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(54) VENTRICULAR ASSIST SYSTEM WITH SECONDARY IMPELLER

HERZKAMMERUNTERSTÜTZUNGSSYSTEM MIT ZWEITEM LAUFRAD

ROUE SECONDAIRE DE SYSTEME D'ASSISTANCE VENTRICULAIRE

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- **MALANOSKI S B ET AL: "STABLE BLOOD LUBRICATED HYDRODYNAMIC JOURNAL BEARING WITH MAGNETIC LOADING" , ASAIO JOURNAL, J.B.LIPPINCOTT CO.,HAGERSTOWN,MD, US, VOL. 44, NR. 5, PAGE(S) M737-M740 XP000802393 ISSN: 1058-2916 page 738; figure 1**
- **NAKAMURA ET AL: 'Blood flow analysis for the secondary impeller of an IVAS heart pump' ASAIO J. vol. 43, US, pages M773 - M777**

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Description

Field of the invention

[0001] The present invention relates to the medical arts. It finds particular application in cardiac assist technologies using rotodynamic blood pumps, also known as left ventricular assist devices (LVAD) in assisting patients with failing hearts and will be described with particular reference thereto. It is to be appreciated that the present invention is also applicable to other types of pumps, and is not limited to the aforementioned application.

Background of the invention

[0002] Rotodynamic pumps (axial flow, mixed flow, and centrifugal) have prospective applications in cardiac assist technologies. A typical cardiac assist system includes the blood pump itself, electric motor (usually a brushless DC motor integrated into the pump), drive electronics, microprocessor control unit, and an energy source, such as rechargeable batteries. These pumps can be used in fully implantable systems for chronic cardiac support where the whole system is located inside the body and there are no drive lines penetrating the skin. For more temporary support, the pump is located inside the body but some system components, including drive electronics and energy source, may be placed outside the patient body.

[0003] The inverted, shaftless, brushless motor design is utilized because it has a significant advantage over typical motor/drive shaft configurations. There are no openings in the housing that would allow blood into the motor, and the housing precludes air or other fluid from entering the bloodstream. A primary drive impeller of the pump encloses a drive magnet and is driven by a stator and coil assembly disposed radially inward from the motor rotor, i.e., an inverted motor. In order to avoid friction and subsequent heat buildup, the blood of the patient is used as a fluid bearing between the impeller and the stator.

[0004] A potential problem with this system is that the blood can become heated and/or stagnant, and partially solidify by forming a thrombus or heat coagulation of blood proteins on the stator housing surface or on the secondary impeller of the motor rotor in the inverted fluid film bearing assembly. Such a situation is undesirable and potentially life-threatening to the patient who is dependant on the proper function of such a device. Accordingly a need exists for a well-washed or continuous flow of blood that serves as the bearing between the rotor and stator components. Malonoski et al. (ASAIO Journal, 1998, vol 44, M737-M740) show a rotary blood pump device having a secondary impeller.

[0005] The present invention however provides a new and improved apparatus that avoids thrombus and/or coagulated protein formation/deposition and overcomes the above referenced problems and others.

Summary of the Invention

[0006] In accordance with the present invention as defined in claim 1, a cardiac assist device is provided. A drive stator is received within a housing along with an impeller assembly. The impeller assembly includes primary and secondary impellers, and a drive rotor. The primary impeller provides a motive force which transports blood from an inlet port to an outlet port. The secondary impeller cycles blood to lubricate and cool a bearing between the impeller assembly and the stator housing.

[0007] In accordance with a more limited aspect of the present invention, the secondary impeller comprises radial vanes that exhibit symmetry relative to radii extending from a center of the impeller assembly.

[0008] In accordance with another more limited aspect of the present invention, a left ventricular assist device is provided. A brushless DC motor and an impeller assembly are contained within a volute housing assembly. The impeller assembly comprises a primary impeller, an annular magnet drive rotor, and a secondary impeller. The secondary impeller comprises a plurality of radial vanes that are smooth and rounded, with an axial height at an outer radius greater than an axial height at an inner radius.

[0009] One advantage of the present invention is a blood pump with a single moving part with no seal between the motor and blood compartments.

[0010] Another advantage resides in avoiding problems associated with drive shaft interfaces.

[0011] Another advantage is the creation of blood flow and wash patterns that avoid the formation of blood element depositions.

[0012] Still further benefits and advantages of the present invention will become apparent to those skilled in the art upon a reading and understanding of the preferred embodiments.

Brief Description of the Drawings

[0013] The invention may take form in various components and arrangements of components. The drawings are only for purposes of illustrating preferred embodiments and are not to be construed as limiting the invention.

FIGURE 1 is a cross-sectional view of a blood pump in accordance with the present invention;

FIGURE 2A is a cross-sectional view of a volute housing assembly in accordance with the present invention;

FIGURE 2B is a cross-sectional view of the volute housing assembly taken generally along the lines 2B-2B of FIGURE 2A;

FIGURE 3 is a cross-sectional view of a stator assembly in accordance with the present invention;

FIGURE 4A is an elevational view of an impeller assembly, particularly illustrating the primary impeller, in accordance with the present invention;

FIGURE 4B is a cross-sectional view of the impeller assembly taken generally along the lines 4B-4B of FIGURE 4A;

FIGURE 5A is an elevational view of a secondary impeller in accordance with the present invention;

FIGURE 5B is a cross-sectional view of the secondary impeller taken generally along the lines 5B-5B of FIGURE 5A.

