

[54] **PULSATILE MAGNETO-MOTIVE
ARTIFICIAL HEART**

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[58] Field of Search .. 3/1, DIG. 2; 128/1 D, DIG. 3;
417/412, 413

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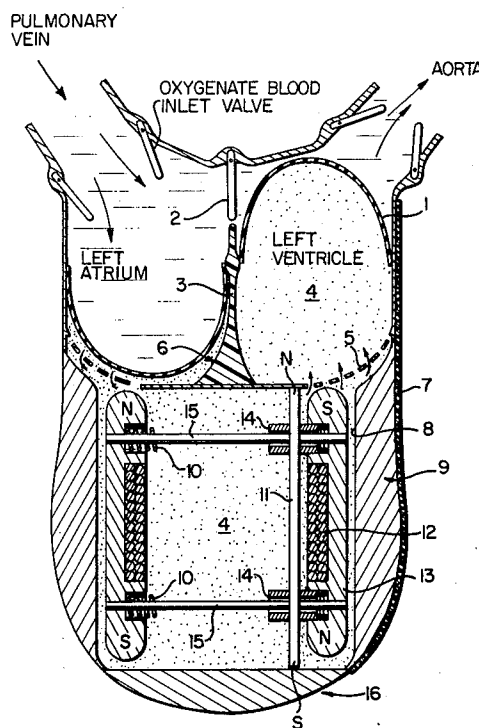
