

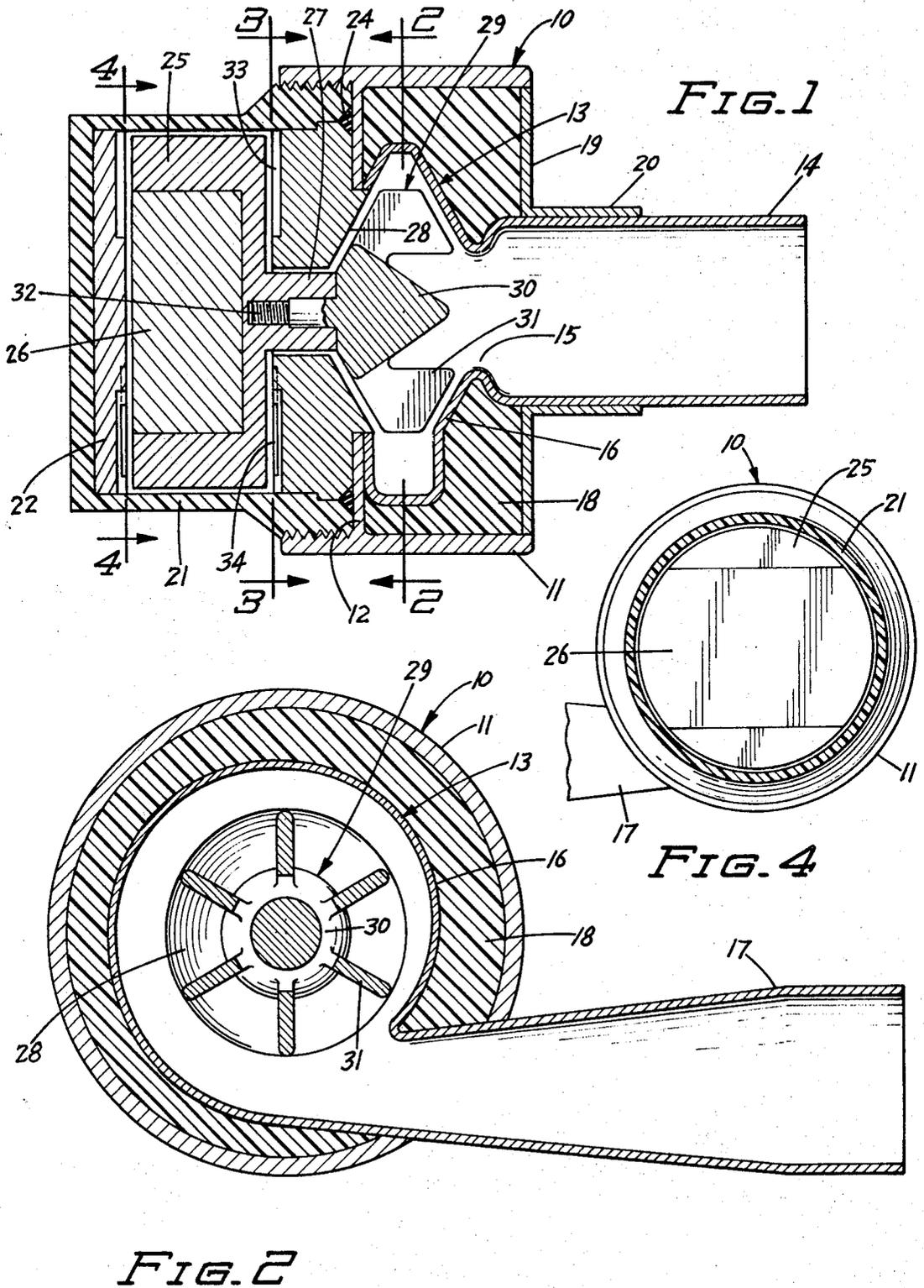
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IMPLANTABLE BLOOD PUMP