Detailed Description of the Preferred Embodiment

[0014] With reference to FIGURE 1, a centrifugal flow blood pump comprises three primary subassemblies, namely a volute housing assembly **10,** a stator assembly **12,** and a rotating assembly or rotor **14.** Blood from a patient flows into an inlet port **16** of the blood pump. Arrows (unnumbered) indicate the direction of travel of the blood through the pump in the preferred embodiment. The blood flow into the pump has energy imparted to it by the rotating annular rotor, specifically by primary impeller **18.** The blood proceeds around the volute housing, first entering a volute channel **20** and a primary portion exiting the pump via a discharge port **22**.

[0015] A small portion of the blood flows into a second channel or passage 2**4**, specifically a first passage portion **24a** that extends axially from a rear face of the primary impeller and is radially interposed between the rotor and a post formed by an axial extension **10a** of the stator housing that protrudes into a pump chamber defined in the volute housing. As is well known, the chamber is in fluid communication with the inlet and outlet, and the primary impeller pumps the blood from the axial inlet to the tangential outlet. The secondary impeller (to be described in greater detail below) is provided at an opposite end of the rotor assembly remote from the primary impeller. A second passage portion **24b** of the second channel defined at a second end of the rotor, i.e., remote from the primary impeller, continues from the first passage portion **24a** and flows radially inward through the secondary impeller toward a rotational axis of the rotor. The small portion of blood flow then proceeds axially along a third passage portion **24c** between the rotor **14** and the axial extension of the housing. The secondary channel thus forms a fluid or blood bearing that is continuously renewed during operation of the pump. Blood exits the bearing near the primary impeller **18** and is replenished by new blood flowing through the secondary channel **24.**

[0016] As illustrated in Fig. 1, the cross-sectional dimension of the second channel varies from one portion to the next. Particularly, the channel has the largest dimension along the first portion **24a** and the smallest dimension along the third portion **24c.** The channel dimensions, in conjunction with the impeller geometry, speed, number of blades, clearance, pressure gradient, and flow recirculation, provide parameters for an effective fluid film bearing free of blood element deposition.

[0017] A jacketed cable **26** is received through a base portion **28** of the housing for connection with the stator assembly **12** contained in the axial extension. The cable carries power and control connections to and from the pump particularly to the stator assembly **12.**

[0018] With reference to FIGURES 2A and 2B, the volute housing assembly **10** in the preferred embodiment is formed by a single casting that is subsequently cut into two separate pieces before being joined again to form a one-piece housing. When separated, the individual pieces are machined and polished, removing any casting imperfections or anomalies within the volute section 2**0**, prior to being welded together. Alternately, the volute housing assembly can be a single cast component, with no seams to weld. Preferably, the volute housing assembly **10** is made of titanium with walls approximately 2.5 mm thick. Both the inlet and discharge ports **16, 22** are configured for coupling **34** to adjacent fluid lines or passages. For example, the housing is externally threaded at each port for ease of connection with a corresponding female threaded coupling to provide a secure, sealed interconnection. The ports are preferably equipped with a guide surface or fitting pilot **36** for orienting connection to a fluid conduit (not shown).

[0019] The inlet port 1**6** communicates with an inlet throat **38** that has a slightly smaller diameter than the inlet port. In this manner, blood passes through the throat and is accelerated. This reduces pre-whirl of the blood entering the impeller **18.** A conical diffuser **40** leading to the discharge port **22,** and downstream of the primary channel, decreases the velocity of the pumped blood before it enters the aorta. In the preferred embodiment, the conical diffuser **40** widens to the discharge port **22** at an included angle of approximately 7°, although other diffuser angles and configurations can be used without departing from the scope and intent of the present invention.

[0020] A recess **42** is included in a base of the volute housing body **30.** Inserts **44,** are circumferentially spaced about the housing and adjusted to receive fasteners after the impeller assembly **14** and the stator assembly **12** have been inserted into the housing assembly. A volute tongue **46** extends inwardly from the housing along a tangent with the rotor to separate the diffuser from the pump chamber and direct the blood into the conical diffuser **40** at the end of the primary channel.

[0021] With reference to FIGURE 3, stator windings 50 are located within the axial extension of the housing. An electrical connector **52** represented at a distal end of the jacketed cable **26** connects the pump to a power supply and control circuitry (not shown). In the preferred embodiment, the stator windings **50** are connected to the power supply which is located outside the body of the patient. The stator windings 5**0** and electrical connections are inserted into the stator housing axial extension and multiple inserts or shims **54** disposed about the stator windings **50,** adjust position and ensure a tight and secure fit of the windings within the axial extension. The housing cover **28** is secured to the axial extension of the housing 1**0** with an attachment device **56,** preferably a single fastener or screw that locks into a self-locking helical receptacle **58** at an opposite end of the axial extension. Seal members such as O-rings **60, 62** seal any possible apertures through which body fluids might enter the housing.

