

[54] **PULSATOR PUMP AND HEAT EXCHANGER FOR BLOOD**[76] Inventor: **Robert C. Brumfield**, 73 Emerald Bay, Laguna Beach, Calif. 92657[22] Filed: **Dec. 13, 1971**[21] Appl. No.: **207,162**[52] U.S. Cl. **415/90, 415/178, 128/DIG. 3, 128/DIG. 1 D, 415/DIG. 4**[51] Int. Cl. **F04 7/0, F03 5/00**[58] Field of Search **128/DIG. 2, DIG. 3, 128/1 D; 415/DIG. 4, 90, 178, 180**[56] **References Cited****UNITED STATES PATENTS**

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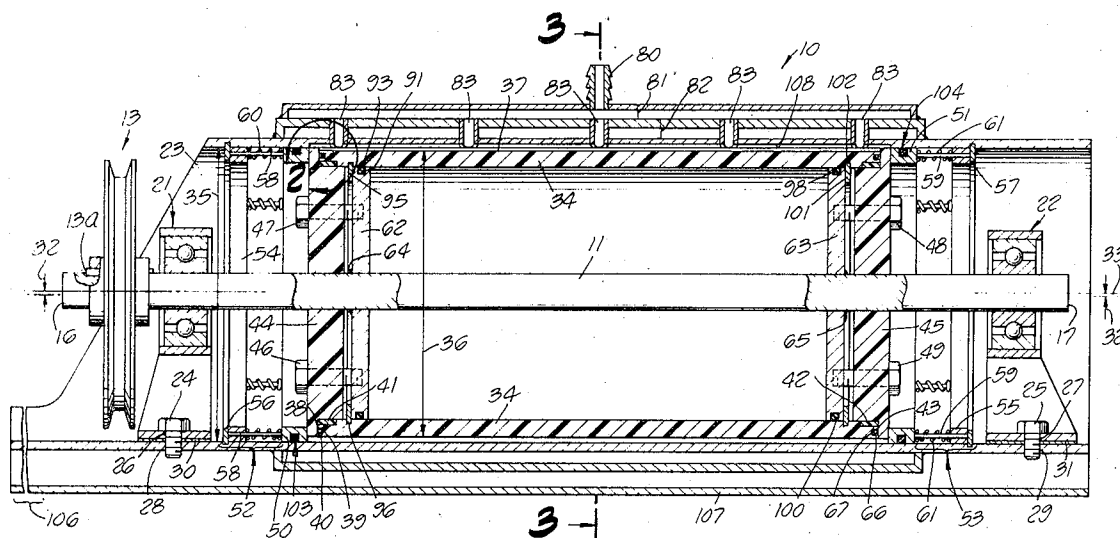
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[57] **ABSTRACT**

A slow variable speed drive rotates a pulsator pump

and heat exchanger which can circulate pulsed blood flow extra-corporeally at a required blood temperature to a patient. The pump has a cylindrical rotor shell permanently mounted in a closely fitting internally cylindrical stator housing. The rotor has a support shaft which is eccentrically disposed parallel to the internal axis of symmetry of the stator housing and also to the rotor symmetry axis.

Thus the rotor shell has its exterior surface also eccentrically disposed parallel to the rotor shaft axis of symmetry, providing controlled laminar flow of admitted blood. Laminar flow pumping means are provided, together with Taylor mixing vortices. Admitted patient blood is pumped as a thin blood film in pulsed laminar flow between the rotor and stator as the rotor exterior surface eccentrically approaches the stator surface, and in pulsed laminar Taylor vortex flow as the rotor surface recedes from the stator surface. The blood is introduced into the pump through a manifolded blood inlet having a longitudinal groove disposed in the inner face of the stator housing, the groove distributing blood to the annular space between the rotor and stator. A second similar blood outlet combination includes a longitudinal groove in the inner stator face, facilitating blood removal from the pump. The manifolded and jacketed stator housing provides heat transfer means for controlling the temperature of treated-blood of the patient.

