United States Patent [19]

Kovacs

[11] **3,791,769**

[45] **Feb. 12, 1974**

[54] **MAGNETIC HEART PUMP**

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[22] Filed: **June 4, 1970**

[21] Appl. No.: **43,519**

[52] **U.S. Cl.** **417/417,** 3/1, 417/413

[51] **Int. Cl.** **F04b 17/04**

[58] **Field of Search** ..... 3/1, DIG. 2; 310/80, 103; 417/410, 413, 415–417, 470

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[57] **ABSTRACT**

A magnetically driven heart pump wherein relative movement between opposing magnetic fields induce pump piston motion, which simulates the pulsatile pumping action of a natural heart. The heart pump has two separate parts. The first part comprises the pumping and valve chambers, and is adapted to be imbedded within the chest cavity. The second part, adapted to be strapped to the exterior of the chest wall, carries the magnet and mechanical linkage. The motion of the exterior magnet induces pump piston motion within the pumping chamber.

7 Claims, 4 Drawing Figures

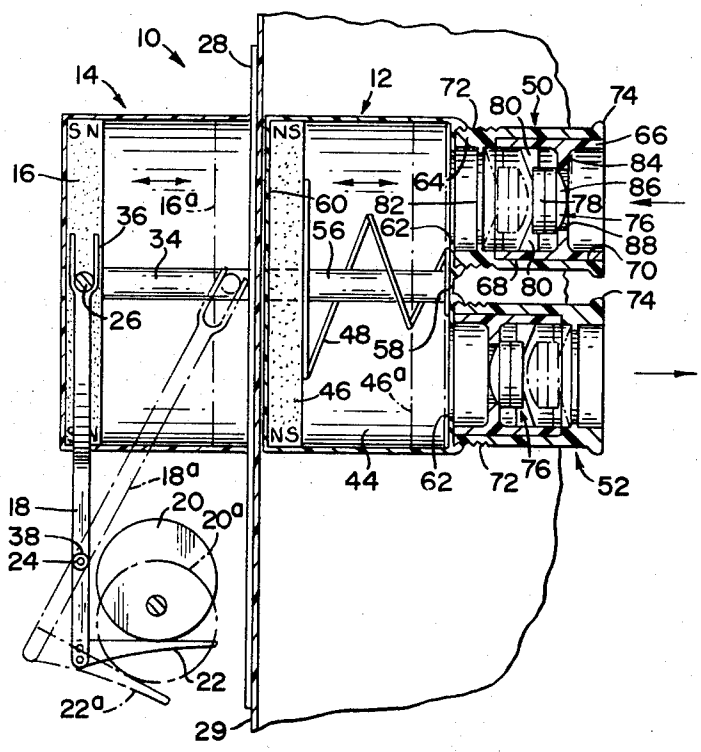


FIG. 1

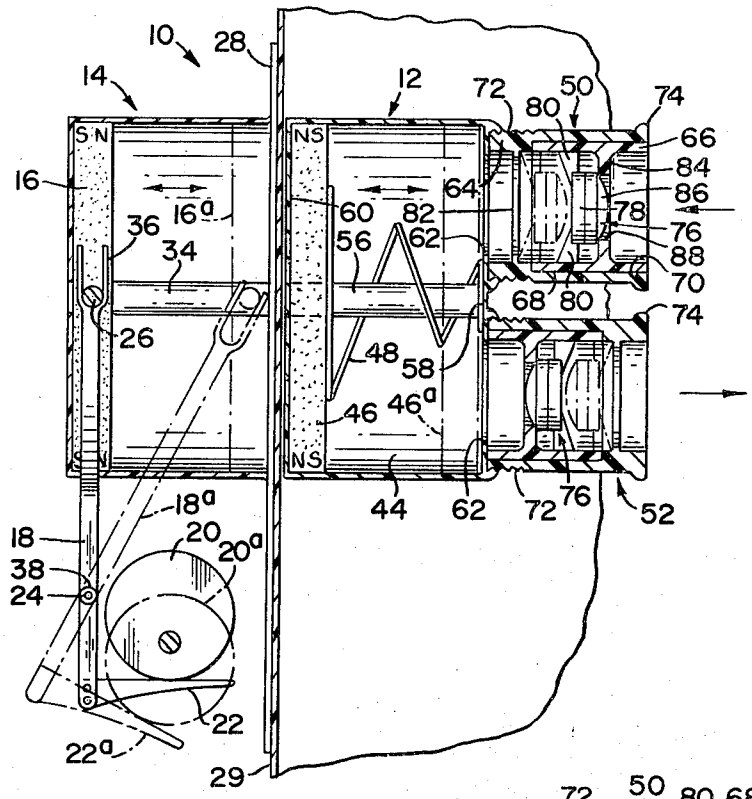


FIG. 3

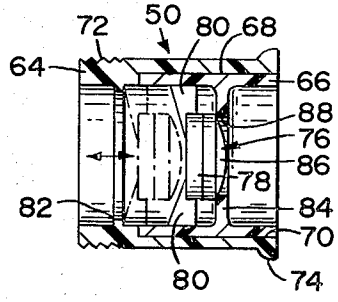
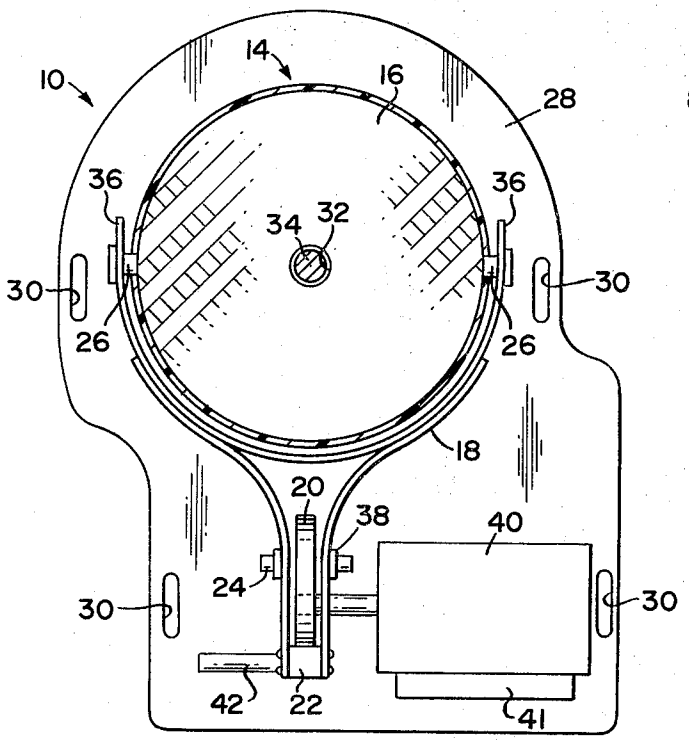


FIG. 2



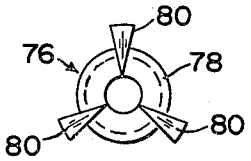


FIG. 4

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MAGNETIC HEART PUMP

This invention relates generally to magnetically operated pumps and in particular to a magnetic pump for use within the chest to simulate the rhythmic contractions of a natural heart.

In medicine today there has been much effort put toward the development of various artificial body organs. Of all parts of the human body, none is so simple yet so complicated as the human heart. There are many problems inherent in the fabrication of a mechanical heart that must be solved. For instance, the heart pump must be lightweight, it must be of simple, rugged, dependable construction so that the chances of breakdown or failure are reduced to an absolute minimum. It must be relatively inexpensive to manufacture. It must be capable of simulating the action of a natural heart, that is, it must not damage the blood cells during the pumping cycle while at the same time the pulsatile action of the natural heart must be duplicated. These and other similar problems have kept scientists and engineers from developing a successful, practical, reliable heart pump.

It is therefore an object of this invention to provide a heart pump which will duplicate both the pulsatile pumping action of the natural heart together with the associated blood pressure ranges generated in the arterial system.

Another object of this invention is to provide a heart pumping chamber wherein damage to blood cells is kept at a minimum due to the fact that the pumping rates correspond to normal heart rates.

Still another object of this invention is to provide a heart pump capable of being manually operated in the event of actuator power failure.

A further object is to provide a pump chamber having a per beat volume which corresponds to the average volume of blood pumped by the human heart.

A still further object is to provide a heart pump in which the chances of clotting within the pumping chamber are decreased.