3,608,088

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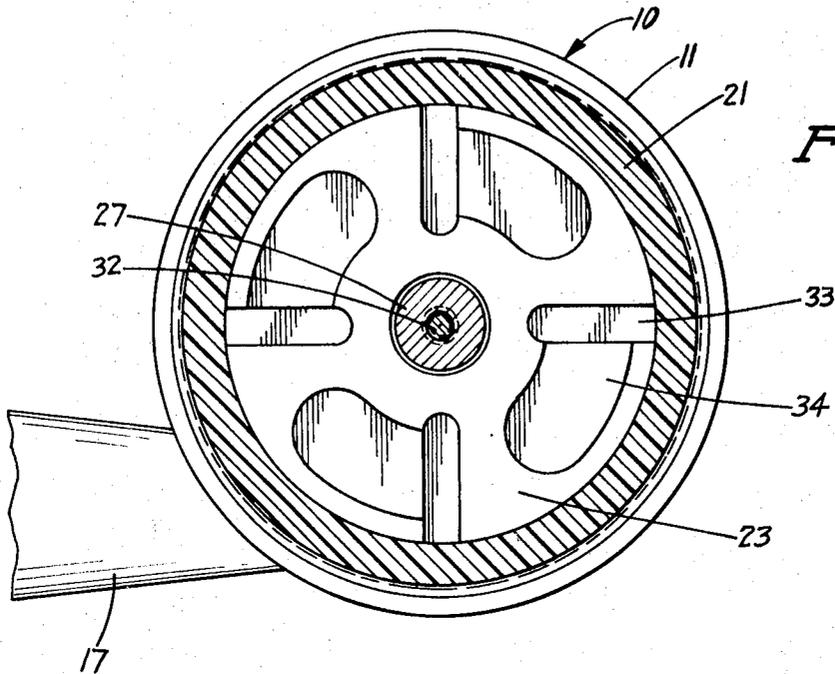