3 Claims, 5 Drawing Figures

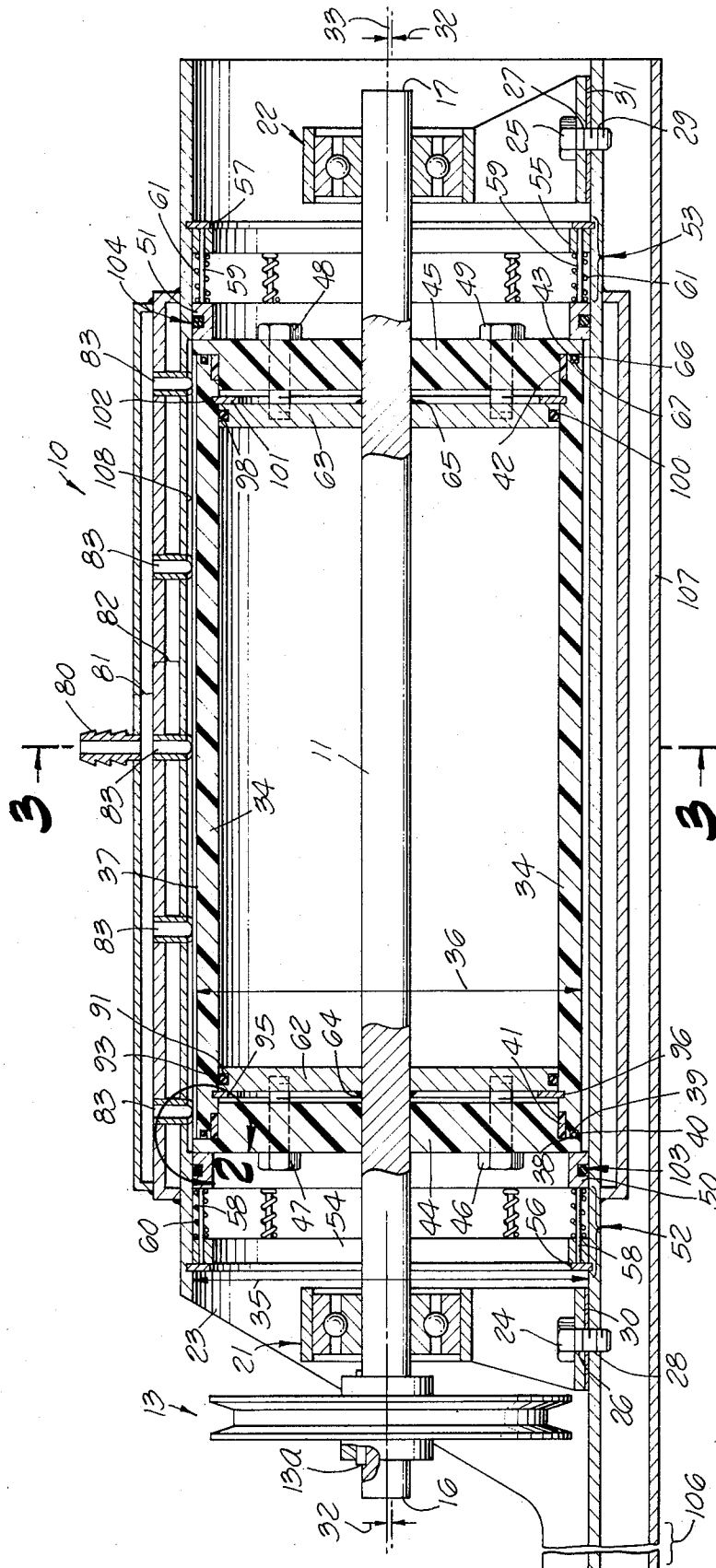