Another object is to provide a heart pump which has a failsafe system.

Another object is to provide a portable heart pump which is easily strapped to the chest of the user.

Another object is to provide a heart pump of simplified construction utilizing a minimum number of moving parts.

Another object is to provide a heart pump in which a portion of the pump is permanently imbedded within the chest cavity of the user.

Another object is to provide a heart pump wherein a movement of one magnetic field induces a corresponding movement in a second magnetic field.

Another object is to provide a pump piston which will translate in response to varying magnetic field strength.

Another object is to provide a flow check valve for use as a replacement for a defective natural heart valve.

Another object is to provide a flow check valve which will maintain constant coaxial alignment regardless of relative rotational movement.

Another object is to provide a flow check valve which permits symmetrical flow through a valve chamber.

Another ojbect is to provide a resilient face seal which insures uniform valve seat sealing despite surface variations on the valve seat.

Another object is to provide a flow check valve with greater flow rate capacity than a ball check valve having the same valve port opening and chamber diameter.

Another object is to provide flow check valve housing guide struts which are radially extending and insure coaxial alignment of the valve plate with the valve seat.

Another object is to provide a flow check valve which allows symmetrical blood flow through the chamber thereby reducing clotting tendencies.

Another object is to provide a heart pump which is capable of pumping rates ranging from 60 to 80 cycles per minute.

Another object is to provide a heart pump, the pulsatile action of which is caused by an external linear reciprocating cam driven magnetic actuator.

Another object is to provide a heart pump wherein reciprocating motion is imparted by induction to the pump piston in the pump chamber.

Another object is to provide a heart pump capable of producing a rhythmic pressure gradient corresponding to the natural heart's diastolic to systolic blood pressure range.

Other objects of the invention will in part be obvious and will in part appear hereinafter.

The above and other objects not specifically enumerated are efficiently obtained by providing a heart pump which duplicates both the pulsatile pumping action of the natural heart, and the associated blood pressure ranges generated in the arterial system. This is accomplished by the use of high-permeability magnets. The magnets are arranged co-axially in a pair of chambers such that their fields tend to oppose and repel each other. The external, actuator magnetic is cam driven by a mechanical linkage to produce a linear reciprocating motion roughly corresponding to a normal pulse rate. The reciprocating motion of the actuator magnetic induces a like motion in the piston magnet located within the pump chamber. The cyclic motion of the actuator produces the rhythmic piston pumping action which is adjusted to have a pressure gradient corresponding to the natural heart's diastolic-systolic blood pressure range.

The pump-chamber is located within the patient's chest cavity while the external actuator is located on the outside directly over the imbedded pump chamber. At the distal end of the pump is located a plurality of flow check valves which are adapted to be attached to the left atrium and the aorta in order to control blood flow during the pumping stages.

The invention accordingly comprises the features of construction, combination of elements, and arrangement of parts which will be exemplified in the construction hereinafter set forth, and the scope of the invention will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in connection with the accompanying drawings in which:

FIG. 1 is a cross-section view of the magnetically driven pump of the present invention.

FIG. 2 is a front view of the heart pump showing the external actuator, cam throw arm and cam torque unit.

FIG. 3 is a cross-section view of a flow check valve.

FIG. 4 is a front view of the valve plate chamber guide struts for the flow check valve.

Similar reference characters refer to similar parts throughout the several views of the drawing.

Referring now to FIG. 1, heart pump 10 of the present invention is generally shown to consist of two separate units, the internal pump chamber 12 and the external actuator 14. The internal pump chamber 12 is adapted to be placed within the thoracic cavity and secured to the rib cage while external actuator 14 is located on the outside of the body directly over and proximate with internal pump chamber 12 and is adapted to be strapped to the patient. External actuator 14 has a circular disc magnet 16 made of a high permeability substance such as Alnico I, Alconax II, Genoflux II or any other like substance. Magnet 16 is adapted to reciprocate in the direction indicated in the arrows of FIG. 1, between the positions shown by magnet 16 and 16a, in response to the movement of cam operated throw arm 18. A schematic of this mechanical movement is illustrated in FIG. 1 wherein cam shaft 20, cam riser arm 22 and throw arm 18 are shown operatively connected to disc magnet 16 by pivot axis 24 and pivot pin 26. The opposite extreme of the mechanical movement is illustrated by the phantoms, cam shaft 20*a*, cam riser arm 22*a*, throw arm 18*a*, cam 20*a*, and disc magnet 16*a*.