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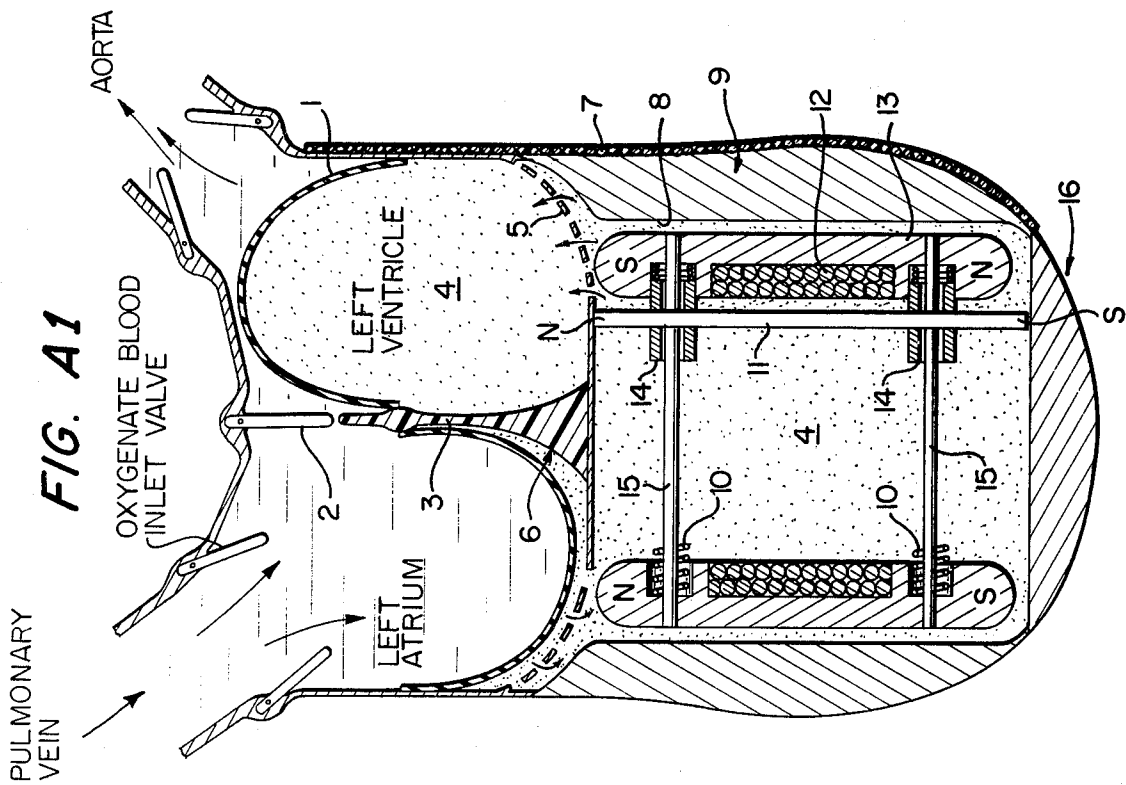
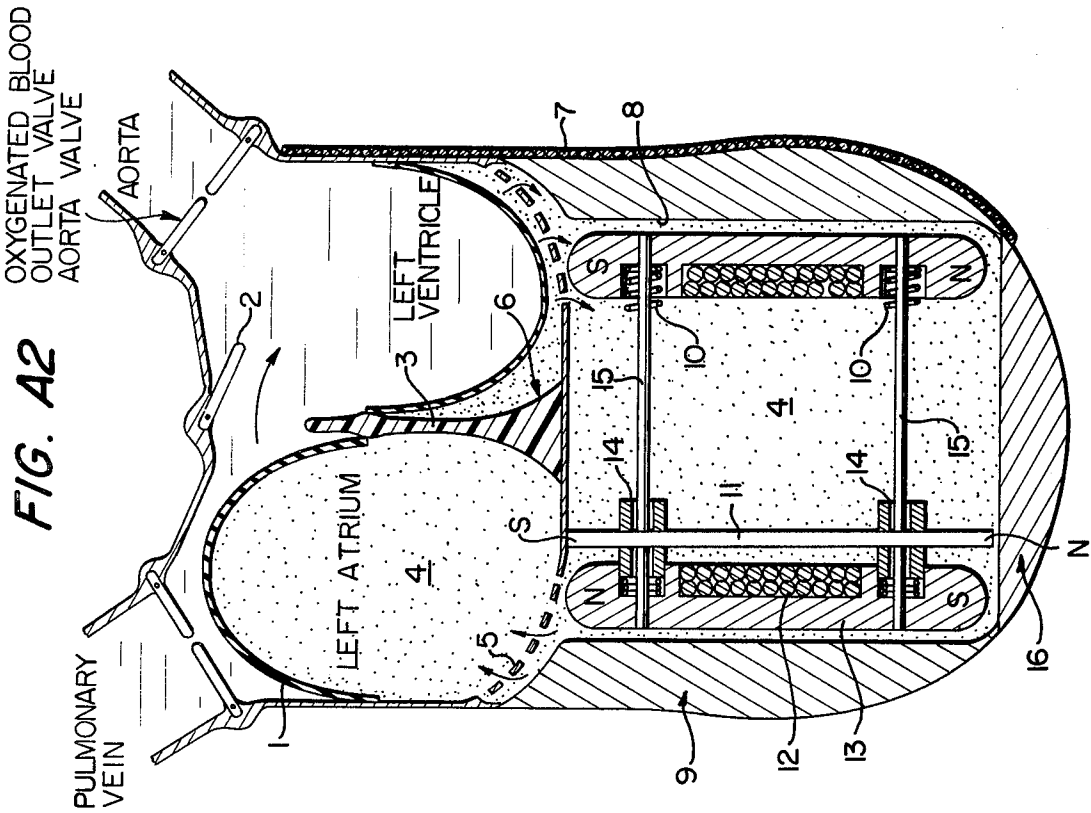
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[57] **ABSTRACT**