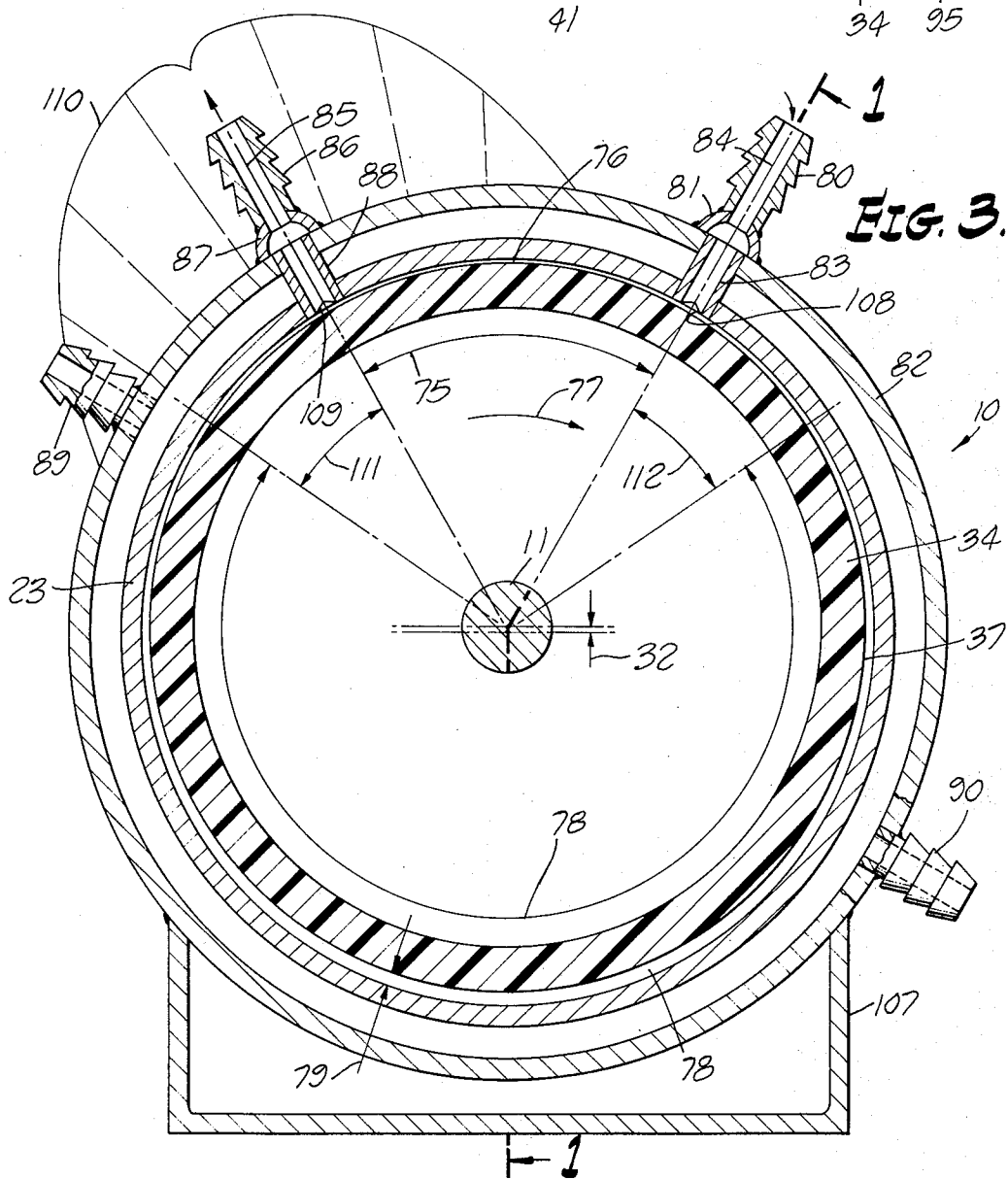
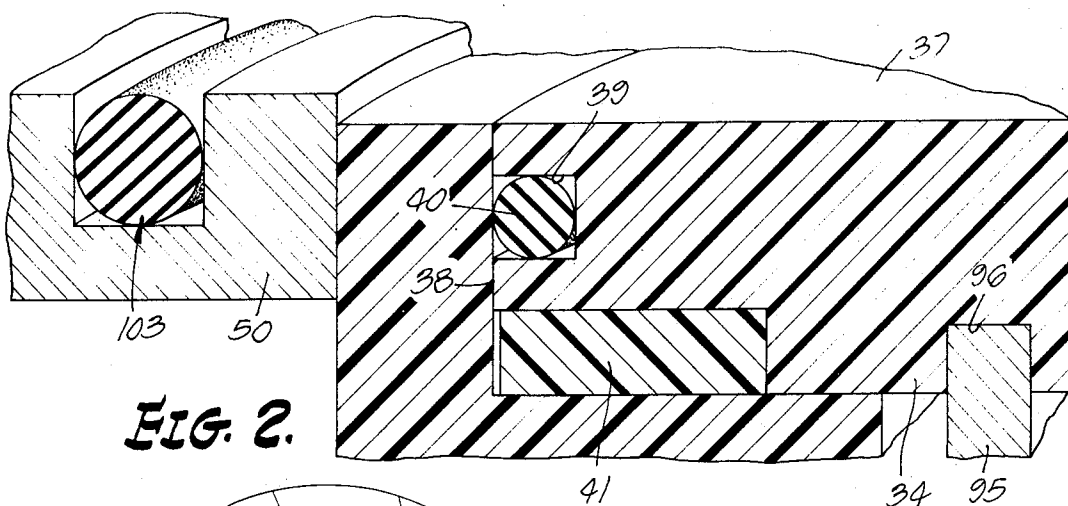