FIG. 3

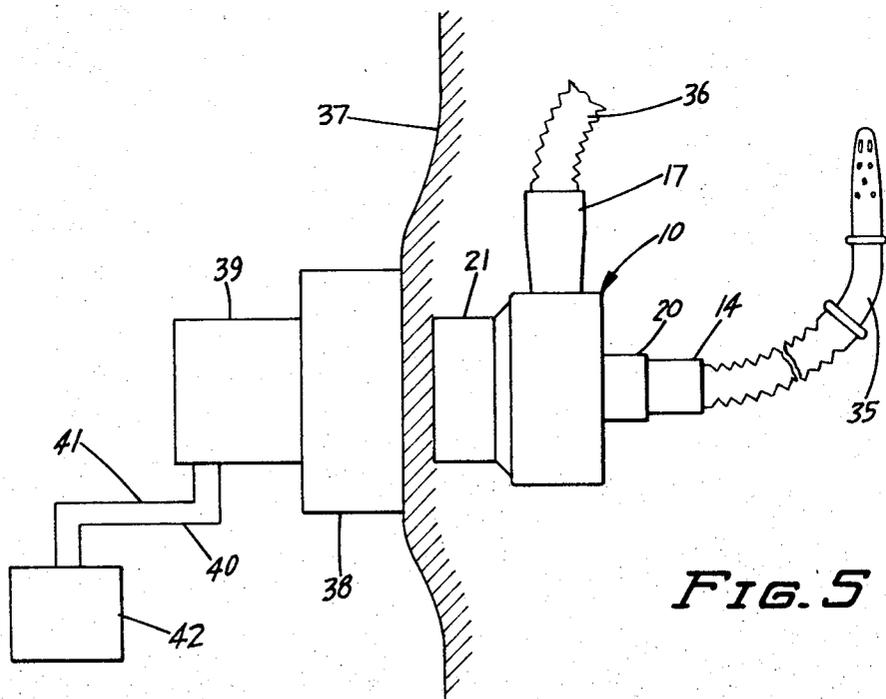


FIG. 5

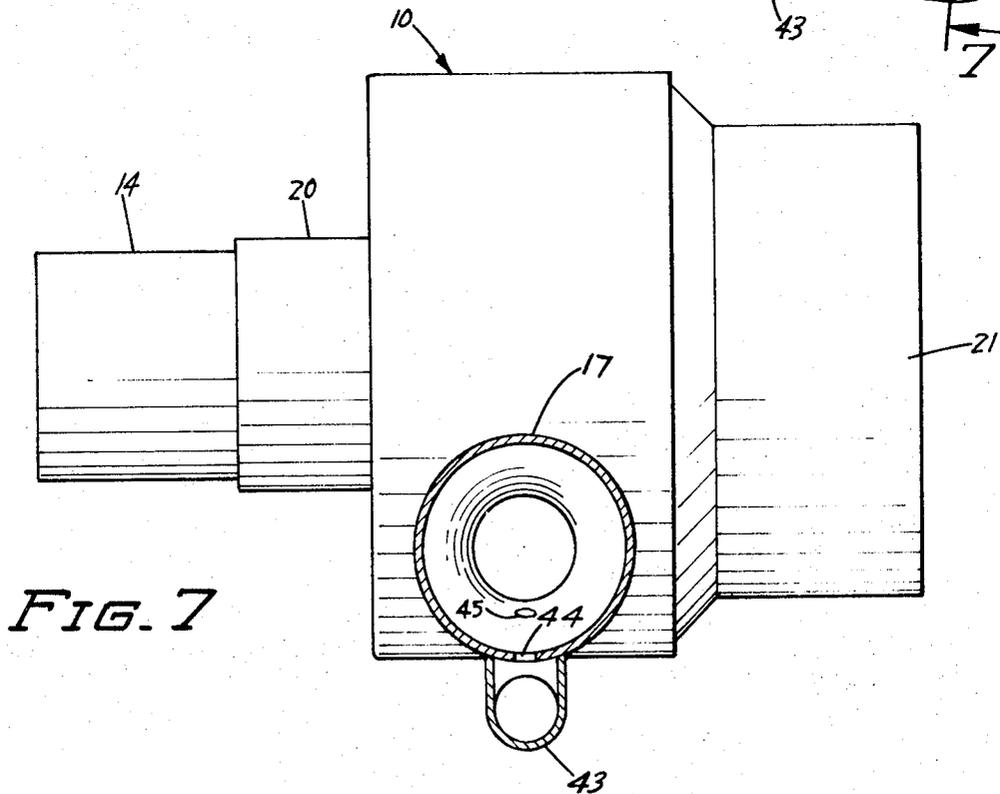
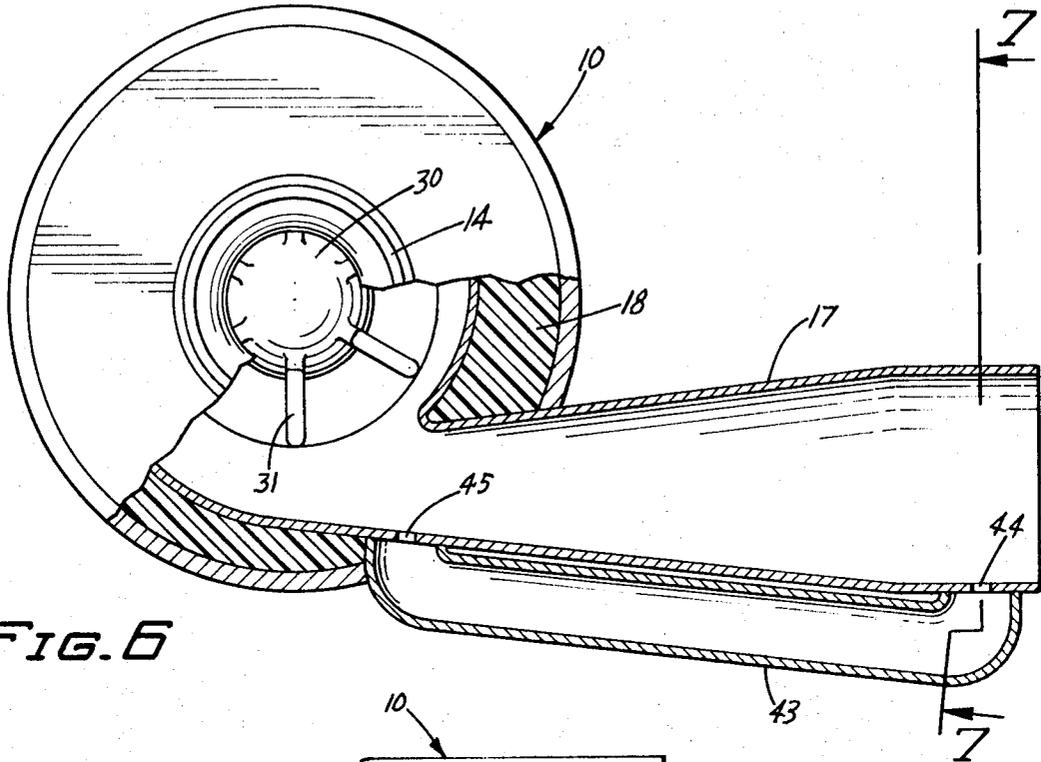
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IMPLANTABLE BLOOD PUMP

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5 Claims

ABSTRACT OF THE DISCLOSURE

A centrifugal blood pump and method of pumping blood to provide assistance to a failing heart. The pump is intended to be implanted and is provided with a magnetic drive system which permits a synchronous magnetic coupling with an outside power unit with no wires or tubes through the skin. The pump has but a single moving part. It is lubricated by the pumped blood and provides an indefinite lifetime of service-free performance.