A permanently implantable artificial heart utilizing a pulsatile magneto-motive pump consisting of a pump chamber, which has two cobalt rare-earth permanent magnets spaced apart relative to one another so that unlike poles of each magnet face each other across a predetermined gap, one electromagnetic coil, a ferro-magnetic piston and a hydraulic fluid. The complete heart consists of two separate half hearts each having one pulsatile magnetic pump, an atrium, a ventricle, respective valves and collapsible hydraulic sacs. A dc pulse applied to the coil determines the pumping stroke rate of the piston which forces hydraulic fluid in and out of the collapsible sacs causing alternating positive and negative pressure gradients in the atrium and ventricle of the heart, thus producing with the help of one directional check valves, a one-directional pulsatile blood flow circulation. The pumping mode of the pistons is designed to act counter directional to each other whereby generated torque forces are greatly neutralized. The total heart is designed to duplicate the natural heart's pumping action by emptying both ventricles simultaneously while the atria are in the process of filling.

10 Claims, 5 Drawing Figures





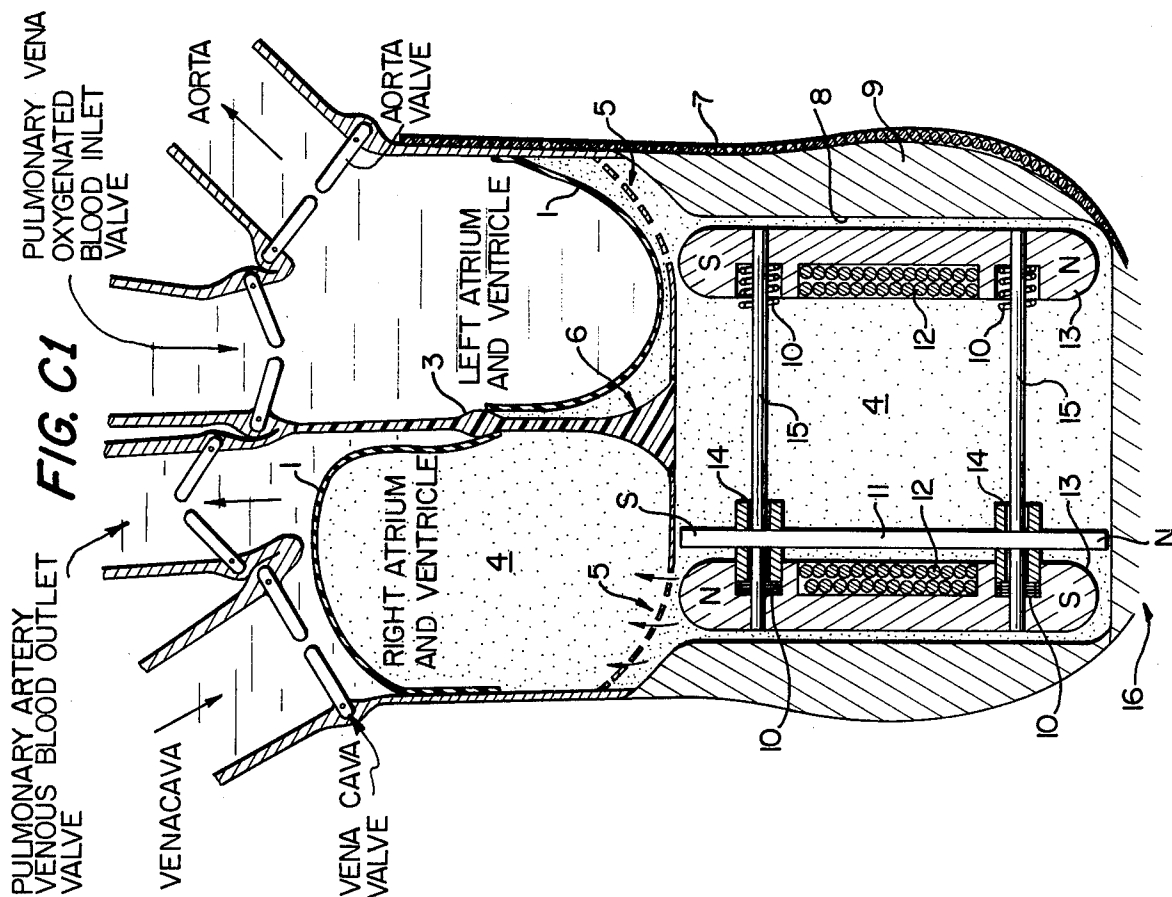


FIG. B1

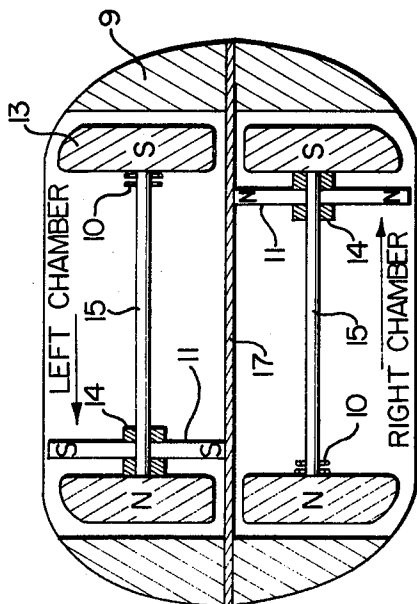
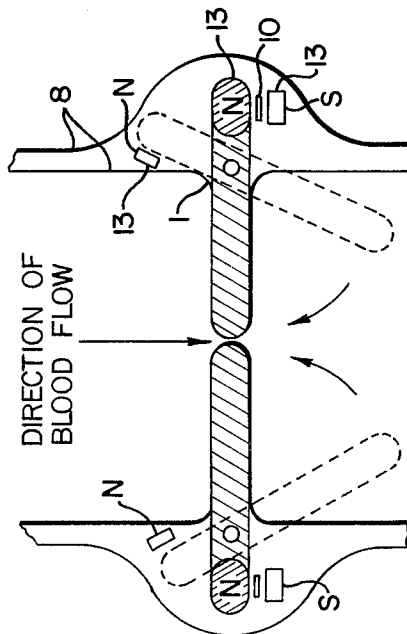