FIG. 1.



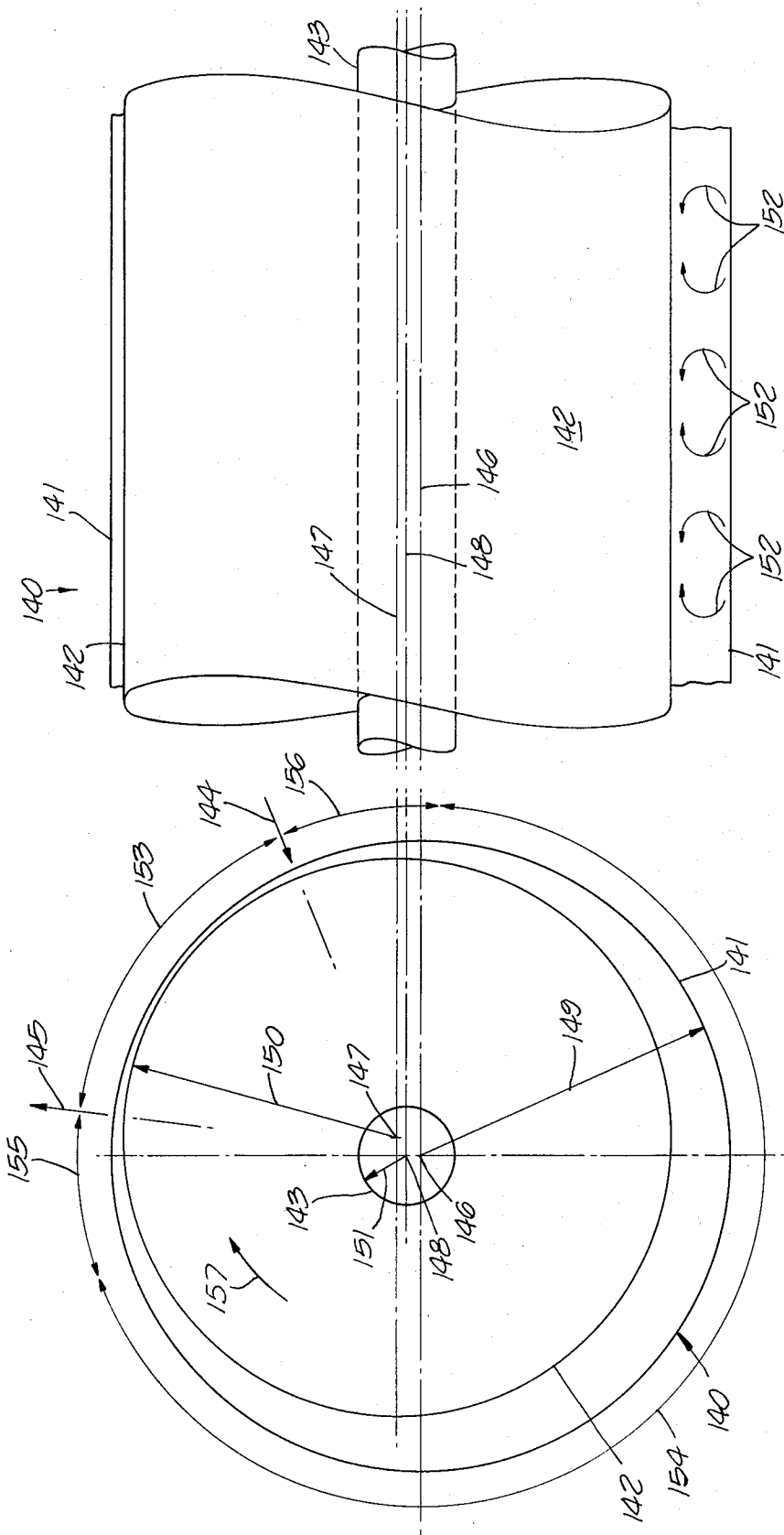


FIG. 5.

FIG. 4.

PULSATOR PUMP AND HEAT EXCHANGER FOR BLOOD

CROSS-REFERENCE TO RELATED APPLICATION

This application is related to the pending U.S. Pat. application, Ser. No. 190,800, filed Oct. 20, 1971 by the same inventor.

BACKGROUND OF THE INVENTION

A patient's blood can be mechanically pumped during advanced patient treatment and during radical cardio-pulmonary surgery. Likewise, there can be a need to provide a prescribed pulse in the extra corporeal blood circulation.

Apparatus for pumping blood is classified in Class 128 Subclass 258.5, and in Class 103 Subclasses 99 and 148.

SUMMARY OF THE INVENTION

A slow variable speed drive rotates a pulsator pump and heat exchanger which can circulate pulsed blood flow extra-corporeally at a required blood temperature to a patient. The pump has a cylindrical rotor shell permanently mounted in a closely fitting internally cylindrical stator housing. The rotor has a support shaft which is eccentrically disposed parallel to the internal axis of symmetry of the stator housing and also eccentrically disposed parallel to the rotor symmetry axis. The rotor shell has its exterior surface also eccentrically disposed parallel to the rotor shaft axis of symmetry, providing controlled laminar flow of admitted blood. Laminar flow pumping means together with Taylor mixing vortex flow are provided for the pumped blood.