Referring now to FIG. 2, a front view of heart pump 10 is shown. Here, external actuator 14 is shown supported upon mounting plate 28. Plate 28 is shaped to fit the chest of the wearer and can be made of a light plastic such as nylon, lexan or some other suitable material. The surface of mounting plate 28 in contact with the skin 29 may also be lined with a foam strip or other material to reduce contact discomfort. Mounting plate 28 is attached to the body by any conventional means such as body harness straps (not shown) which are attached to mounting plate 28 through slots 30.

Circular disc magnet 16 has a centrally located aperture 32 which is adapted to receive disc guide rod 34 attached to mounting plate 28. Guide rod 34 keeps disc magnet 16 aligned during its reciprocating movement to and from internal pump chamber 12. Pivot pins 26 radially extend from disc magnet 16 and are received by yokes 36 of throw arm 18. Throw arm 18 is here shown to be generally Y-shaped and made of a rigid, lightweight material and pivotally attached at 38 to pivot axis 24 which is in turn fixedly attached to mounting plate 28 by suitable fastening means such as screws, clamps and the like. Cam riser arm 22 is attached to the end of throw arm 18 so as to contact with and follow cam 20 as it is rotated by a conventional power source 40, such as a cam torque unit. Power source 40 shown here is a small DC gear head motor, either linear or rotary conversion, which is powered by a portable power pack 41. However, the specific power source is not critical and any motive means of this generalized type may be used. In addition, in the event of a power failure, a cam riser arm extension 42 is provided so that the user can maintain the pumping action by manually depressing the cam riser arm at a normal pumping rate until the unit can be repaired. The entire external actuator assembly 14 is designed to be covered by a snap-on high impact molded, plastic cover (not shown) or similar covering in order that the unit be protected from damage by impact.

Referring again to FIG. 1, internal pump chamber 12 of heart pump 10 consists of pump chamber 44 within which is located a second circular disc magnet 46 and a return spring 48, together with check valves 50 and 52 to control in flow and out flow from pump chamber 44. Pump chamber 44 is adapted to be fixedly attached within the thoracic cavity by suitable fastening means such as plastic coated wire (not shown) to the ribs of the wearer. Internal pump chamber 12 could be made of materials such as tantalum, molded lexan, nylon, dacron, vitailium, stainless steel (teflon lined) or other durable, non-reactive substance. This magnet 46 is generally of the same design as magnet 16 and is similarly made of a material such as Alnico V, Alconax II, Genoflux II or any similar material which has a high permeability. Magnet 46 also has a centrally located aperture which receives a second disc guide rod 56. This guide rod 56 is molded integrally with or fixedly attached to walls 58 and 60 of pump chamber 44 and serves to guide disc 46 during its reciprocating motion. Located between disc magnet 46 and front wall 58 is a return spring 48 which is designed to urge disc magnet 46 against rear wall 60 of pumping chamber 44, as illustrated by the solid lines in FIG. 1. Return spring 48 can be made of any suitable substance such as tantalum or a tempered teflon coated, stainless steel. The spring is designed for telescopic compression such that on full compression, the spring length equals the thickness of the spring wire.

Located in front wall 58 of pumping chamber 44 are apertures 62 into which check valves 50 and 52 are threadably engaged. These check valves serve to control blood flow to and from chamber 44. Referring now to FIG. 3, it is noted that check valve 50 is constructed from two sections, 64 and 66, which may be made of a molded plastic such as lexan, nylon, or dacron. The periphery of section 66 is circular and adapted to be placed within section 64 and sealed by a molecular solvent so as to form a cohesive, leak proof bond between the outer wall 68 of section 66 and the interior wall 70 of section 64. Section 64 is provided with threads 72 which are adapted to engage and provide a leak proof seal between check valve 50 and aperture 62 of front wall 58. The distal end of check valve 50 is provided with a radially extending annular suture ring 74 to aid in graft attachment of the valve to living tissue. Within valve 50 is floating valve plate 76 which consists of a molded plastic disc 78 having three radially extending guide struts 80 which are integrally molded at a 120° radial spacing about the periphery of disc 78. Floating valve plate 76 is free to move transversely within valve chamber 70 in response to a pressure differential within valve 50. As indicated by the arrows of FIG. 3, the leftward movement of floating valve plate 76 is checked by an inwardly extending annular ring 82 molded to the interior wall 70 of section 64 and the rightward movement of floating valve plate 76 is checked by internally extending annular ring 84 molded to section 66.

