APPARATUS FOR USE IN THE EXTRACORPOREAL CIRCULATION OF BLOOD

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This invention relates to apparatus for use in the extracorporeal circulation of blood and is herein illustrated as embodied in a novel and improved pump of the compressible tube-rotary impeller type.

As will be appreciated by those skilled in the art, it has heretofore been proposed to provide pumping means located exteriorly of the body for taking over, respectively, the pumping actions of the right and left sides of the heart, and the invention involves the blowing of the heart during surgical repair thereof which is very greatly facilitated by the “dry field” obtained as a result of relieving the heart of its usual task of circulating the blood of the patient. Obviously, a prime requisite of a pump of this type is complete dependability, while other important characteristics include simplicity of construction, and ease of operation and control. In addition, it is most imperative that the arrangement be such that the introduction of air into the blood stream is effectively avoided and the danger of damage to the blood corpuscles, trauma or hemolysis, substantially eliminated. It is, therefore, a principal object of this invention to provide a novel and improved pump for use in the extracorporeal circulation of blood in which all of these essential characteristics are obtained.

As herein illustrated the improved pump includes two units each having an inlet and an outlet associated with a transparent material, and having an open upper end, a closed lower end, and a separate inlet connection. The inlet and outlet of each pumping unit is connected to a reservoir by means of suitable conduit means, and located in each of the reservoirs in an opening extending from a pumping unit outlet is a normally closed valve means. Leading from each of the mentioned conduit means, in a position between the pump outlet and the mentioned normally closed valve is a connection for a conduit means adapted to deliver blood to the patient, while two other conduit means are associated, respectively, with the inlet connections of the reservoirs for receiving blood from the patient. As will presently appear, the four conduit means for delivering and receiving blood are so connected to arteries and veins of the patient and that one of the pumping units is connected to a reservoir for receiving venous blood from the venae cavae and this pumping unit forces the blood into the pulmonary artery and thence to the lungs, this pumping unit thus functioning to perform the pumping action of the right auricle and right ventricle of the patient’s heart, while the other pumping unit is connected to the other reservoir which receives arterial blood from the pulmonary vein, and this pumping unit forces the blood into the aorta and thence through the patient’s body, this pumping unit thus functioning to perform the pumping action of the left auricle and left ventricle.

Referring to the drawings, FIG. 1 is a diagrammatic view of the novel apparatus of this invention;

FIG. 2 is a plan view of an improved pump used in the novel apparatus shown in FIG. 1, this view also showing mechanism for driving the pump;

FIG. 3 is a view in end elevation, at an enlarged scale and with parts shown in vertical section substantially on line III—III of FIG. 5 and looking in the direction of the arrows of the left-hand portion of the improved pump shown in FIG. 2;

FIG. 4 is a view in side elevation of a part of the pump shown in FIG. 5 with certain parts omitted or broken away and others shown in vertical section; and

FIG. 5 is a view in side elevation of the portion of the pump shown in FIG. 3.

Referring to these drawings, the apparatus which is illustrated in part schematically in FIG. 1 comprises two reservoirs 10 and 12 formed of glass or other transparent material, and of the shape shown. Each of these reservoirs has an open upper end and a closed lower end and the two reservoirs are physically connected by means of two cross struts 14, 15, the latter of which is preferably formed of a tubular member, while the former is a solid rod. The upper end of each reservoir is disposed at an angle to the body portion thereof so that when the reservoirs are supported with their open upper ends extending...
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substantially vertically, their body portions slope downwardly to their closed ends in the manner illustrated in FIG. 4. Reservoir 40 has formed therein an inlet connection 16 and three other connections 19, 19 and 20, while the reservoir 12 has an inlet connection 22 and three other connections 24, 25 and 26.

Located adjacent to these two reservoirs is a pump comprising two pumping units, shown schematically in FIG. 1, and indicated generally by reference characters P-1 and P-2. Each of these pumping units includes a compressible tube T-1 (T-2) and a cooperating rotary impeller R-1 (R-2) mounted on a radially extending arm A-1 (A-2). As is illustrated in FIG. 2 of the drawings, the arms A-1 and A-2 are mounted on the opposite ends of a common drive shaft S which is arranged to be rotated, through suitable speed reducing gearing G, by means of the output shaft of a variable speed drive D driven by a motor M and having a control handle H. As will presently be explained, there is associated with each of the arms A-1 and A-2 an adjusting mechanism adapted to be controlled by means of a hand knob K-1 (K-2) for causing the rotary impeller to vary the action of the rotary impeller on the compressible tube.