Admitted patient blood is pulsatingly pumped by the exchanger pump, between the doubly eccentrically disposed rotor and stator. The blood flows lamina-ly in a thin film as a position on the eccentrically disposed rotor surface approaches the stator surface. Laminar Taylor vortex flow occurs as the same position on the rotor surface recedes from the stator surface. The stator housing is manifolded and jacketed, providing heat transfer means for controlling the patient's circulating blood temperature. Blood inlet and outlet conduits are conductively secured to the stator housing. The blood is introduced into the pump through a manifolded blood inlet having a longitudinal groove disposed in the inner face of the stator housing, the groove distributing blood to the annular space between the rotor and stator. A second similar blood outlet combination also includes a longitudinal blood distribution groove collecting blood for removal from the pump.

Included in the objects of this invention are:

To provide a variable speed pump for pulsatingly pumping patient blood extra-corporeally.

To provide a blood pump capable of extra-corporeally pumping blood during a surgical procedure, or the like.

To provide a blood pump capable of providing a variable rate of pulsed blood flow in extra-corporeal patient blood circulation.

To provide an effective thin blood film suitable for rapid heat exchange in a blood pump.

To provide an effective Taylor mixing vortex in a blood circulating device useful in an extra-corporeal patient blood pump.

Other objects and advantages of this invention are taught in the following description and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The description of this invention is to be read in conjunction with the following drawings:

FIG. 1 is an elevational sectional and partial perspective view of the blood pump.

FIG. 2 is an enlarged perspective partial sectional view through 2—2 of FIG. 1.

FIG. 3 is a cross sectional view through 3—3 of FIG. 1 illustrating the overall cross sectional configuration of the blood pump.

FIG. 4 schematically illustrates in cross section the configuration of the stator axis of symmetry, rotor axis of symmetry and the rotor shaft axis of symmetry which are required to produce the pulsatingly pumped blood flow.

FIG. 5 is a further schematic partial axial view of the cross section of FIG. 4, illustrating the pumping mechanism of the blood pump of FIGS. 1 and 3.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Refer to FIG. 1, FIG. 2 and FIG. 3 in detail as required. In FIG. 1 the blood transport pulsator pump 10 is shown in side elevational sectional view detail, having rotor shaft 11 eccentrically disposed substantially throughout a major fraction of the length of pump 10. A rotative drive pulley 13 and shaft key 13a are secured adjacent a first shaft terminus 16. A pair of rotor shaft bearing supports 21 and 22 are each adjacently disposed to shaft terminus 16 and 17 respectively. The bearing supports 21 and 22 are secured in precise positions on the rotor shaft 11, each said bearing support being removably securely locked to the shaft 11 by conventional means. A rigid tubular pump base 23 has a precise internal diameter 35 adaptively providing an internal cylindrical stator housing for the pump 10. Precisely ground guide pin screws 24 and 25 are shown threaded into precision threaded apertures 28 and 29 respectively in the pump base 23, through the precisely located apertures 26 and 27 respectively in the bearing supports 21 and 22. As in conventional precision bearing supports, a second pair of ground guide pin screws secure the pair of bearing supports 21 and 22 on opposed bases of bearing supports, not shown. The pair of unseen ground guide pin screws likewise are precisely screwed into threaded apertures in the pump base 23, precisely locating unseen opposed apertures in the bearing supports 21 and 22 respectively, providing precise location of 21 and 22.

A pair of first pump eccentricity adapters 30 and 31 are adaptively disposed between the pair of bearing supports 21 and 22 respectively and the rigid tubular pump base 23. The first pump eccentricity adapters 30 and 31 are secured by the respective guide pin screws 24 and 25, disposing the rotor shaft 11 in a precisely fixed first eccentricity value E_1 parallel with the internal axis of symmetry 33 of the precision diameter 35 of the internally cylindrical stator housing 23. The first pump eccentricity adapters 30 and 31 can be metal shims; they can also be equivalent well known means for precisely fixing the first eccentricity value E_1 of shaft 11 with respect to the axis of symmetry 33 of the pump stator housing 23. Thus the first eccentricity E_1 of shaft 11 is displaced vertically upward. The first ec-

centricity can equivalently be disposed along any internal radius of the 360° arc of the pump stator housing 23, for the purpose of positioning the shaft 11 in a predetermined first eccentricity value E_1 or the equivalent. Other securing means can be used, replacing shims as shaft eccentricity adapters, such as securing indexing pins, precisely machined lands or grooves, or the like.