[0022] It will also be appreciated from a close examination of FIGURE 3 that the stator assembly is offset within the axial extension. That is, the wall thickness of the axial extension differs over its circumferential extent. For example, the wall thickness along the top (as viewed in FIGURE 3) is less than the wall thickness along the bottom. This provides a purposeful offset for controlling motion of the rotor and controlling the fluid film bearing formed between the rotor and housing. More particular details of this offset feature are shown and described in U.S. Patent No. 5,324,177.

[0023] FIGURES 4A and 4B illustrate three main features of the impeller assembly **14,** namely the primary impeller **18,** a secondary impeller **70,** and an annular magnet **72.** The primary impeller **18** includes multiple blades, e.g. seven blades, shaped such that together, the primary blades provide a mixed flow, i.e., combined axial and radial flow. The annular magnet **72** extends around a circumference of the impeller assembly **14** and mates with the post containing the stator windings **50** of the stator housing **12.** The annular magnet **72** is preferably magnetized in a longitudinal, circumferentially spaced pattern, commonly known as a four pole pattern. Alternately, a plurality of individual magnets can be arranged in a similar pattern. The annular magnet **72** is inserted into the impeller assembly, sealing the magnet **72** within the rotor assembly envelope formed between the primary **18** and secondary **70** impellers. The assembly is welded or otherwise bonded shut.

[0024] Details of the secondary impeller **70** disposed at one end or on a base of the impeller assembly **14,** are more particularly illustrated in FIGURES **5A** and **5B**. The secondary impeller **70** comprises a plurality of straight, radial blades **80,** nine blades in the preferred embodiment. Each blade **80** has a rounded outboard tip 82 that is approximately twice the height of a radial inner portion **84.** The height difference is realized with a revolved scallop cut, shaping each of the blades **80** similarly. All transitions or edges of the blades are gradual, avoiding sharp corners or other crevices, wherein blood can become lodged. The preferred embodiment of the secondary impeller **70** as described establishes a rotor-balancing pressure distribution across the back of the rotating assembly while allowing a radial inflow of blood to continually wash through the secondary channel 2**4** between the impeller assembly **14** and the housing. The particular shape of the secondary impeller blades 80 keeps the blood moving to prevent stagnation/long residence times and the blades **80** free of thrombus formation.

[0025] In the preferred operation of the blood pump, the secondary impeller **70** establishes a radial pressure gradient across the base of the impeller assembly **14,** such that control of rotating assembly hydraulic thrust and a differential pressure across the bearing is achieved. The pressure gradient and circulation of blood around the vanes help to avoid thrombus formation on the impeller and within the bearing.

[0026] The blood flow through the secondary channel **24** supplying the bearing is very low, relative to the flow through the primary channel 20. The design of the secondary impeller allows a balance between bearing flow, and creating too great an axial hydraulic loading. The thrust resulting from axial hydraulic loading is balanced by the axial magnetic stiffness of the motor components. The pressure at the outboard tips **82** of the blade is essentially equal to and fixed at the pressure at the primary impeller **18.** A radial pressure gradient is created inboard of the secondary impeller tips. The higher the gradient, the lower the pressure at the secondary end of the bearing. If the pressure gradient is equal to the opposing primary impeller, then both the hydraulic thrust and the net bearing pressure and flow are zero. If the pressure gradient is too low, then both the bearing flow and hydraulic thrust on the impeller assembly **14** increases.

[0027] The invention has been described with reference to the preferred embodiment. Modifications and alterations will occur to others upon a reading and understanding of the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims.

Claims

1. A cardiac assist device comprising:

a housing (10) having an inlet (16) and an outlet (22);

a rotor assembly (14) adapted for rotation about a drive axis including a primary impeller (18) for transporting blood from the inlet (16) to the outlet (22), and a secondary impeller (70) for cycling blood through a bearing (24) interfaced between the rotor assembly (14) and the housing (10),

the secondary impeller (70) having a series of spaced blades circumferentially spaced about the drive axis and disposed in substantially radial orientation for improving recirculation through the blood bearing (24) wherein the secondary impeller blades (80) extend axially outwardly from the rotor assembly (14) **characterized in that** said secondary impeller blades have a varying axial height over a radial dimension.

2. The cardiac assist device according to claim 1 wherein the secondary impeller blades (80) have rounded edges.

3. The cardiac assist device according to claim 1 or 2 wherein the secondary impeller blades (80) have a scalloped undercut whereby an outer radial portion (82) of each blade extends outwardly a greater dimension than an inner radial portion (84) of each blade.

4. The cardiac assist device according to any of claims 1 to 3 wherein the secondary impeller blades (80) are disposed on a face of the rotor and the scalloped undercut includes a concave surface extending inwardly in each blade from an outer radial edge to an inner radial edge.

5. The cardiac assist device according to any of claims 1 to 4 wherein each blade (80) of the secondary impeller has a concave surface.

6. The cardiac assist device according to any of claims 1 to 5 further comprising an inverted motor and fluid film bearing including a stator (12) received on a post formed by an axial extension of the housing (10) and receiving an annular rotor (14) having a drive magnet (72) disposed therein that is radially supported and rotationally driven by the stator (12), a clearance (24) defined between the annular rotor and housing extension defining a bearing that is adapted to be supplied with a well-washed circulating flow of blood by the secondary impeller (70).