The inlet and outlet of the pumping unit P-1 are connected to the two connections 18 and 20 of the reservoir 10 by conduit means comprising tubes 30, 32, and connecting glass tubes 31, 33, while the inlet and outlet of the pumping unit P-2 are connected to the connections 24 and 26 of the reservoir 12 by conduit means comprising tubes 34, 36 and connecting glass tubes 35 and 37. Associated with the tube 32, which is connected to and leads from the outlet of the tube T-1 of the pumping unit P-1, is a valve means comprising a clamp device 40 and a branch connection 42 which is located between the mentioned valve means and the outlet of the tube T-1. In a like manner, there is associated with the tube 36, which is connected to and leads from the outlet of the tube T-2 of the pumping unit P-2, a valve means comprising a clamp device 44 and a branch connection 46 which is located between the last-mentioned valve means and the outlet of the tube T-2.

Extending between the connections 19 and 25 is a tube 48 which provides a bypass conduit means in which there is a normally closed valve means comprising a clamp device 50. Suitable conduit means 52, 54, 56 and 58 are associated respectively with the inlet connections 16 and 22 and the branch connections 42 and 46.

The two pumping units P-1, P-2 of the pump are of identical construction, one being a mirror image of the other, so that a detailed description of one of these units, for example the one which is illustrated on the left in FIGS. 1 and 2 of the drawings, will be sufficient for a complete understanding of the construction and mode of operation of the double unit pump arrangement of this invention. Referring to FIG. 3 of the drawings, this pumping unit comprises a housing 60 shaped to provide a circular recess 62 having adjacent to its open end an annular flange 64. This housing is secured to a portion of the radial member associated with the speed reducing gear G, FIG. 2, by means of screws 68, 68, FIG. 5, and is provided with a bore 69 through which one end of the common drive shaft S projects, this shaft being square with the housing 60, FIG. 3 and concentric with the recess 62, FIG. 5. Fastened to this shaft within the recess 62 is radially extending arm 70 (corresponding to the arms A-1 and A-2 of FIG. 1) which is grooved as indicated at 72 to receive a sliding block 74, held in the groove by means of a cover 76. Formed integrally with this block is a trunnion 78 on which a roller (corresponding to the rollers R-1 and R-2 of FIG. 1) is supported, which roller, when secured, is journaled. The trunnion 78 projects through a clearance slot 82 formed in the arm 70 as shown in FIG. 3.

Secured to the arm 70 is a member 86 having a bore 88 therein for rotatably receiving the hub 90 of a bevel gear 92. This gear has a clearance hole 94 through which there passes a hollow shaft 96 which is secured to the arm 70 and to which the aforementioned bevel gear is drivingly connected by means of a set screw 98 and keyway 100 formed in the screw 96. The lead screw 96 is internally threaded to receive a second lead screw 102, of the same hand as the screw 96, which is threaded through a bore 104 in the block 74 and secured thereto by a locknut 106. The lead of the screw 96 is different from that of the screw 102 for a purpose which will presently appear.

For rotating the bevel gear to effect radial adjustment of the roll 80, the following arrangement is provided. Secured to the arm 70, coaxially of the shaft S, is a stud 110 on which there is rotatably and slidably supported an adjusting knob 112 (corresponding to the knobs K-1 and K-2 of FIGS. 1 and 2) having an enlarged hub portion 114 which is provided with a circumferential groove 116 (FIG. 3). Formed in the arm 70 is a V-shaped guideway 120, FIG. 3, for the rotatable and slidably mounted stud 110. Journalled on this stud portion 124 is a bevel gear 126, held in place by means of a headed screw 128. Surrounding the hub of the gear 126 is the body portion 130 of a yoke member 130 having a pair of arms 132, 132 which are received within the annular groove 116 of the hub portion of the adjusting knob 112. Also rotatably and slidably mounted on the stud 110 is a bevel gear 136 the hub of which is grooved as indicated at 140, 140 and projects into a recess 142 formed in the hub portion 114 of the adjusting knob 112.