The rigid cylindrical rotor shell 34 is also eccentrically disposed on the rotor shaft 11, represented by the second eccentricity E_2 . The values of E_1 and E_2 are not separately represented on FIG. 3, due to their small size. The resultant pump overall eccentricity, which is a vector sum E , of $E_1 + E_2 = E$, is the eccentricity value 32, illustrated in FIG. 3.

The system schematic 140 of FIGS. 4 and 5 together illustrate on an exaggerated scale the stator 141, the rotor 142, and the shaft 143. The typical relative positions of the stator center 146, the rotor center 147, and the shaft center 148 are equivalent to the pump configuration illustrated in detail in FIG. 3. The schematic blood inlet is 144 and the blood outlet is 145. The resultant eccentricity 32 of FIG. 3 is also equivalent to the resultant eccentricity E of FIG. 4, and provides pump pulsed transport of blood with laminar flow throughout the pump cycle.

Since turbulent blood flow in mechanically pumped extra-corporeal blood circulation is known to be destructive to formed blood elements, such as corpuscles and the like, it is very desirable to provide a blood pump which has a laminar flow pumping cycle. The blood laminar flow arc sector 75 in FIG. 3 is provided by disposing the rotor shell 34 in the resultant eccentricity 32, providing a thin laminar blood pumping means 76. The means 76 is formed between the stator 23 and the rotor 34 over the arc 75. Further, laminar flow of blood in the pump 10 or the like is maintained over the remainder of the pump arc by providing laminar flow with Taylor vortices over the pumping arc 78. The arcs 111 and 112 respectively denote transition into and transition out of the pumping means 76. The significance of the laminar flow with Taylor vortices is disclosed in detail below.

Referring again to FIGS. 4 and 5 in detail, the pump can be operated in the Taylor number (Ta) range of $41 < Ta < 400$

where

$$Ta = U_i d / \mu \sqrt{d / R_i},$$

and

U_i = peripheral velocity of rotor 142,

R_i = radius 150

d = radius 149 - radius 150

μ = viscosity of blood

as referenced by Schlichting, H., Boundary Layer Theory, N.Y., McGraw-Hill, 1968.

Turbulent flow develops at the high Taylor number $Ta = 1715$, corresponding to a Reynolds number $R = 3960$. Below the above Taylor number, the generated Taylor vortices 152 have axes which locally rotate in alternate opposite directions, such as the vortices 152 of FIG. 5. The Taylor vortices 152 provide excellent mixing means, promoting high rates of heat transfer. Similarly, the Taylor vortices 152 and the like equivalent vortices can promote a high rate of mass transfer across the blood membrane pump cross-referenced in U.S. Ser. No. 190,800, filed Oct. 20, 1971, by the same applicant.

Again in FIGS. 4 and 5, the offset shaft radius 151 is rotated in the direction 157, generating the laminar pumping means 153, and providing a Taylor vortex arc 154, with the incoming transition region 155 and the exiting transition region 156.

The pump parameters limiting pulsed blood flow are defined by

$E_1 > 0$,	$E_2 = 0$	no pulsing of blood positive blood pumping
and		
$E_1 = 0$,	$E_2 > 0$	positive blood pulsing no blood pumping

Hence the shape of the pressure distribution curve 110 of FIG. 3 is determined by the restraints placed on E_1 and E_2 . The shape of the pulse is accordingly modified.

The pump provides a single lobe rotor which impresses a repetitive pressure peak on the blood output flow, as the double eccentric type of lobe approaches the outlet conduit 86 or its equivalent 145, on each pump revolution. By varying the pump RPM, the blood pulse rate or pressure peak can be varied as desired.

Again referring to FIGS. 1 and 2 in detail, a pair of removable circular end plates 44 and 45 are respectively disposed at opposed rotor shell end 38 and end 43. The rotor shell 34 is operationally sealed against blood leakage by the pair of O-rings 40 and 66, which are respectively compressively disposed in the pair of O-ring grooves 39 and 67, located at the shell ends 38 and 43 respectively. The shell 34 has an external diameter 36, a precisely fixed value less than the internal diameter 35 of the stator housing 23, as will be discussed later. The precise diameter 36 of the rotor shell 34 is cooperatively related to the internal precision diameter 35 of the tubular base 23. A very smooth exterior surface is disposed on the cylindrical rotor shell 34 exterior face 37.