FIG. B2



PULSATILE MAGNETO-MOTIVE ARTIFICIAL HEART

SUMMARY OF THE INVENTION

The object of this invention is to provide a totally implantable artificial heart having a long lasting, reliable, space saving multipurpose pump, that by virtue of its novel construction serves also as its own motor and valve. The reliability and life expectancy of the magnetic pump is much higher than that of a conventional motor and pump. The magnetic pump functions without reduction gear, brushes, contacts, ballbearings, separate motor, etc., to mention only a few advantages. The magnetic pump is a bistable device staying in the on or off position without a holding current or mechanical holding force thereby functioning additionally as a valve. The pump motor is the pumping piston itself and is the one and only moving part. Upon electric triggering the pump starts immediately with full power. The cobalt rare-earth magnets and the coil are fully encased so that only the piston and the pumps cylinder come in contact with the pumped medium. The magnetic pump functioning without brushes, contacts, etc., and being fully encased can be operated in an explosive or highly inflammable medium as well as in a vacuum with absolute safety. The temperature in which it can be successfully operated ranges from absolute zero -270°C to $+750^{\circ}\text{C}$.

The operational durability of the magneto-motive pump depends to a high degree on the magnets used.

Modern magnets of the cobalt with rare-earth element type such as the cobalt samarium magnet which has a resistance to demagnetization that is 20 to 50 times superior to conventional magnets of the Alnico type show great advantages as the following tabulation of properties indicates:

Cobalt Samarium Magnets

Magnetic Properties:	
Coersive force	= 9,000 Oersted
Intrinsic coersive force	= 25,000 Oersted
Residual induction	= 9,000 Gauss
Energy product, max.	= 20×10^6 Gauss-Oersted
Curie temperature	= 850°C
Temperature coefficient	= 0.02% per $^{\circ}\text{C}$
Physical Properties:	
Specific gravity	= 8 g/cc
Electric resistivity	= 5×10^{-4} Ohm-cm
Mechanical Properties:	
Tensile strength	= 8,000 psi
Compressive strength	= 10,000 psi
Flexural strength	= 12,000 psi

The cobalt samarium magnet has been shown when exposed to a demagnetizing field H of 9000 Oersted to retain its full magnetic strength. In this invention the two magnets are facing with complimentary poles, thereby creating a circular, fully closed ring flux field with a coil set between them producing a mere few hundred Oersted field strength, and opposing only one magnet at a time while at the same time increasing the field strength of the other magnet. The activation of the coil produces a magnetic flux with the highest flux density within the piston. From the poles of the piston the flux enters the opposite poles of the magnet thus continually magnetizing one pole per piston stroke thereby holding the magnets at their magnetic saturation point and preventing possible degradation. A soft iron shield placed between coil and magnets (also 12) permits a flow of magnetic flux on the outside of the coil thus preventing the flux to enter the similarly poled magnet.

Theoretically, should a field H of say 1000 Oersted temporarily demagnetize some magnetic domains, then it would readily be remagnetized as the field of 9000 Oersted plus the field of 1000 Oersted with an energy product of greater than 20×10^6 Gauss-Oersted again fully closes the circular ring flux field of the two magnets.

In industry the cobalt-samarium magnets are used to focus Travelling Wave Tubes where fields of 9000 Oersted are always opposing.

This should prove beyond doubt that a mere 1000 Oersted field cannot produce a degradation of field strength with time in this application.

In the permanently implantable total artificial heart according to the invention the pump exhibits ideal suitability to closely duplicate the pumping action of a normal heart. Although it may be theorized that a mechanical heart pump must not necessarily have to function as a duplicate of the natural heart pump it does nevertheless solve a lot of problems to adhere respectfully to the modes of the naturally created pumping system.