7. The cardiac assist device according to any of claims 1 to 6 wherein the rotor (14) has an elongated axial dimension with the primary impeller (18) located at a first end thereof and the secondary impeller (70) located at a second end thereof.

8. The cardiac assist device according to any of claims 1 to 6 wherein the inlet (16) extends axially and the outlet (20) extends tangentially from the housing (10).

9. The cardiac assist device according to any of claims 1 to 8 wherein the secondary impeller blades (80) extend axially outward from the rotor assembly (14) a greater dimension at a radial outer edge than a radial inner edge.

10. The cardiac assist device according to any of claims 1 to 9 wherein the secondary impeller blades (80) extend outwardly beyond the outer diameter of the rotor assembly (14).

11. The cardiac assist device according to any of claims 1 to 10 wherein the secondary impeller blades (80) have a concave, rounded contour extending from the radial outer edge to the radial inner edge.

12. The cardiac assist device according to any of claims 1 to 11 wherein the drive assembly includes a stator winding (50) disposed in the housing portion (10).

13. The cardiac assist device according to any of claims 1 to 12 wherein the drive assembly includes a magnet (72) disposed in the rotor assembly (14).

14. The cardiac assist device according to any of daims 1 to 13 wherein the fluid film bearing includes a reduced dimensioned passageway (24) interposed between the rotor assembly (14) and the housing portion (10).

15. The cardiac assist device according to any of claims 1 to 14 wherein the housing portion (10) is non-circular in cross-section.

16. The cardiac assist device according to any of claims 1 to 15 wherein radial inner portions of the second impeller blades (80) are dimensioned to have a larger clearance with the housing (10) than outer tips of the blades.

17. The cardiac assist device according to any of claims 1 to 16 wherein radial inner portions (84) of the second impeller blades (80) are one-half the height of the outer tips (82) of the blades.

18. The cardiac assist device according to any of claims 1 to 17 wherein the secondary impeller (70) comprises a plurality of straight radial blades (80), each blade having a rounded outboard tip (82) that is twice the height of a radial inner portion (84).

Patentansprüche

1. Eine das Herz unterstützende Vorrichtung, wobei die Vorrichtung umfasst:

ein Gehäuse (10) mit einem Einlass (16) und einem Auslass (22);

eine Rotoranordnung (14), die für eine Rotation um einen Achsenantrieb angepasst ist, der ein erstes Antriebsrad (18) für den Bluttransport vom Einlass (16) zum Auslass (22) und ein zweites Antriebsrad (70) für den periodischen Blutdurchlauf durch eine Aussparung (*bearing*) (24) beinhaltet, die zwischen der Rotoranordnung (14) und dem Gehäuse (10) liegt, wobei das zweite Antriebsrad (70) eine Reihe von Lamellen in regelmäßigen Abständen besitzt, die kreisförmig um den Achsenantrieb angeordnet und im Wesentlichen in radialer Ausrichtung ausgerichtet sind, so dass die Re-Zirkulation durch die Aussparung für das Blut (24) verbessert wird, wobei die Lamellen (80) des zweiten Antriebsrads sich von der Rotoranordnung (14) axial nach außen erstrekken, **dadurch gekennzeichnet, dass** die Lamellen des zweiten Antriebsrads eine variierende axiale Höhe über einer radialen Ausdehnung besitzen.

2. Die das Herz unterstützende Vorrichtung gemäß Anspruch 1, wobei die Lamellen (80) des zweiten Antriebsrads abgerundete Kanten haben.

3. Die das Herz unterstützende Vorrichtung gemäß Anspruch 1 oder 2, wobei die Lamellen (80) des zweiten Antriebsrads einen zinnenförmigen Unterschnitt besitzen, wobei ein äußerer radialer Anteil (82) jeder Lamelle sich in einer größeren Ausdehnung nach außen erstreckt als ein innerer radialer Anteil (84) jeder Lamelle.

4. Die das Herz unterstützende Vorrichtung gemäß einem der Ansprüche 1 bis 3, wobei die Lamellen (80) des zweiten Antriebsrads auf einer Seite des Rotors angeordnet sind und der zinnenförmige Unterschnitt eine konkave Oberfläche beinhaltet, die sich von einer äußeren radialen Kante nach innen in jede Lamelle bis zu einer inneren radialen Kante ausdehnt.

5. Die das Herz unterstützende Vorrichtung gemäß einem der Ansprüche 1 bis 4, wobei jede Lamelle (80) des zweiten Antriebsrads eine konkave Oberfläche hat.

6. Die das Herz unterstützende Vorrichtung gemäß einem der Ansprüche 1 bis 5, wobei die Vorrichtung weiterhin einen invertierten Motor und eine Flüssigkeitsfilmaussparung (*fluid film bearing*) umfasst, die einen Stator (12) beinhaltet, der auf einem Pfosten gehalten wird, der von einem axialen Fortsatz des Gehäuses (10) ausgebildet wird, und einen ringförmigen Rotor (14) mit einem darin angebrachten Antriebsmagneten (72) aufnimmt, der vom Stator (12) radial unterstützt und rotationsmäßig angetrieben wird, und die eine Aussparung (24) beinhaltet, die zwischen dem ringförmigen Rotor und der Gehäuseausdehnung ausgebildet wird, die eine Aussparung ausbildet, die dafür angepasst ist, dass sie vom zweiten Antriebsrad (70) mit einem gut gewaschenen, zirkulierenden Blutfluss versorgt wird.