Each of the end plates 44 and 45 precisely fit respectively into the rotor end 38 and rotor end 43, also coaxially sealed by the pair of compressible gaskets 41 and 42 respectively. Two pairs of removable securing bolts, the pair of bolts 46 and 47 together with the pair 48 and 49 are shown securing the removable circular end plates 44 and 45 respectively. The pair of bolts 46 and 47 together with the pair of bolts 48 and 49 are shown threaded into the fixed inlet plates 62 and 63, as will be discussed later. Obviously each removable end plate 44 and 45 can be secured with the required number of removable securing bolts as is necessary to secure the rotor shell end fluid tight.

To maintain the removable end plates 44 and 45 fluid tight during rotation, a pair of removable fluid seals 50 and 51 are respectively secured against the plates 44 and 45. Securing means 52 and 53 applied against the pair of removable fluid seals 50 and 51 respectively are disposed internally in the tubular stator housing 23. Typically the securing means 52 consists of an annular support ring 54 precisely disposed in the tubular stator housing 23, the support ring 54 being locked in position by a removable retainer ring 56, which in turn holds multiple spring guide pins 58, each guide pin 58 being loaded by one of multiple expansion springs 60. In a similar manner the removable fluid seal 51 is secured in position by the means 53. The means 53 comprising as above, the annular rigid support ring 55 located in position by the removable retainer ring 57, which in turn positions the multiple spring guide pins 59, each one of the guide pins having a single expansion spring 61 disposed thereon.

The fixed circular end plate 62 and the fixed circular outlet plate 63 are permanently coaxially secured in position on the rotor shaft 11, providing a pair of precisely fixed index support positions. The fixed inlet plate 62 is disposed inside a rotor end 38 and the fixed outlet plate 63 is disposed inside a rotor end 43. The plate 62 is secured to the shaft 11 as by the weldment 64, and the outlet plate 63 is secured to the shaft 11 by the weldment 65.

Referring to FIGS. 1 and 3 together in detail, a blood inlet conduit 80 is shown conductively secured to a blood inlet manifold 81. The manifold 81 in turn is permanently secured to a heat transfer shell jacket 82 which cylindrically encircles the rigid tubular pump base 23 over that length of the pump base 23 which comprises the stator housing. The multiple blood inlet vents 83 are radially disposed through the heat transfer jacket 82 and the stator housing 23 providing sealed vents 83 from the blood manifold 81 into the inlet blood groove 108 distributing blood into the blood laminar flow arc sector 75, shown in FIG. 3. Thus patient blood can be conductively flowed through the conduit 80, serially through the blood inlet manifold 81, then through the multiple blood inlet vents 83 and inlet groove 108, into the blood laminar flow arc sector 75. When the rotor shell 34 rotates in the direction of the arrow 77, blood laminar pumping means 76 are generated over the blood laminar flow arc sector 75 for the length of the rotor shell 34.

The blood manifold outlet 87 conductively secured to the blood outlet conduit 86, is in turn disposed parallel along the external surface of the heat transfer jacket 82, as is the blood inlet manifold 81. The multiple blood outlet vents 88 are similarly disposed through the heat transfer jacket 82 venting into the outlet groove 109. The pair of heat transfer fluid inlet and outlet conduits 89 and 90 respectively are attached to the jacket 82 as shown in FIG. 3. The conduits 89 and 90 permit the desired heat transfer fluid to be circulated in the jacket 82, as will be later discussed, maintaining the patient's blood at the desired temperature.

Further details of the blood pump construction are outlined below. The O-ring groove 91 is disposed in the fixed inlet plate 62, sealed by the O-ring 93. The snap retaining ring 95 fits in the retaining ring groove 96, providing an index position for the rotor shell 34. At the opposed end of the pump 10 a second O-ring groove 98 is filled by the O-ring 100, providing a seal preventing blood leakage. The snap retaining ring 101 is disposed in the retaining ring groove 102, which in turn is located in the rotor shell 34, providing a second indexing position for the shell 34. Conventional O-rings and groove combinations 103 and 104 are disposed in the seals 50 and 51 respectively, providing sealing means. The stator housing extension 106 can be that length which is required to provide a working platform for the assembly and dis-assembly of the pump 10. The internal cylindrical surface of stator housing 23, defined by the stator diameter 35, can be coated with a polyurethane coating physiologically compatible with patient blood. The support base 107, extending the length of the stator housing provides a support base for the pump.

Typically the rotor shell 34, the O-rings 40 and 66, and the pair of compression gaskets 41 and 42 are assembled at a factory, ready for placement in a pump 10 as required. The subcombination is to be used as re-

quired in a medical procedure and then discarded, the remainder of the pump cleaned as necessary, and a second subcombination replaces the first subcombination.