The pulsatile magneto-motive heart pump has been designed to duplicate the natural pumping modes of an actual heart very closely.

It also consists of two atria and two ventricles of which both ventricles are simultaneously emptied while the atria are in the process of filling.

Moreover a simple but very reliable one-directional valve system has been designed which together produce both the high and the low pressure periods (systolic and diastolic) as found in the natural heart's pumping action, thereby eliminating negative pressure states in both atria due to the suction action of the ventricles as found in designs omitting that principle. The check-valve system is designed to give a natural one-directional pulsatile blood flow circulation and it responds similarly as the natural valve system to an increased blood pressure gradient which overcomes the magnetic force of attraction of the valve flaps thereby opening the valve. A reduction of the blood pressure gradient causes the valve to close and remain closed against an increased blood pressure gradient force in the opposite direction. Thus permitting a one-directional blood flow circulation only. The valve flaps and the elastic diaphragm sacs are constructed not to come in contact with either the chamber walls nor with each other thereby preventing hemolysis.

The atria are designed as large elastic blood reservoirs thus providing for rapid ventricular filling. The large atria are filled by venous pressure without the necessity of applying the negative pressure gradient. The atria are designed to counter any negative pressure gradient by collapsing slightly inward thus preventing the propagation of the negative pressure gradient to the venous system. The complete separation of right and left heart into two independent units reduces the surgical problems considerably. Each separate heart unit is individually controlled, thus permitting a more detailed imitation of the physiologic stroke characteristics.

The pumping mode of the pistons is designed to act counter-directional to each other whereby generated torque forces are greatly neutralized.

The hearts are shown with a induction coil for transmission of electric energy through the patients chest and the battery for storage. Should a superior power source be used such as possibly the plutonium-238 iso-

tope power source then of course there is no need for the coil and batteries.

The hearts are designed to give the wearer a feeling of security and confidence for should a diaphragm (sac) rupture and the hydraulic fluid used be of a nature not harmful to the wearer's system then the normal function of the heart would not be interrupted. The hydraulic fluid would slowly be replaced by the blood and a gradual hemolysis would occur.

By employing a different colour marking fluid in each separate heart unit, say blue in one and green in the other, this would indicate in which heart unit a diaphragm rupture occurred. For the wearer there would be ample time to seek medical aid as with additional blood transfusions many days could be bridged without harmful effects. Unlike gas-driven heart pumps, air embolism cannot occur because there is no gas present.

The primary advantages between the artificial heart using the pump constructed according to this invention and other constructions known from the prior art are simplicity, reliability, compactness and functional life expectancy.

When compared with a natural heart the following characteristics become evident:

Natural heart		Magneto-Motive heart
Circumference	25 cm	Yes
Breadth	9 cm	Yes
Length	15 cm	Yes
Weight	300 gr	Possible (without batteries, induction coil and hydraulic fluid)
		Each side - yes
Output 5 to 10 litres/min		
Aortic arterial pressure 120-180 mm Hg		Yes
Pulmonary arterial pressure 20-80 mm Hg		Yes
Pump rate 60-120 beats/min		Yes
Diastole 0.5 sec		Yes
Systole 0.3 sec		Yes
Ventricular volume 120 ml		Yes

A further embodiment of the invention envisages heart design which bears such advantages as: one heart unit, less weight, lower power consumption, smaller volume, etc. But as all things in nature it is counterbalanced with the disadvantage namely that it pumps blood alternately into the pulmonary circulation and with the next stroke into the main circulatory system. Should this pumping mode not prove detrimental to the human organism then it should possibly be given priority. The embodiments disclosed are limited to two for reasons of brevity, but it should be noted that a number of different heart units may be designed within the scope of the present invention. The pulsatile magneto-motive pump, motor, valve used in the heart system has been successfully tested by the inventor over a period of almost three years. The novel construction of the closed ring flux field that continually magnetizes the permanent magnets and the application of the superior cobalt rare-earth magnets allowed this invention for the first time to become functionally possible.

BRIEF DESCRIPTION OF THE DRAWINGS

A better understanding will be gained of the nature of the instant invention from a study of the following detailed description thereof taken with reference to the attached drawings wherein:

FIGS. A-1 and A-2 show the Pulsatile Magneto-Motive Pump in action in the left heart of a Perma-

nently Implantable Total Artificial Heart according to one aspect of the invention.