This gear is normally held in position shown in FIG. 3, by a spring 146, with its hub engaging a stop ring 148 on the stud 110. A relatively lighter spring 150, seated against an adjusting nut 152 on the stud 110, preferably holds the knob 112 and its hub portion 114 in the position shown in FIG. 3, with the bottom of the recess 142 in engagement with the end of the hub of the gear 136. The hub portion 114 is driven into the gear 136 by means of pins 154, 154 which are received within the groove 140, 140.

Extending outwardly from the recess 62 are two grooves 156, 162, FIG. 5, which are disposed at substantially right angles to each other and extend generally tangential to the outer wall of the recess 62, indicated in FIG. 3 by the reference character 164. A portion of the annular flange 64 is cut away, as indicated at 166, 168 in FIG. 5 of the drawings to provide a recess for a keeper plate 170, preferably formed of a plastic or other transparent material, which is held in place by screws 172, 172, 177. When this keeper plate is removed, a single loop of a compressible tube 180, formed of rubber or suitable plastic material, may be placed in the recess in engagement with the outer wall 164 thereof and with its opposite ends extending outwardly through the grooves 160, 162 which are of a width substantially equal to the normal outside diameter of the tube. The grooves 160, 162 are of the same depth as the recess 62 and inasmuch as the axial distance of the bottom of this recess to the inside of the flange 64, which is just sufficient to accommodate the tube when it is fully flattened to somewhat less than twice the diameter of the tube, the ends of the tube, as they project outwardly beyond the housing 60, are deflected slightly away from each other out of the central plane of this housing.

As will be readily apparent when the shaft S is rotated, the bevel gears 116, 126, 136 roll on the tubes T-1, T-2 (FIG. 1) will be progressively compressed by the roll 80, which acts as a rotary impeller, so that liquid in the tube will be subjected to a pumping action and caused to flow in the direction of the arrows in FIGS. 1 and 5 of the drawings. This pumping action is interrupted once
The mode of operation of the apparatus will now be outlined with particular reference to FIGS. 1 and 2 of the drawings. The apparatus is set up in the operating room adjacent to the patient with the two reservoirs 10, 12 mounted on a suitable stand, or other type of support, at a level somewhat below the patient and with the pump unit, see FIG. 2, located close by on the floor. In order to save valuable floor space, the pump unit may be supported on a suitable frame and in the vertical position shown in FIG. 2. Without attempting to explain the details of the surgical procedure involved, which forms no part of the present invention, the conduit means 52, 54, 56 and 58 are cannulated with appropriate blood vessels of the patient, as diagrammatically illustrated in FIG. 1, so that the patient's heart is entirely bypassed. Initially, each of the two reservoirs is partially filled with a saline solution, or with blood, and with the values 40, 44 opened the pump is started. Now, as blood flows from the pulmonary vein into the reservoir 10 through the conduit 52 and from venous cave into the reservoir 12 through the conduit 54, these valves are gradually closed to cause the pump units to circulate the oxygenated blood which flows into the reservoir 10 through the body of the patient and the venous blood which flows into the reservoir 12 to the lungs of the patient.

The speed of rotation of the common drive shaft S of the pump is set, by means of the control handle H on the variable speed drive D, Fig. 2, so that the cyclic action of the two pumping units is comparable to the normal pulse of the patient, which this cyclic action of the pump simulates, while the pumping action of each pumping unit P-1 and P-2 is initially adjusted to approximate that required to take care of the blood which flows into the two reservoirs and to equalize the flow through the reservoir 10 with the flow through reservoir 12. This state of equality of flow, or the lack thereof, is readily apparent to the operator by his observation of the level of the blood within these two reservoirs, which, as already indicated, are made of transparent material for this purpose. As will be apparent, the flow of blood through the reservoir 10 may be very quickly and accurately regulated by the operator through a suitable manipulation of the control knob K-1, while the flow through the reservoir 12 can similarly be regulated by means of the knob K-2. In this manner the action of the pump can be controlled in accordance with the requirements of the patient during the operation. In the event that such action should become necessary for any reason, the entire system of the blood in the two reservoirs may be very quickly balanced by temporarily opening the by-pass valve 50 located in the conduit 48. The hollow strut 15 provides an automatic by-pass for preventing overflow of one or the other of the reservoirs 10 or 12 should the level of the blood therein rise to an undue high level.

The cyclic rate of the pump, i.e., the simulated pulse, may be readily increased or decreased by varying the speed of rotation of the common drive shaft S in the manner explained above and this change will be the same for each of the two units which, as explained, correspond to the right and left sides of the heart. After such a change in the cyclic rate of the pump it may be necessary for the operator to make a slight readjustment in the pumping action of the two units in order to maintain the desired quantity and equality of flow through the two reservoirs. This can, of course, be readily accomplished in the manner explained above.