The invention described herein was made in the course of work under a grant or award from the Department of Health, Education and Welfare.

This invention is directed to a centrifugal magnetically driven blood pump designed to be used as a cardiac assist device, and the method of using the same. Although the primary purpose of the pump of the present invention is as an implanted assist to or replacement for a failing heart in a living body, it can also be used as a blood pump for open heart surgery where bypass of the heart is needed. To allow complete implantation with no wires or tubes through the skin, a magnetic drive system is utilized which is operated from a magnetic or electromagnetic energy source outside of the body.

The invention is illustrated in the accompanying drawings in which the same numerals identify corresponding parts and in which:

FIG. 1 is a section on a plane passing through the longitudinal axis (the axis of rotation) of the pump;

FIG. 2 is a transverse section on the line 2-2 of FIG. 1 and in the direction of the arrows;

FIG. 3 is a transverse section on the line 3-3 of FIG. 1 and in the direction of the arrows;

FIG. 4 is a transverse section on a reduced scale on the line 4-4 of FIG. 1 and in the direction of the arrows;

FIG. 5 is a schematic representation showing the pump of the present invention implanted within the body and coupled through the skin with an external power unit;

FIG. 6 is an end elevation partially in fragmentary transverse section similar to FIG. 2 and showing a modified form of blood pump providing pulsatile flow; and

FIG. 7 is a section on the line 7-7 of FIG. 6 and in the direction of the arrows.

Referring now to the drawings, the pump according to the present invention includes a cylindrical pump housing, indicated generally at 10, having a cylindrical tubular wall 11 and a transverse annular flange 12 extending inwardly from the inside surface of wall 11 intermediate of the ends of housing 10. A pump casing, indicated generally at 13, is inserted partially within the housing 10. The pump casing 13 includes an inlet tube 14 coaxial with the longitudinal axis of the pump and communicating through a slightly choked orifice 15 with a scroll impeller housing 16 from which a tangential downstream diffuser tube 17 provides a discharge outlet. The pump casing 13 is held in place within the pump housing 10 against one face of flange 12 by virtue of a cast inert lightweight fill material 18, such as epoxy resin or the like. Desirably the space between the pump housing and pump casing is

substantially completely filled. The cast material is covered by an annular cover plate 19 fitted within one end of the pump housing and being secured to a sleeve 20 which fits around the outside of the blood entry tube 14.

The inside wall of the pump housing on the opposite side of flange 12 is threaded to receive an externally threaded rotor housing 21. Rotor housing 21 is generally cup-shaped and flat at its closed end. A rear thrust plate 22 is disposed against the inside bottom of the rotor housing and a front thrust plate 23 is disposed in the open end of the rotor housing pressed against the face of flange 12. An O-ring 24 held in a V-shaped groove formed between the rotor housing and front thrust plate is compressed against flange 12 to form a seal. Rotor 25 is supported between the thrust plates 22 and 23.

Rotor 25 includes a high energy bar magnet 26 set in and secured in a transverse slot in the rear face of the rotor 25 so as to form a flush fit and uninterrupted surface. The rotor shaft 27 extends through a central opening in the front thrust plate 23, the forward face of which is concave and serves to complete the scroll impeller housing. An impeller, indicated generally at 29, is disposed within the scroll chamber. Impeller 29 includes a conical hub 30 supporting a plurality of radially extending blades 31. The impeller blades 31 are generally in the form of isosceles trapezoids secured at one end of their bases to hub 30. Hub 30 has a threaded shank 32 which is received in the rotor shank. The threads of shank 32 are opposite in direction from the direction of rotation of the rotor such that accidental detachment of the impeller from the rotor by unscrewing of the shank is made impossible.

Plates 22 and 23 function as fluid dynamic thrust and journal bearings that are lubricated with blood for support of the pump rotor. As best seen in FIG. 3, the inward faces of the thrust plates are provided with a plurality of radial channels 33 each of which communicates with an arcuate channel 34 of lesser depth for maintaining the parallel flat faces of the rotor lubricated with blood. The face of thrust plate 22 is a mirror image of that of plate 23, as shown in FIG. 3.