FIG. B-1 shows a top view of the two chamber halves pumping counter-directional thereby greatly neutralizing created torque forces.

FIG. B-2 shows a magnetic one-directional blood flow valve.

FIG. C-1 shows a further embodiment of the invention where one pulsatile magneto-motive pump serving as a complete artificial heart where one heart chamber serves the function of both atrium and ventricle and where a partition, the hearts septum, separates left from right heart.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

The present invention functions due to the use of a novel construction of a magneto-motive pump, which also functions as its own magneto-motive motor and as a magneto-motive valve all these functions being incorporated into one unit to form a permanently implantable total artificial heart. The invention as may be seen from the drawings, includes two cobalt rare-earth permanent magnets (13) set at a distance apart so that the magnetic poles of one magnet face the magnet poles of the other magnet having opposite magnetic polarity thereby forming a closed ring flux field. The two magnets are rigidly mounted into a piston chamber which also serves as a magnetic shield (8). At the magnets midsection an electro magnetic coil (12) encircles the inside of the piston chamber. A ferro-magnetic piston (11) slides between the magnets inside the coil with two guide blocks (14) containing linear bearings on two guiding rods (15). Compression springs (10) check the sliding motion.

A dc pulse is provided which energizes the coil producing magnetic lines of force which are perpendicular to the poles of the permanent magnets. The highest flux density produced by the coil is concentrated within the ferro-magnetic piston whereby the piston becomes magnetically polarized. The piston is thereupon repelled by like poles and attracted by unlike poles of the permanent magnets. This action is reversed by a dc pulse of opposite polarity thus resulting in a reciprocating motion of the piston between the magnetic poles of the magnets respective to the alternating electric pulse frequency.

The reciprocating motor motion of the piston between the magnets (13) is utilized by the introduction of a piston rod thus resulting in the formation of a Reciprocating Magneto-Motive Motor.

The reciprocating motor changes its function to a pump through the introduction of a hydraulic fluid. The piston now pumps hydraulic fluid in the reciprocating mode through the pump chamber.

The introduction of a magnetic one-directional check valve system further results in the development of a one-directional pulsatile pumping action. The piston after completion of a stroke remains in a holding bistable position at the face of the magnets due to the magnetic force of attraction without the necessity of mechanical means or holding current until the subsequent dc pulse is applied.

Additionally the introduction of a seal piston housing, a seal piston contact surface at the magnets face and substituting the piston with a valve sealing piston

the pump functions as a Bistable Pulsatile Magneto-Motive Valve.

FIGS. A-1 and A-2 represent therefore a Permanently Implantable Total Artificial Heart according to the instant invention comprising as two separate units the left and the right heart.

According to one embodiment of the invention each heart unit has a magneto-motive pump, two elastic diaphragm sacs (1), one atrium chamber, one ventricle chamber, three magnetic one-directional valves and the encasing for the heart units. The pump forces hydraulic fluid (4) through two perforated parts of the pump cylinder (5) alternatively against the elastic diaphragm sacs (1) into the atrium and out of the ventricle chamber. The atrium diaphragm sac forces the blood through the magnetic one-directional ventricular inlet valve (2) into the ventricle (FIG. A-2). The next stroke fills the atrium through the magnetic one-directional oxygenated blood inlet valve from the pulmonary vein and the ventricle forces the blood through the magnetic one-directional oxygenated blood outlet valve into the aorta (FIG. A-1). The stroke characteristic is controlled individually or combined by a pace sensor (6) built into the partition (3) below the ventricle inlet valve and regulated by an electronic circuit (16) at the base of each heart unit. To complete the system an induction coil (7) for the transmission of electrical current through the wearers chest wall and batteries (9) for the storage thereof are included.

FIG. C-1 represents in an alternative embodiment of the invention a single heart unit where each chamber functions dually as atrium and ventricle alternatively and being separated completely by a partition, the hearts septum. Four one-directional magnetic valves direct the blood flow. The pump corresponds to that shown in the embodiment according to FIGS. A-1 and A-2.