The face 86 of plastic disc 78 may be provided with a resilient, contour forming substance so as to provide a uniform seal on the valve seat portion of the valve port opening 88 formed by annular ring 84, despite wearing of the valve seat.

Check valve 52 is of similar construction as check valve 50 except that the relative positions of the elements are reversed so as to check the flow of blood in the opposite direction.

The natural heart pumps blood by means of rhythmic contractions, this type of pump action is generally called pulsatile since the pumping pressure varies from diastolic to systolic. Diastolic pressure is the pressure in the arterial system during the relaxed heart condi-

tion, that is, during which period the left ventricle chamber is filling with blood from the left atrium chamber. The systolic pressure is the pressure generated in the arterial system during the contracted heart conditions, that is, during the period when the heart's left ventricle chamber pumps blood into the arterial system via the aorta. This rhythmic variation of pumping pressure, from diastolic to systolic and vice versa, produces the pulsatile blood flow characteristic of the heart's pumping action. The description of operation of heart pump **10**, infra, shall begin at the end of the diastolic pumping cycle. At this period of the pumping cycle, pump chamber **44** is full of oxygenated blood received from the natural heart's left atrium chamber via check valve **50**. Check valve **52**, which is fully closed due to the diastolic pressure of the blood in the aorta, controls the flow of blood from pump chamber **44** to the aorta of the body's arterial system. At this time, circular disc magnets **16** and **46** are in the solid line positions as shown in FIG. **1**, as are throw arm **18**, cam riser arm **22** and cam **20**.

The systolic pumping cycle proceeds then as follows: Cam shaft **20** rotates from the initial solid line position toward its dotted line position, **20***a*. The downward urging of cam riser arm **22** pivots throw arm **18** about pivot axis **24** in a clockwise direction, hence urging actuator magnet **16** toward its dotted line position **16***a*. As magnet **16** moves to the right along guide rod **34**, the magnetic polarity configuration shown causes magnet **46**, located within pumping chamber **44**, to be urged to the right also. The field strength of magnet **16** is sufficiently high to overcome return spring **48** and magnet **46** proceeds to its dotted line position **46***a*. As the pressure within pump chamber **44** becomes greater than the diastolic pressure within the aorta, check valve **52** opens and blood flows into the arterial system. Simultaneously, floating valve plate **76** of check valve **50** is seated against annular ring valve seat **84**. As the volume of blood within chamber **44** decreases, the velocity of magnet **46** increases, then decreases. This is due to a lessening of pressure in the aorta together with the inertia of magnet **46**, blood flow, and the increasing spring force. This naturally occurring velocity gradient in the motion of magnet **46** produces a pumping pressure gradient corresponding to the blood pressure gradient defined by the natural diastolic-systolic range. When cam **20** and throw arm **18** has advanced their respective dotted line positions, **20**a and **18**a, the systolic pumping cycle is completed and the configuration of the moving elements will all be in their dotted line position as shown in FIG. **1**. At this time, the diastolic pumping cycle begins and all elements begin the movement back to the solid line position. This return motion of magnet **16** permits magnet **46** to return to its initial starting position by virtue of the restoring force provided by return spring **48**. As magnet **46** begins to return toward rear wall **60** of pumping chamber **44**, check valve **50** opens and check valve **52** closes since relative internal pressure is now that of the diastolic cycle and oxygenated blood from the left atrium is beginning to fill pump chamber **44**. Also, the velocity gradient decreases as magnet **46** approaches its initial start position due to the continuous decrease in restoration force resulting from the continued relaxation of return spring **48**. This continued reduction in velocity gradient results in a pumping pressure gradient corresponding to the systolic-diastolic blood pressure transition of the natural heart. Therefore, when cam **20** and throw arm **18** have returned to the solid line position, the diastolic pumping cycle is complete and the system is ready to commence another systolic pumping cycle as is described above.