A pump 10 having a rotor 34 whose diameter 36 is approximately 4 inches and whose length is proportioned to pump the required blood flow rate for an adult patient, can typically operate in the range of 60 to 100 RPM, supplying a needed pulsed blood flow. Such a machine can also be used as a blood pump for perfusion of an organ, such as a heart or kidney, prior to surgical transplant procedure. When required, as in transplant procedure or the like, a refrigerant such as water or a Freon as is necessary, can be used to cool blood and organs to temperatures typically 28°C or less for hypothermia. Likewise warmer water can be provided to warm patients and patient's blood as becomes necessary. The machine stores small amounts of patient's blood during medical procedures and has the advantage of decreasing patient blood loss under critical conditions.

The pump 10 can be a permanent apparatus suitable for use in medical procedures, with a replaceable essentially single use plastic rotor shell. The shell can be separately prepared in a factory for use as required in a specific medical procedure.

Many modifications and variations in the improvement in a pulsator blood transport pump can be made in the light of my teaching. It is therefore understood that within the scope of the appended claims, the invention may be practiced otherwise than as has specifically been described.

I claim:

1. In an apparatus for pumping extra-corporeal patient blood, said apparatus having a right cylinder rotor secured on a rotor shaft, an internally cylindrical stator housing cylindrically enclosing said rotor, and means providing cooperative bearing support for said rotor shaft, the blood transport pump combination comprising:
 - a rigid cylindrical rotor shell having its rotational axis of symmetry precisely displaced parallel to the rotor axis of symmetry, said rotor shell and said rotor shaft being positively secured together, said rotor shaft adaptively disposed in said stator housing, said shell having an external diameter precisely less than said internal diameter of said stator housing,
 - a pair of rotor shaft bearing supports, each one of said pair of bearing supports disposed adjacent one shaft terminus, said bearing supports secured to precise positions on said rotor shaft,
 - a pair of eccentricity adapters, each one of said adapters cooperatively securing one of said pair of bearing supports, disposing said rotor shaft in a precisely fixed resultant eccentricity parallel with the internal axis of symmetry of said internally cylindrical stator housing,
 - a blood laminar flow arc sector precisely disposed between said rotor and said stator housing, said resultant eccentricity cooperatively fixing the laminar flow arc sector value, said arc sector providing blood pumping means during rotation of said rotor, and
 - a blood Taylor vortex flow arc sector precisely disposed between said rotor and said stator housing, said resultant eccentricity cooperatively fixing said Taylor vortex arc sector value, said arc sector pro-

viding blood film mixing means during rotation of said rotor;

whereby the rotating said rotor provides pulsed laminar blood flow in said laminar flow arc sector and provides pulsed laminar transitional and Taylor vortex flow in the remainder of the pump arc sector.

2. An apparatus in accordance with claim 1 wherein a heat transfer shell jacket covers the external cylinder face of said stator housing, said jacket having a fluid inlet conduit and a fluid outlet conduit secured to said jacket, said inlet conduit, said jacket and said outlet conduit together providing a serial passageway for a heat transfer fluid suitable for controlling patient blood temperature.

3. A blood transport pulsator pump combination comprising:

a slow speed drive and a rotor shaft means coaxially secured together,

a cylindrical pump rotor having its cylindrical axis of symmetry precisely displaced parallel to the rotor axis of symmetry, said rotor mounted on and secured to said rotor shaft means, together providing a blood pump rotor means,

an internally cylindrical stator pump housing fitting around and cylindrically enclosing said pump rotor, said rotor shaft means being eccentrically dis-

posed parallel to the internal axis of symmetry of said stator pump housing, said pump housing and said pump rotor proportioned and cylindrically axially copositioned providing a substantial thin annular laminar flow arc area during rotor rotation, and cooperatively providing a substantial Taylor vortex flow arc sector area during rotor rotation,

means providing cooperative bearing support, securing said rotor shaft means and said stator housing, means providing cooperative blood sealing support, securing said rotor shaft means and said stator housing,

means providing heat transfer control disposed in the wall of said stator pump housing, providing temperature control of blood pumped,

means conductively secured to said stator housing, adjacent to said area of laminar flow of blood, providing a blood inlet conduit,

means conductively secured to said stator housing disposed in said area of laminar flow of blood, providing a blood outlet conduit,

whereby the rotating said rotor provides laminar blood flow in said laminar flow arc sector and provides laminar transitional and Taylor vortex flow in the remainder of the pump arc sector.

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