FIG. B-2 represents a magnetic one-directional blood flow valve. Two valve flaps open under an increased given blood pressure gradient and close due to magnetic attraction when the blood pressure gradient reverses. The valve flaps are plastic and contain a permanent magnet (13) or soft iron piece which is magnetically attracted by a permanent magnet mounted rigidly inside the outer wall. The valve flaps are hinged and prevented from opening in the other direction by a stopper block and concussion spring (10).

The valve flaps and the inner wall are covered by an elastic diaphragm (1) preventing the blood from entering the magnetically shielded compartment.

It should be understood that the present invention is not limited to the embodiments disclosed but to present such modifications as reasonably and properly come within its scope and as might be suggested by one skilled in the pertinent art to which the invention relates.

I claim:

1. A permanently implantable artificial heart for pumping blood around a circulating system, said heart having a left heart portion and a right heart portion each heart portion comprising:

a casing having an upper part and a lower part;
at least one atrium chamber means disposed in the upper part of said casing and having a magnetic one-directional inlet valve for permitting blood to flow thereto;

at least one ventricle chamber means disposed in the upper part of said casing and housing a magnetic one-directional outlet valve for permitting blood to flow therefrom;

a semi-rigid chamber wall separating said atrium chamber means and said ventricle chamber means, said wall having a magnetic one-directional ventricle inlet valve to allow blood to flow from said atrium chamber means to said ventricle chamber means, said magnetic one-directional ventricle inlet valve, said magnetic one-directional outlet valve and said magnetic one-directional inlet valve forming a one-directional check valve system;

a first elastic diaphragm sac separating said atrium chamber means from the lower part of said casing, said first elastic sac being expandable into said atrium chamber means to substantially fill the space therein;

a second elastic diaphragm sac separating said ventricle chamber means from the lower part of said casing, said second elastic sac being expandable into said ventricle chamber means to substantially fill the space therein;

pump chamber means rigidly disposed in the lower part of said casing;

reciprocating bistable electro-magnetic pumping means for generating a reciprocating pumping motion, having an hydraulic pumping medium and rigidly disposed in said pump chamber means;

means permitting said reciprocating pumping means to alternatively pump said pumping medium into said first and second elastic diaphragm sacs to fill said sacs and cause expansion thereof into respective ones of said chamber means and thereby generate pulsatable motion in said artificial heart which forces blood, under the agency of said one-directional check valve system, in a one-directional mode around said circulatory system.

2. An artificial heart as claimed in claim 1 wherein said pumping means comprises:

at least two permanent magnets rigidly mounted in said pumping chamber means so that the poles of one magnet face the poles of the other at a given distance therebetween, said facing poles having opposite polarity thus forming a closed ring flux field that cannot be magnetized under a given operating condition;

ferro-magnetic piston means reciprocally slidable between the poles of said permanent magnets;

electromagnetic coil means rigidly disposed between said permanent magnets and operatively surrounding said ferromagnetic piston means;

means for energizing said coil with an alternating dc pulse so that said coil generates an alternating electromagnetic flux field to cause said ferro-magnetic piston means to be continuously magnetically polarized in opposite directions and thereby execute said reciprocating pumping motion between said magnetic poles by being alternately repelled and attracted therebetween.

3. An artificial heart as claimed in claim 1 wherein said means permitting said pumping means to pump said pumping fluid into said first and second diaphragm sacs comprises perforations in the wall of said chamber means adjacent the separation of said atrium chamber means and said ventricle chamber means with the lower part of said casing.

4. An artificial heart as claimed in claim 2 wherein said permanent magnets are of the cobalt rare-earth type.

5. A permanently implantable artificial heart for pumping blood around a circulatory system, said heart comprising:

a casing having an upper part and a lower part; first and second chamber means disposed in said upper part, each chamber means capable of functioning both as an atrium and a ventricle;

a chamber wall dividing said first and second chamber means and preventing communication therebetween;

a first inlet and first outlet passage of said first chamber means, said first inlet passage having a first magnetic one-directional inlet valve and said first outlet passage having a first magnetic one-directional outlet valve, said first inlet and first outlet valves allowing blood to flow into and out of said first chamber means respectively;

a second inlet and second outlet passage of said second chamber means, said second inlet passage having a second magnetic one-directional inlet valve and said second outlet passage a first magnetic one-directional outlet valve, said second inlet and said second outlet valves allowing blood to flow into and out of said second chamber means respectively;

