the presence of a predetermined pressure differential across the valve and close under the reverse pressure differential. Both valves 39 and 40 are of this construction and operation. Valve 39 is located within chamber 16, being secured across opening 44 of passage 25 by a rim 45 of said valve fitted into a channel 46 of end wall 14. When the inlet pressure of the blood, as in passage 25, is greater than the pressure within chamber 16, valve 39 will open and allow blood to enter chamber 16. When the pressures on each side of valve 39 become equal and when the reverse pressure differential exists, the lips 42 and 43 of said valve will close and valve 39 will act as a check valve to prevent blood from flowing back into inlet passage 25. Valve 40 is located in a like orientation within outlet reservoir 31 and is secured in place by rim 47 fitted in channel 48 of end wall 15. Upon the pressure in chamber 16 becoming greater than the pressure within the outlet reservoir 31 said valve will open to allow flow therethrough, and will close under the reverse pressure differential to prohibit said flow.

It is essential to the operation of the pump that the valves located in the inlet and outlet passages open and close in tandem. When valve 39 is open to permit flow into chamber 16 valve 40 should be closed to prohibit flow from said chamber until the pressure within said chamber increases to equal the pressure on the inlet side of the valve 39 and cause it to close. At that time valve 40 will open to allow flow from chamber 16. The valves are positioned with respect to chamber 16 in a manner such as to cause the pressure differentials across the two valves at any time to be effective to give this tandem operation. As the inlet and outlet of the pump are connected in series through the circulatory system of the body, the pressures at inlet and outlet are substantially equal. Variation of the pressure in chamber 16 thus will give pressure differentials of the same magnitude across both the inlet and outlet valves, but of reverse relation to the valves so that one opens while the other closes. Diaphragm 13 is intended to be flexed to cause such variations in the volume of the chamber as are needed to give pressure variations therein for operation of the valves.

In the embodiment of my invention described in Figure 3, I have shown a housing or casing 49 placed about diaphragm 13 to define a cavity or second chamber 52 having diaphragm 13 as one wall. A liquid-tight seal to prevent seepage between chamber 16 and cavity 52 is provided by the mating of the shoulders or recessions 50

and 51 of casing 49 with the flanged ends 17 and 18 of diaphragm 13. A threaded port 53 in casing 49 receives a pipe or conduit 54 connected to a pumping member 55. A liquid is provided in said pumping member to be driven by piston 56 into conduit 54 and cavity 52. Said piston is driven by a motor 58 through an eccentric 57. When said liquid is driven into said cavity a pressure will be applied to diaphragm 13 and said diaphragm will be flexed to reduce the volume of chamber 16 and to act on the effectively incompressible blood to cause an increase in pressure within the chamber. As the motor 58 rotates the eccentric 57, the piston 56 will release the pressure from the liquid. Said liquid then returns to the pumping member 55 through conduit 54 and the flexible diaphragm 15 may relax with the withdrawal of the pressure applied by the liquid. The relaxing of the diaphragm will reduce the pressure within the chamber 13. Such variations in pressure produce the pressure differentials needed to cause operation of valves 39 and 40. Continued rotation of the eccentric will cause the pumping member 55 to cyclically deliver liquid to cause flexure of said diaphragm and continued operation of the pump.

Figure 3 also shows one of a plurality of bolts 59 which pass through housing 31, end walls 14 and 15, and plate 60. Said bolts join with nuts 61 and 62 to provide sufficient longitudinal force to fix the pieces of the pump described in their respective positions and to assure the proper seal between the various parts. Plate 60 may be used for mounting said pump.

As has been shown pump 10 is relatively simple in operation. When it is to be used as a bypass for the human heart it will be initially evacuated to prevent air from entering the bloodstream. Upon the introduction of blood from the circulatory system through tubing 11, valve 39 will open to permit chamber 16 to be filled with blood. Thereafter the flexure of the diaphragm and operation of the valves as previously described will cause a continuous cyclical operation of the pump, with blood flowing therethrough to return to the body by tubing 12 with minimum mechanical damage to the blood.

In Figures 1 and 2 I have shown a second embodiment of my invention. A housing 71 has been machined to define a circular chamber therein as shown at 72. One side of said chamber is open and across said open side is placed a circular flexible diaphragm 73 which is fixed in place by a ring 74. A plurality of screws 75 pass through ring 74 and diaphragm 73 to secure them against housing 71 and obtain a liquid-tight seal between diaphragm 73 and housing 71. A thin plate 76 having substantially the curvature of the diaphragm in its most flexed position is placed on top of diaphragm 73. A screw 77 is passed upward through said diaphragm 73 and said plate 76 and locked tightly with said diaphragm and plate by a nut 78. The upper end of screw 77 is then joined to link 79 of a lever system 80.