7. Die das Herz unterstützende Vorrichtung gemäß einem der Ansprüche 1 bis 6, wobei der Rotor (14) eine elongierte axiale Ausdehnung besitzt, wobei das erste Antriebsrad (18) an einem ersten Ende davon gelegen ist, und das zweite Antriebsrad (70) an einem zweiten Ende davon gelegen ist.

8. Die das Herz unterstützende Vorrichtung gemäß einem der Ansprüche 1 bis 6, wobei der Einlass (16) sich axial erstreckt und der Auslass (20) sich tangential vom Gehäuse (10) erstreckt.

9. Die das Herz unterstützende Vorrichtung gemäß einem der Ansprüche 1 bis 8, wobei die Lamellen (80) des zweiten Antriebsrads sich von der Rotoranordnung (14) in einer größeren Ausdehnung an einer radialen äußeren Kante axial nach außen erstrekken als an einer radialen inneren Kante.

10. Die das Herz unterstützende Vorrichtung gemäß einem der Ansprüche 1 bis 9, wobei die Lamellen (80) des zweiten Antriebsrads sich bis hinter den äußeren Durchmesser der Rotoranordnung (14) nach außen erstrecken.

11. Die das Herz unterstützende Vorrichtung gemäß einem der Ansprüche 1 bis 10, wobei die Lamellen (80) des zweiten Antriebsrads eine konkave, abgerundete Kontur besitzen, die sich von der radialen äußeren Kante bis zur radialen inneren Kante erstreckt.

12. Die das Herz unterstützende Vorrichtung gemäß einem der Ansprüche 1 bis 11, wobei die Antriebsanordnung ein Statorgewinde (50) beinhaltet, das im Gehäuseanteil (10) angeordnet ist.

13. Die das Herz unterstützende Vorrichtung gemäß einem der Ansprüche 1 bis 12, wobei die Antriebsanordnung einen Magneten (72) beinhaltet, der in der Rotoranordnung (14) angeordnet ist.

14. Die das Herz unterstützende Vorrichtung gemäß einem der Ansprüche 1 bis 13, wobei die Flüssigkeitsfilmaussparung einen Durchlass (24) geringeren Ausmaßes beinhaltet, der zwischen der Rotoranordnung (14) und dem Gehäuseanteil (10) eingefügt ist.

15. Die das Herz unterstützende Vorrichtung gemäß einem der Ansprüche 1 bis 14, wobei der Gehäuseanteil (10) im Querschnitt nicht kreisförmig ist.

16. Die das Herz unterstützende Vorrichtung gemäß einem der Ansprüche 1 bis 15, wobei die radialen inneren Teile der Lamellen (80) des zweiten Antriebsrads so dimensioniert sind, dass sie mit dem Gehäuse (10) eine größere Aussparung besitzen als die äußeren Spitzen der Lamellen.

17. Die das Herz unterstützende Vorrichtung gemäß einem der Ansprüche 1 bis 16, wobei die radialen inneren Anteile (84) der Lamellen (80) des zweiten Antriebsrads halb so groß sind wie die Höhe der äußeren Spitzen (82) der Lamellen.

18. Die das Herz unterstützende Vorrichtung gemäß einem der Ansprüche 1 bis 17, wobei das zweite Antriebsrad (70) eine Vielzahl von geraden, radialen Lamellen (80) umfasst, wobei jede Lamelle eine abgerundete Außenbordspitze (82) besitzt, die zweimal so groß ist wie die Höhe eines radialen inneren Anteils (84).

Revendications

1. Dispositif d'assistance cardiaque comprenant :

un corps (10) comportant un orifice d'entrée (16) et un orifice de sortie (22) ;
un bloc rotor (14) adapté pour tourner autour d'un axe d'entraînement comprenant une roue à aubes primaire (18) pour le transport du sang depuis l'orifice d'entrée (16) jusqu'à l'orifice de sortie (22), et une roue à aubes secondaire (70) pour réaliser un recirculation de sang à travers un palier (24) en interface entre le bloc rotor (14) et le corps (10), la roue à aubes secondaire (70) comportant un ensemble d'ailettes espacées sur la circonférence autour de l'axe d'entraînement et disposées selon une orientation sensiblement radiale pour améliorer la recirculation à travers le palier à sang (24), dans lequel les ailettes (80) de la roue à aubes secondaire s'étendent axialement vers l'extérieur du bloc rotor (14), **caractérisé en ce que** les ailettes de ladite roue à aubes secondaire présentent une hauteur axiale variable dans le sens radial.

2. Dispositif d'assistance cardiaque selon la revendication 1 dans lequel lesdites ailettes (80) de la roue à aubes secondaire présentent des bords arrondis.