a first elastic diaphragm sac separating said first chamber means from the lower part of said casing, said first elastic sac being expandable into said first chamber means to substantially fill the space therein;

a second elastic diaphragm sac separating said second chamber means from the lower part of said casing, said first elastic sac being expandable into said second chamber means to substantially fill the space therein, said first magnetic one-directional magnetic inlet and outlet valves forming a first one-directional check valve system, and said second magnetic one-directional magnetic inlet and outlet valves forming a second one-directional check valve system of said artificial heart;

pump chamber means rigidly disposed in the lower part of said casing;

reciprocating bistable electro-magnetic pumping means for generating a reciprocating pumping motion rigidly disposed in said pump chamber means and having an hydraulic pumping medium and at least two permanent magnets rigidly mounted in said pump chamber means so that the poles of one magnet face the poles of the other at a given distance therebetween, said facing poles having opposite polarity thus forming a closed ring flux field that cannot be magnetized under a given operating condition; ferromagnetic piston means reciprocally slidable between the poles of said permanent magnets; electromagnetic coil means rigidly disposed between said permanent magnets and operatively surrounding said ferro-magnetic piston means; means for energizing said coil with an alternating dc pulse so that said coil generates an alternating electromagnetic flux field to cause said ferromagnetic piston means to be continuously magnetically polarized in opposite directions and thereby execute said reciprocating pumping motion between said magnetic poles by being alternately

repelled and attracted therebetween; means permitting said reciprocating pumping means to alternatively pump said pumping medium into said first and second elastic diaphragm sacs to fill said sacs and cause expansion thereof into respective ones of said first and second chamber means and thereby generate pulsatable motion in said artificial heart which forces blood, under the agency of said first and second one-directional check valve systems, in a one-directional mode around said circulatory system.

6. An artificial heart as claimed in claim 5 wherein said means permitting said pumping means to pump said pumping fluid into said first and second diaphragm sacs comprises perforations in the wall of said chamber means adjacent the separation of said atrium chamber means and said ventricle chamber means with the lower part of said casing.

7. An artificial heart as claimed in claim 5 wherein said permanent magnets are of the cobalt rare-earth type.

8. A permanently implantable artificial heart for pumping blood around a circulatory system said heart comprising:

a casing having an upper part and a lower part; at least two chamber means disposed in said upper part and having corresponding inlet and outlet passages for transporting blood to and from each of said chambers respectively so that as blood is entering one chamber it is simultaneously leaving the other;

a one-directional check valve system disposed in said inlet and outlet passages for controlling and allowing the flow of blood in one direction through said heart and into said circulatory system;

a first elastic diaphragm sac separating one of said two chamber means from the lower part of said casing, said first elastic diaphragm sac being expandable into said one of said chamber means to substantially fill the space therein;

a second elastic diaphragm sac separating the other of said two chamber means from the lower part of said casing said second elastic diaphragm sac being expandable into said other of said two chamber means to substantially fill the space therein;

reciprocating bistable electromagnetic pumping means for generating a reciprocating pumping motion rigidly disposed in the lower part of said casing, and having an hydraulic pumping medium; at least two permanent magnets rigidly mounted in said chamber means so that the poles of one magnet face the poles of the other at a given distance therebetween, said facing poles having opposite polarity thus forming a closed ring flux field that cannot be magnetized under a given operating condition; ferromagnetic piston means reciprocally slidable between the poles of said permanent magnets; electromagnetic coil means rigidly disposed between said permanent magnets and operatively surrounding said ferro-magnetic piston means; means for energizing said coil with an alternating dc pulse so that said coil generates an alternating electromagnetic flux field to cause said ferromagnetic piston means to be continuously magnetically polarized in opposite directions and thereby execute said reciprocating pumping motion between said magnetic poles by being alternately repelled

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and attracted therebetween, whereby said pumping means alternatively pumps said pumping medium into said first and second elastic diaphragm sacs to fill said sacs and cause expansion thereof into respective ones of said chamber means and thereby generate pulsatable motion in said artificial heart which forces blood, under the agency of said one-directional check valve system means, in a one-directional mode around said circulatory system.

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9. An artificial heart as claimed in claim 8 wherein said one-directional check valve system means comprises a plurality of magnetically operable one-directional valves.

10. An artificial heart as claimed in claim 8 wherein said permanent magnets are of the cobalt rare-earth type.

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