While check valves **50** and **52** have been described herein as used in combination with the magnetic heart pump **10**, it is within the contemplation of this invention that these check valves also be used separately as replacements for defective natural heart valve such as the aortic, mitral, tricuspid and pulmonary valves independent of and separately from the above described heart pump **10**. Valve **50** may be adapted for use in any system wherein a pulsating pressure gradient exists across floating valve plate **76**. The flow associated with the pressure gradient will move valve plate **76** in the direction of decreasing pressure and the maximum displacement of the valve plate **76** will be determined by the location of annular ring **82** relative to the annular ring **84**. As illustrated by the solid and dotted line position, shown in FIG. **3**, the valve plate guide strut **80** serves to maintain constant axial alignment with valve port opening **88** regardless of any axial rotation that may occur. Also, struts **80** and disc **78** permit symmetrical blood flow through the valve chamber thereby reducing the probability of blood clot formation tendency due to uneven flow rates as may occur in ball valve structures. In addition, resilient seat **86** is provided in order that a uniform seal is present despite possible surface variations which may occur in the valve seat during use.

It is also within the contemplation of this invention that electro-magnets be used in place of magnet **16** and **46** or that a combination of permanent magnets and electro-magnets be used.

It is further within the contemplation of this invention that the above described pumping unit be used outside the body of the patient thereby utilizing only connecting tubes to transmit the pumped blood.

It will thus be seen that the objects set forth above, among those made apparent from the preceding description, are efficiently attained and, since certain changes may be made in the above construction without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described, and all statements of the scope of the invention, which, as a matter of language, might be said to fall therebetween.

Now that the invention has been described:

What is claimed is:

1. A device for pumping fluids comprising a pumping chamber having a magnetically responsive first piston disposed therein, said first piston having a first and second position, a first pressure responsive free floating shuttle valve having a first and second position, said first pressure responsive free floating shuttle valve communicating with said chamber such that when the ambient is greater that the internal pressure of said pumping chamber said first shuttle valve is in first position allowing fluid to flow into said chamber and when said internal pressure is greater than said ambient pressure said first pressure responsive free floating shuttle valve is in said second position to seal said pumping

chamber, a second pressure responsive free floating shuttle valve with said chamber, said second pressure responsive free floating shuttle valve having a first and second position, said second pressure shuttle valve being in said first position when the ambient pressure is greater than the internal pressure of said pumping chamber to seal said chamber and in said second position when the ambient pressure is less than the internal pressure of said pumping chamber to allow fluid to flow from said chamber, means to generate a magnetic field, said magnetic field generating means arranged relative to said first piston to generate a variable magnetic field thereon, said magnetic field generator means and said first piston being mechanically free to move said first piston from said first position to said second position to generate a pressure change within said pumping chamber, piston return means to return said piston to said first position to cause said pressure within said pumping chamber to vary first above and then below said ambient pressure whereby fluid within said pumping chamber is caused to flow respectively out of and into said pumping chamber through said first and second valves to substantially exhaust fluid from said chamber, said axis of translation of said first piston, first pressure responsive free floating shuttle valve and said second pressure responsive free floating shuttle valve being parallel.

2. The device of claim 1 wherein variable magnetic field means comprises a magnet external to said pumping chamber, mechanical reciprocating means adapted to move said second magnet alternatively from a remote to a proximate and return to a remote location from said magnetically responsive first piston.

3. The device of claim 2 wherein said mechanical reciprocating means comprise a cam rotating means to rotate a cam, a cam riser arm attached to one end of a pivoted throw arm and pivotally connected at the distal end to said magnet, said mechanical reciprocating means operatively secured to frame means which are adapted to be portably secured to the chest of the user.

4. The device of claim 1 wherein said piston return means comprise a non-reactive spring.

5. The device of claim 2 wherein said magnetically responsive piston is axially aligned and coextensive with said magnet.

6. The device of claim 5 wherein said magnetically responsive piston is a permanent magnet.

7. The device of claim 1 wherein said pump chamber and valves are constructed of lightweight, durable, non-reactive plastic material.

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