As will be apparent, with the apparatus of this invention, a single operator is enabled to control the operation of the pump and to regulate the flow through the two reservoirs in any desired manner appropriate to conditions met during the operation. Moreover, the novel and improved pump is very dependable in action and, because of the simplicity of its construction, there is little, if any, likelihood of mechanical difficulties arising. The pump
tube 180 (T-1 or T-2) is very easily replaceable in the event of damage during use and, should mechanical failure of one or both of the pumping units occur during an operation, these tubes could be quickly removed and replaced. In another standby pump with only a very brief interruption of the circulation of blood. As explained above, the limit of outward adjustment of the pressure roll may be such that the compressible tube used in each pumping unit can never be entirely closed by the roll. Thus, danger of damage to the blood by squeezing of the corpuses may be effectively avoided. In addition, the action of the rotary impeller in moving the blood through the compressible tube is an easy one and such that other damage to the blood is avoided.

After use, the various pieces of tubing which have been employed for the several conduits referred to above, as well as the two pieces of tubing used in the pumping units themselves, may be entirely discarded or, if desired, these pieces of tubing may be cleaned and sterilized for future use. The same is also true with respect to the two reservoirs which may be made of glass or of a suitable transparent plastic of a type which can be either sterilized or such as would warrant being discarded after use.

The two reservoirs are connected together by the struts to form one unit. As indicated above, this unit is mounted on a suitable stand at a level slightly below that of the patient. As the blood flows into these two reservoirs through the conduits just provided, a syphon effect is produced. This syphon effect may be increased or decreased by lowering or raising the two reservoirs, which is easily accomplished because of their simple construction, to facilitate or retard the rate of flow of blood from the patient into the reservoirs. As shown in FIG 1, the inlet 22 to the reservoir 12 which receives blood from the venous cavity, is so located that the blood flows some distance down along the inner wall of the inclined body portion of the reservoir. This, it has been found, tends to avoid foaming of the blood and also provides a convenient visual indication of the rate of flow of blood from the patient. On the other hand, the inlet 26 to the reservoir 12, which receives blood from the pulmonary vein, is located well below the level of blood in that reservoir to avoid entrainment of air. By providing the connections 18, 20 and 24, 26 adjacent to the lower portion of their respective reservoirs, the operator can, by maintaining the level of blood in these reservoirs well above these connections, avoid any danger of air entering the circulating blood stream. Should occasion require, blood from a donor may be added to either or both of the reservoirs through their open upper ends and an automatic gravity feed device may be provided for this purpose.

Having thus described our invention, what we claim as new and desire to secure by Letters Patent of the United States is:

1. A pump for use in the extracorporeal circulation of blood comprising a pair of pumping units each having a circular shaped compressible tubular pumping member, a support for each of said pumping members, a pump shaft extending through said supports and centrally located to said circular pumping members, a pair of arms secured to said shaft, an impeller member mounted for radial adjustment on each of said arms and adapted to cooperate with one of the pumping members, a separate means carried by each of said arms for manually operable to effect radial adjustment of the impeller member thereon to vary the action of said impeller member on its associated pumping member during the operation of the pumping unit, and power-operated means for rotating said pump shaft.

2. A pump for use in the extracorporeal circulation of blood comprising a pair of pumping units each having a circular shaped compressible tubular pumping member, a support for each of said pumping members, a pump shaft extending through said supports and centrally located relatively to said circular pumping members, a pair of arms secured to said shaft, a rotary impeller member mounted for radial adjustment on each of said arms and adapted to cooperate with one of the pumping members, a separate means carried by each of said arms for manually operable to effect radial adjustment of the impeller member thereon to vary the action of said impeller member on its associated pumping member during the operation of the pumping unit, and power-operated means for rotating said pump shaft.

3. A pump for use in the extracorporeal circulation of blood comprising a pair of pumping units each having a circular shaped compressible tubular pumping member, a support for each of said pumping members, a pump shaft extending through said supports and centrally located relatively to said circular pumping members, a pair of arms secured to said shaft, a rotary impeller member mounted for radial adjustment on each of said arms and adapted to cooperate with one of the pumping members, a separate means carried by each of said arms for manually operable to effect radial adjustment of the impeller member thereon to vary the action of said impeller member on its associated pumping member during the operation of the pumping unit, and power-operated means for rotating said pump shaft.