The pump is constructed of materials which are compatible with the body fluids with which they come in contact when the pump is implanted. For example, the pump housing, thrust plates, rotor and impeller are desirably all formed from stainless steel. The pump casing is desirably formed by electro-deposition of nickel over a smooth gold-plated copper core, which is then dissolved to provide a smooth surfaced impeller chamber to minimize cell injury. The rotor housing is formed from a rigid material which is electrically non-conducting, such as polycarbonate resin or polypropylene or a ceramic material, such as alumina. The magnet is formed from a high energy magnetic iron-aluminum-nickel-cobalt-copper alloy material, such as that sold under the trade names Alnico VIII or Alnico IX. In some instances where economy of size is a critical factor, magnetic platinum-cobalt alloys may be used.

Referring to FIG. 5, there is shown schematically the manner in which the blood pump according to the present invention may be implanted, as for example in the chest cavity. Blood inflow to the pump is through a rigid cannula 35 into the left ventricular cavity to the inlet 14. Outflow is from the diffuser 17 through a Dacron graft 36 to the descending thoracic aorta. In this manner the pump receives and discharges blood which otherwise would pass through the heart so as to reduce the flow of blood through the heart and reduce the pumping load otherwise put on the heart.

As shown, the pump is implanted with the outside transverse surface of the rotor housing 21 underlying the skin

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surface 37 and the axis of rotation substantially normal to the skin surface. The rotor 25 of the pump is driven from a drive magnet indicated schematically at 38. The drive magnet is a high energy bar magnet similar to that of the pump rotor. It is desirably enclosed in a circular plate as in the pump rotor so as to minimize air drag. It is mounted to be rotated by a direct current motor 39 connected by conductor wires 40 and 41 to a suitable power source 42, such as a small portable battery pack which is easily carried by the patient. The drive magnet is disposed immediately adjacent the skin surface in axial alignment with the pump rotor. Alternatively, the pump rotor may be driven by setting up a rotary electromagnetic field by means of suitable coils disposed adjacent the skin surface in alignment with the pump.

In use, the blood from tube 35 is slightly accelerated as it passes through the throat 15 into the scroll impeller chamber. The blood is pumped centrifugally by action of the impeller blades rotated at high speeds. The inverted venturi exit from the impeller chamber decelerates the blood flow before its return through tube 36.

Where pulsatile blood flow is considered to be desirable or necessary, the pump output pressure can be made to simulate the pressure pulsations of the natural heart by either of two methods: The drive unit 38-39 may be driven at changing speeds so as to cause the output pressure to change. The r.p.m. of the impeller controls the output pressure. Alternatively, as shown in FIGS. 6 and 7, the pump structure may be modified by the addition to the exit diffuser 17 of a fluid oscillator 43 to cause the blood flow to vary from efficient recovery of kinetic energy (diffuser flow unseparated) to inefficient recovery (diffuser flow separated) giving the desired pressure changes while maintaining the rotor speed constant. The fluid oscillator 43 is in the form of a tube extending generally parallel to the diffuser 17 and communicating at one end with the mouth of the diffuser through a port 44 and at the opposite end with the narrow throat of the diffuser through a port 45.

The mode of operation of the fluid oscillator is as follows: Flow in the diffuser is established and full pressure recovery at the downstream port 44 of the oscillator makes the pressure at 44 higher than at the upstream port 45 and therefore accelerates fluid in oscillator 43. When the oscillator velocity at port 45 reaches some critical value the main diffuser flow separates and the pressure recovery at port 44 drops. The flow in the oscillator 43 decelerates so that the oscillator velocity at port 44 falls below a critical value and diffuser flow will reattach. After a time lag the pressure at port 44 rises again and the process repeats. Time constants and pulse heights can be modified by changing the dimensions of the oscillator 43 and the size and locations of the ports 44 and 45.

Where the pump of the present invention is to be used as a total replacement for the heart it is provided with a second scroll chamber and impeller. The second chamber lies in parallel side-by-side relation with the first. The chambers are axially aligned, the impellers of both being driven from the same shaft. The innermost of the two chambers is provided with a radial or tangential inlet and tangential outlet. Since both impellers rotate at constant speed, variations in pressure to correspond to those of the heart are achieved by varying the sizes of the impellers and chambers.