The lever system 80 of which link 79 is a part includes a lever arm 81 pivoted at point 82. At 82 a pin 83 is passed through the upper extension of a thin leg 84 attached to the body of housing 71 by screws 85 and 86. Arm 81 extends across the body of the pump along a diameter of diaphragm 73. At a point on the lever arm which is essentially the center of diaphragm 73, said link 79 is attached to lever arm 81. A spring 87 is attached to lever arm 81 at 88 to apply a downward force on said arm to provide a force at link 79 sufficient to flex the diaphragm and to cause said arm to ride against cam 97 throughout the entire revolution of said cam. The other end of said spring is fixed to a screw 89 passing through an extended portion 90 of a second leg 91 attached to housing 71 at 92 by screws 93 and 94. Nuts 95 and 96 are provided on each side of the extended portion 90 of the leg to set screw 89 for adjustment of the spring tension. Cam 97 is driven by a continuously running motor 98 and as the cam is revolved, the lever arm 81 is caused to move up and down

in accordance with the contour of said cam. Link 79 will follow the motion of arm 81 to flex diaphragm 73. Plate 76 is provided to insure that the force causing flexure will be distributed substantially over the entire surface of diaphragm 73.

A tubular adapter 100 having a passage 101 therethrough is suitably fitted in an aperture 99 through housing 71 to give a liquid tight seal with said housing. Adapter 100 extends into chamber 72 a sufficient distance to provide for the placing of valve 102 across its inner end. An extension 103 of housing 71 has a second aperture 104 therethrough and an adapter 105 having a passage 106 is appropriately fitted in said port. Valve 108 is secured across the end of adapter 105 within a secondary chamber defined by a small casing 107 attached to extension 103 of housing 71.

Valve 108 is made of soft pliable material, in this instance rubber, and is of the shape shown in Figure 1. Valve 108 is provided with a slit therein at 111 which defines a set of lips in the plane of diaphragm 73. Said lips open or close upon the presence of a pressure differential across said valve 108. Said valve is attached to adapter 105 by the fitting of rim 109 of said valve into a channel 110 provided in adapter 105. Valve 102 is substantially the same as valve 108 and is attached to adapter 100 in the same manner as valve 108 is attached to adapter 105.

Basically the operation of the second embodiment of my invention is essentially the same as that of the first embodiment. As a blood pump for heart bypass purposes the second embodiment of my invention would be placed in parallel with the heart and connected to the circulatory system of the body. A tube or conduit 112 would deliver blood into passage 101. Initially when the blood enters passage 101 the chamber 72 is evacuated and the pressure on the inlet side of valve 102 will be greater than the pressure within chamber 72. Under this pressure differential valve 102 will be caused to open and allow blood to flow into chamber 72. Valve 108 will be closed under the influence of an outlet pressure greater than the pressure within the evacuated chamber. With chamber 72 full of blood the operation of the lever means and flexure of diaphragm 73 will become effective. With motor 98 operating continuously, cam 97 will rotate and lever arm 81 will be actuated in accordance with the contour of said cam. As the lever arm moves down under the influence of spring 87 and cam 97 the diaphragm 73 is flexed inward reducing the volume of chamber 72 and increasing the pressure within said chamber. When the pressure in the chamber becomes greater than the inlet and outlet pressures, valve 102 will close and valve 108 will open to allow the blood to flow from chamber 72. The revolution of cam 97 will raise lever arm against the spring tension and cause diaphragm 73 to be raised and its flexure reduced. The pressure in chamber 72 will drop until it becomes less than the pressures at inlet and outlet and then valve 108 will close and valve 102 will open to permit flow into chamber 72. The opening and closing of the valves to give flow through the pump will be repeated in this manner to give a cyclic operation maintaining continuous flow through the system. The design of the cam and

the speed of rotation of the motor will control the characteristics of the cyclic operation. The blood passing through valve 108 in the manner described enters casing 107 from which it will pass through passage 114 into conduit 115 attached to the end of casing 107 to return to the body and its circulatory system.

In the drawings and specifications above, I have described in detail several possible embodiments of my invention and valve members to be used therein. It is not my intention that the invention be limited only to devices of the particular design shown but rather that my invention be limited only by the claim which follows.

I claim:

A pump for the circulation of blood comprising, a flexible diaphragm cylindrical in shape, end walls enclosing said diaphragm to define a first chamber therein, inlet and outlet means for said first chamber positioned in and extending through said end walls, said inlet and outlet means being adapted to have a source of blood and a blood transmission conduit connected respectively thereto, valve means connected to said inlet and outlet means, said valve means being composed of a thin soft pliant material formed as a single piece having a globular shape with a slit therein through substantially one-half of the circumference of the globe in the plane to the longitudinal axis of the globe said slit defining a pair of lips which have a thickness dimension slightly less than the dimension of the thin pliant material, said lips being normally closed but operative to open on a greater pressure within the globe than without and to close on a reverse pressure differential, said valves being positioned with regard to said chambers such that a variation in pressure within the chamber at any instant causes pressure differentials with respect to valves to cause one valve to be urged open and the second valve to be urged closed, casing means enclosing said diaphragm and securing the same, said casing means forming a second chamber with said diaphragm as one wall, a pumping means connected to said second chamber through a conduit containing liquid to be cyclically driven into said second chamber by said pumping means to apply a pressure against said diaphragm and to flex said diaphragm and vary the volume of pressure within the first chamber affecting pressure differentials of such changing relation to cause operation of the valves and provide for continued intermittent flow of blood through said device when a source of blood is connected thereto.

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