4. A pump having a circular shaped compressible tubular pumping member, a support for the pumping member, a pump shaft extending through said support and centrally located relatively to the circular pumping member, an arm secured to said pump shaft, a rotary impeller mounted on said arm for radial adjustment and adapted to cooperate with the pumping member, means carried by the arm and shiftable in directions extending axially of said pump shaft to effect radial adjustment of said rotary impeller thereon in response to rotation of said pump shaft to vary the action of the impeller on the pumping member during the operation of the pump, and power-operated means for rotating the pump shaft.

5. A pump for use in the extracorporeal circulation of blood comprising a pair of pumping units each having a circular shaped compressible tubular pumping member, a support for each of said pumping members, a pump shaft extending through said supports and centrally located relatively to the circular pumping members, a pair of arms secured to said shaft, a rotary impeller member mounted for radial adjustment on each of said arms and adapted to cooperate with one of the pumping members, an adjusting knob carried by each of said arms and shiftable axially of said pump shaft, means controlled by said knob and operable to effect radial adjustment of the impeller member thereon in response to rotation of the pump shaft to vary the action of said impeller member on its associated pumping member during the operation of the pumping unit, and power-operated means for rotating said pump shaft.

6. A pump having a circular shaped compressible tubular pumping member, a support for the pumping member, a pump shaft extending through the support and centrally located relatively to said circular pumping member, an arm secured to said pump shaft, a rotary impeller mounted on said arm for radial adjustment and adapted to cooperate with the pumping member, an adjusting knob carried by said arm and shiftable in directions extending axially of said pump shaft, means controlled by said knob and operable to effect radial adjustment of the impeller member thereon in response to rotation of the pump shaft to vary the action of said impeller on the pumping member during the operation of the pump, and power-operated means for rotating the pump shaft.

7. A pump for use in the extracorporeal circulation of blood comprising a pair of pumping units each having a circular shaped compressible tubular pumping member, a support for each of said pumping members, a pump shaft extending through said supports and centrally located relatively to said circular pumping members, a pair of arms secured to said shaft, an impeller member mounted for radial adjustment on each of said arms and adapted to cooperate with one of the pumping members, a separate means carried by each of said arms for manually operable to effect radial adjustment of the impeller member thereon to vary the action of said impeller member on its associated pumping member during the operation of the pumping unit, and power-operated means for rotating said pump shaft.

8. A pump having a circular shaped compressible tubular pumping member, a support for the pumping member, a pump shaft extending through the support and centrally located relatively to said circular pumping member, an arm secured to said pump shaft, a rotary impeller mounted on said arm for radial adjustment and adapted to cooperate with the pumping member, an adjusting knob carried by said arm and shiftable in directions extending axially of said pump shaft, means controlled by said knob and operable to effect radial adjustment of the impeller member thereon in response to rotation of the pump shaft to vary the action of said impeller on the pumping member during the operation of the pump, and power-operated means for rotating the pump shaft.
extending through said supports and centrally located relatively to said circular pumping members, a pair of arms secured to said shaft, a rotary impeller mounted on each of said arms for radial adjustment and adapted to cooperate with one of the pumping members, a differential screw associated with each arm for effecting radial adjustment of the impeller mounted thereon, a reversible drive mechanism carried by each arm for operating the screw associated therewith, an adjusting knob carried by each of said arms and shiftible in directions extending axially of said pump shaft for controlling the drive mechanism carried thereby to cause rotation of its screw in response to rotation of the pump shaft to effect radial adjustment of the impeller on said arm thereby to vary the action of the impeller on its associated pumping member, and power-operated means for rotating the pump shaft.

8. A pump having a circular shaped compressible tubular pumping member, a support for the pumping member, a pump shaft extending through the support and centrally located relatively to said circular pumping member, a rotary impeller mounted on said arm for radial adjustment and adapted to cooperate with said pumping member, a differential screw for effecting radial adjustment of the impeller, a reversible drive mechanism for operating said screw, an adjusting knob carried by said arm and shiftible in directions extending axially of said pump shaft for controlling the drive mechanism to cause rotation of the screw in response to rotation of the pump shaft to effect radial adjustment of said impeller on said arm thereby to vary the action of the impeller on the pumping member, and power-operated means for rotating the pump shaft.

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