The pump has been found to have a very low level of blood damage. The index of hemolysis has been determined to be 0.01 or lower. The pump is optimized in dimensions for the pressure head and flow rates needed, for example, about 100 mm. Hg pressure and 6 liters per minute flow. By way of reference, the outside diameter of the pump housing is approximately two inches. The pressure-flow curves of the pump are such that the blood pressure can be set by controlling the pump r.p.m. only. The pressure curve is flat to within ten percent over the range of body flow needed by the body. Typically, the pump is operated at about 4,000 r.p.m. plus or minus

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a few hundred. No electrical or mechanical feedback controls are needed. The pump need not be self-correcting. It runs at a constant speed which may be changed depending upon the wishes of the doctor or patient in accord with the patient's needs. The implanted pump has but a single moving contiguous assembly. The bearings are lubricated with the pumped fluid blood. So long as the pump is constructed from proper materials to prevent chemical attack, the pump has an indefinite lifetime. There is no wear on the rotor due to wall contact. The external drive motor and magnet or magnetic field unit can be serviced or quickly replaced without surgery.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A non-wear long-life constant speed centrifugal pump for implantation within a living body for pumping blood with minimum hemolysis, said pump comprising:

(A) a rigid housing of size permitting implantation within the thoracic cavity and of material compatible with body fluids,

(B) a scroll chamber within the housing, said chamber being smooth surfaced to minimize cell injury,

(C) an axial inlet to and tangential outlet from said chamber,

(D) impeller means journaled for rotation within said chamber for moving blood therethrough with low level of blood damage at substantially constant pressure at needed body flow rates,

(E) a second chamber within said housing for enclosing drive means,

(F) magnetic drive means within said second chamber for driving said impeller means, said drive means comprising a rotor journaled for rotation within the housing,

(1) said rotor and impeller being secured in axial alignment on a common shaft for rotation as a unit,

(2) said rotor including a magnet disposed transversely of the axis of rotation,

(3) said rotor being supported between a pair of fluid dynamic thrust and journal bearings,

(G) a channel interconnecting said pump chamber and drive means chamber,

(H) the surfaces of said rotor being closely spaced from the walls of said drive means chamber to maintain a thin liquid layer for lubrication of the bearings,

(I) at least the portion of the housing enclosing the drive means being electrically non-conductive, whereby the drive means may be driven at substantially constant speed by a mechanically unconnected external source of magnetic energy.

2. A blood pump according to claim 1 further characterized in that said magnet is a bar magnet composed of high energy magnetic alloy material and set in one face of said rotor.

3. A blood pump according to claim 1 further characterized in that:

(A) said axial inlet is provided with a choked orifice adjacent the pump chamber to accelerate blood flow into the impeller, and

(B) said tangential outlet is an inverted venturi to decelerate blood flow.

4. A blood pump according to claim 1 further characterized in that:

(A) power means are provided to drive said magnetic drive means,

(B) said power means comprising a source of a rotating magnetic field,

(C) said power means being spaced from and mechanically unconnected to said pump drive means, and

(D) said power means being disposed so that said magnetic field is in substantial axial alignment with said

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pump drive means, whereby said power means is adapted to be placed externally of the living body to drive said pump with the body tissue interposed therebetween when said pump is implanted in the body.

5. A centrifugal blood pump comprising:

- (A) a housing,
- (B) a scroll pump chamber within the housing,
- (C) an axial inlet to and tangential outlet from said scroll chamber,

(1) said axial inlet being provided with a choked orifice adjacent the pump chamber to accelerate blood flow into the chamber, and

(2) said tangential outlet being an inverted venturi to decelerate blood flow,

(D) pumping means within said chamber for moving blood therethrough comprising an impeller journaled for rotation in said chamber,

(E) means for providing pulsatile flow from said pump, said means comprising:

(1) a fluid oscillator tube extending longitudinally along said tangential outlet,

(2) a port in said outlet wall adjacent the exit from said scroll chamber communicating with one end of said fluid oscillator, and

(3) a further port in the wall of the outlet downstream from the first port and communicating with the opposite end of said fluid oscillator,

(F) a second chamber within said housing for enclosing drive means,

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(G) magnetic drive means within said second chamber for driving said pumping means, and

(H) at least the portion of the housing enclosing the drive means being electrically non-conductive, whereby the drive means may be driven by a mechanically unconnected external source of magnetic energy.

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