3. Dispositif d'assistance cardiaque selon la revendication 1 ou 2, dans lequel les ailettes (80) de la roue à aubes secondaire comportent une échancrure en feston de sorte qu'une partie radialement extérieure (82) de chaque ailette s'étend plus loin vers l'extérieur qu'une partie radialement intérieure (84) de chaque ailette.

4. Dispositif d'assistance cardiaque selon l'une quelconque des revendications 1 à 3, dans lequel les ailettes (80) de la roue à aubes secondaire sont disposées sur une face du rotor et l'échancrure en feston comprend une surface concave s'étendant vers l'intérieur dans chaque ailette depuis un bord radialement extérieur vers un bord radialement intérieur.

5. Dispositif d'assistance cardiaque selon l'une quelconque des revendications 1 à 4, dans lequel chaque ailette (80) de la roue à aubes secondaire a une surface concave.

6. Dispositif d'assistance cardiaque selon l'une quelconque des revendications 1 à 5, comprenant en outre un moteur inversé et un palier à couche lubrifiante fluide comprenant un stator (12) monté sur un élément vertical formé par un prolongement axial du corps (10) et supportant un rotor annulaire (14) comportant un aimant de commande (72) disposé dans ce dernier qui est supporté radialement et entraîné en rotation par le stator (12), un intervalle (24) ménagé entre le rotor annulaire et le prolongement du corps définissant un palier qui est adéquat pour être alimenté au moyen de la roue à aubes secondaire (70) par un flux circulant de sang correctement nettoyé.

7. Dispositif d'assistance cardiaque selon l'une quelconque des revendications 1 à 6, dans lequel le rotor (14) présente une dimension axiale allongée avec la roue à aubes primaire (18) située à une première extrémité de celui-ci et la roue à aubes secondaire (70) située à une seconde extrémité de celui-ci.

8. Dispositif d'assistance cardiaque selon l'une quelconque des revendications 1 à 6, dans lequel l'orifice d'entrée (16) s'étend axialement et l'orifice de sortie (20) s'étend tangentiellement par rapport au corps (10).

9. Dispositif d'assistance cardiaque selon l'une quelconque des revendications 1 à 8, dans lequel les ailettes (80) de la roue à aubes secondaire s'étendent axialement vers l'extérieur du bloc rotor (14) sur une plus grande distance à un bord radialement extérieur qu'à un bord radialement intérieur.

10. Dispositif d'assistance cardiaque selon l'une quelconque des revendications 1 à 9, dans lequel les ailettes de la roue à aubes secondaire (80) s'étendent vers l'extérieur au-delà du diamètre extérieur du bloc rotor (14).

11. Dispositif d'assistance cardiaque selon l'une quelconque des revendications 1 à 10, dans lequel les ailettes de la roue à aubes secondaire (80) présentent un profil concave et arrondi s'étendant depuis le bord radialement extérieur vers le bord radialement intérieur.

12. Dispositif d'assistance cardiaque selon l'une quelconque des revendications 1 à 11, dans lequel le mécanisme d'entraînement comprend un enroulement de stator (50) disposé dans la partie constituant le corps (10).

13. Dispositif d'assistance cardiaque selon l'une quelconque des revendications 1 à 12, dans lequel le mécanisme d'entraînement comprend un aimant (72) disposé dans le bloc rotor (14).

14. Dispositif d'assistance cardiaque selon l'une quelconque des revendications 1 à 13, dans lequel le palier à couche lubrifiante fluide comprend une voie de passage de dimensions allant en diminuant (24) interposée entre le bloc rotor (14) et la partie constituant le corps (10).

15. Dispositif d'assistance cardiaque selon l'une quelconque des revendications 1 à 14, dans lequel la partie constituant le corps (10) est de section transversale non-circulaire.

16. Dispositif d'assistance cardiaque selon l'une quelconque des revendications 1 à 15, dans lequel les parties radialement intérieures des ailettes (80) de la roue à aubes secondaire sont dimensionnées de façon à définir un intervalle avec le corps (10) supérieur à celui les séparant des extrémités extérieures des ailettes.

17. Dispositif d'assistance cardiaque selon l'une quelconque des revendications 1 à 16, dans lequel les parties radialement intérieures (84) des ailettes (80) de la roue à aubes secondaire sont de hauteur égale à la moitié de celle des extrémités extérieures (82) des ailettes.

18. Dispositif d'assistance cardiaque selon l'une quelconque des revendications 1 à 17, dans lequel la roue à aubes secondaire (70) comprend des ailettes radiales droites (80), chaque ailette présentant une extrémité arrondie en face externe de hauteur deux fois supérieure à celle de la partie radialement intérieure (84).

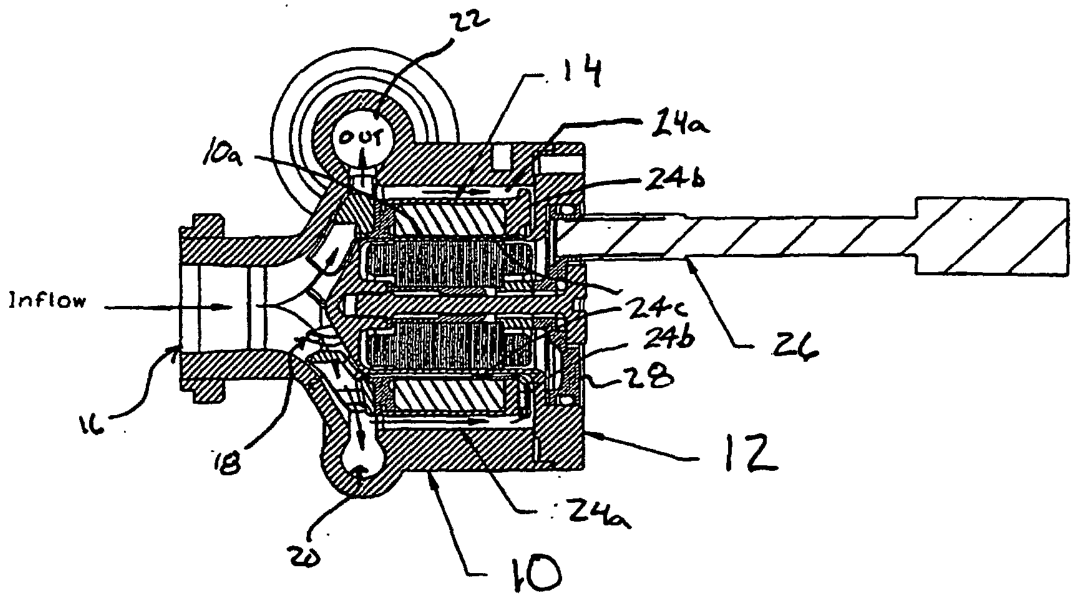


FIGURE 1

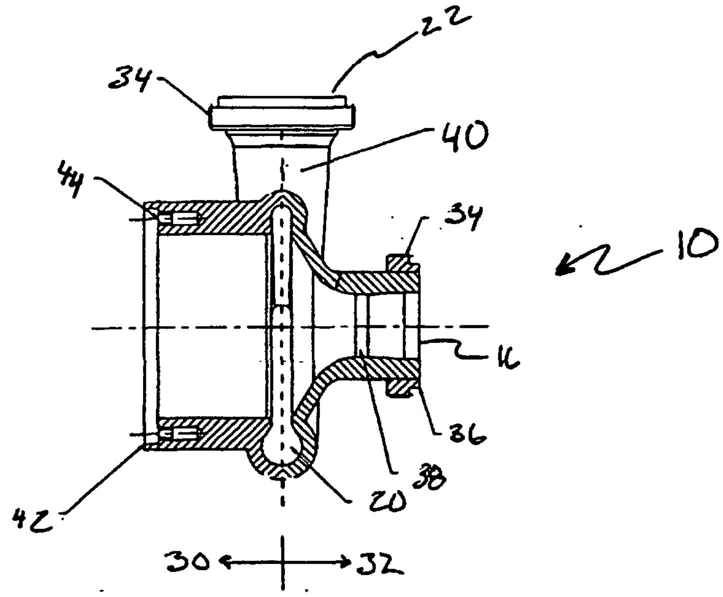
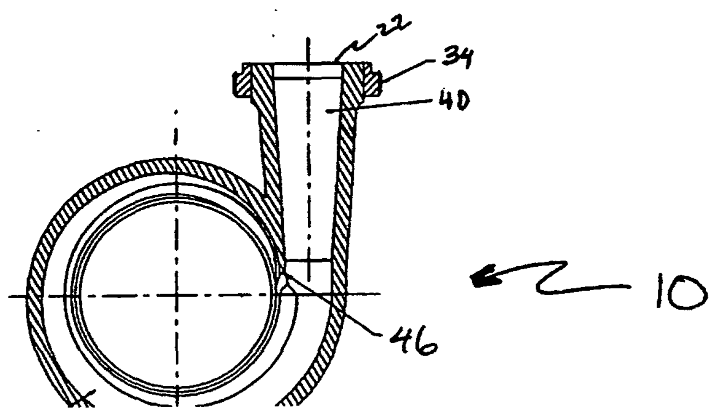


FIGURE 2A



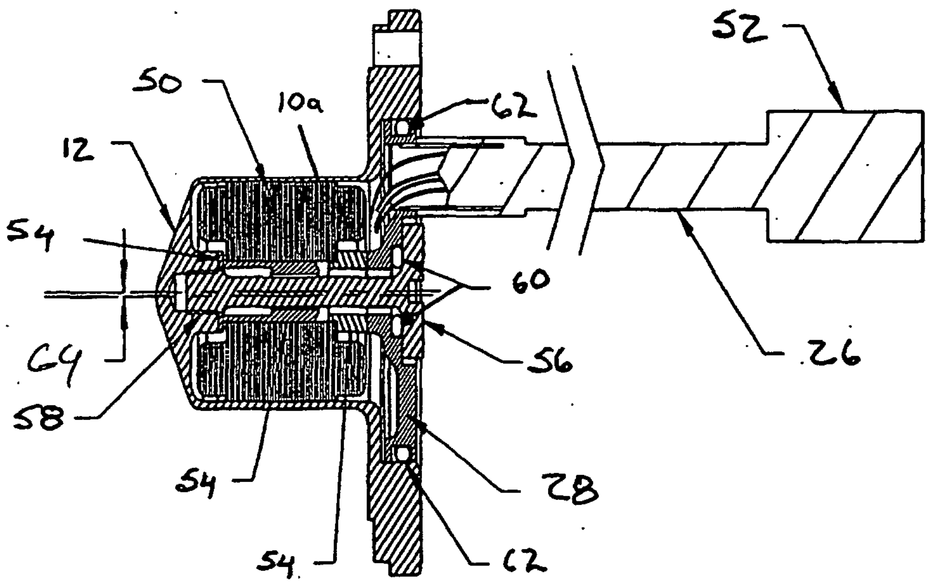


FIGURE 3

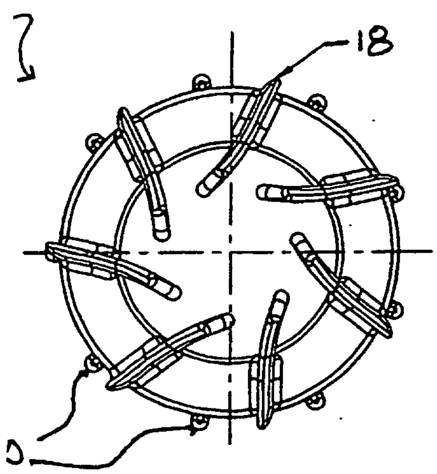


FIGURE 4A

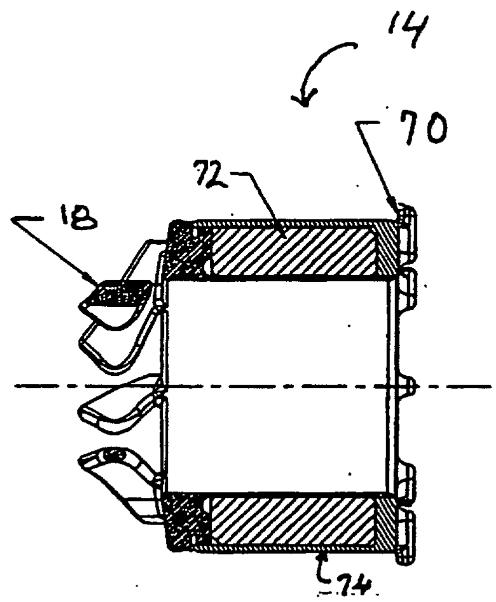


FIGURE 4B

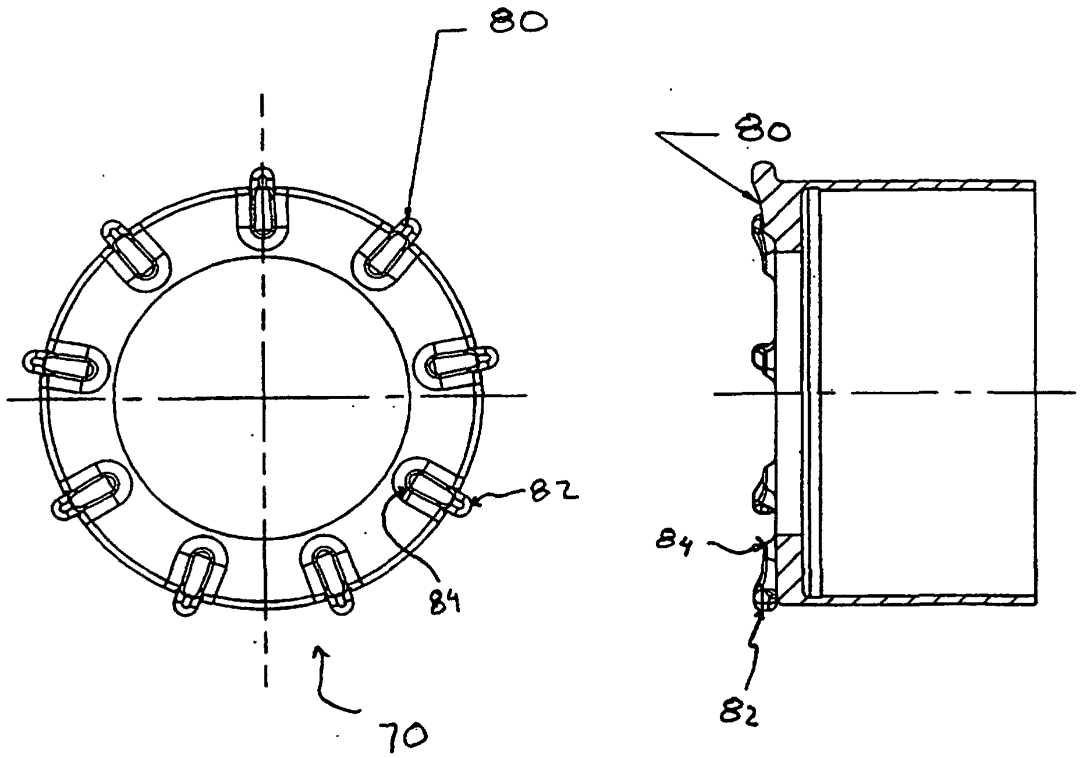


FIGURE 5 A