Aug. 7, 1962 S. H. NORTON 3,048,165

PUMP FOR AN ARTIFICIAL HEART

Filed April 17, 1959 3 Sheets-Sheet 1

Fig 1

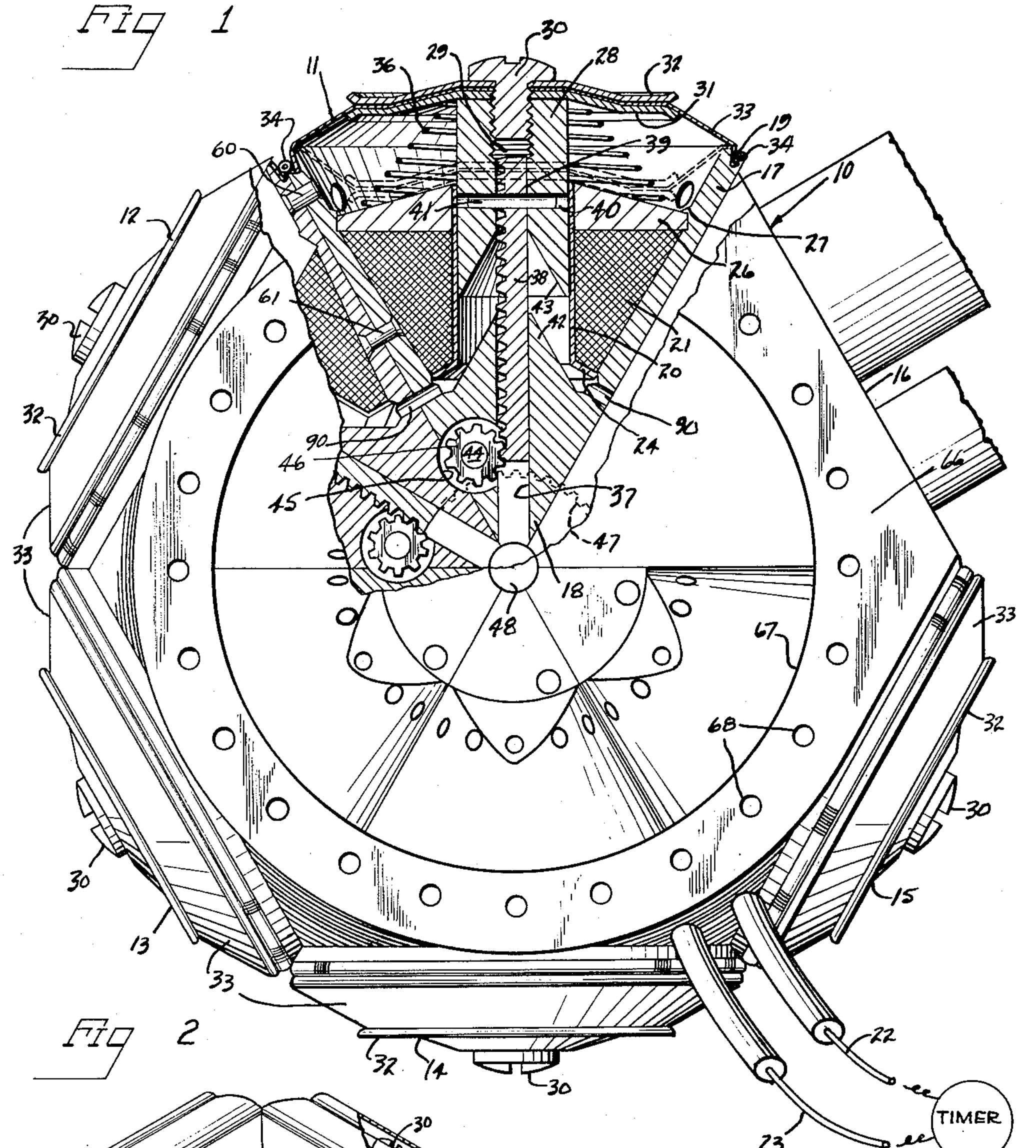
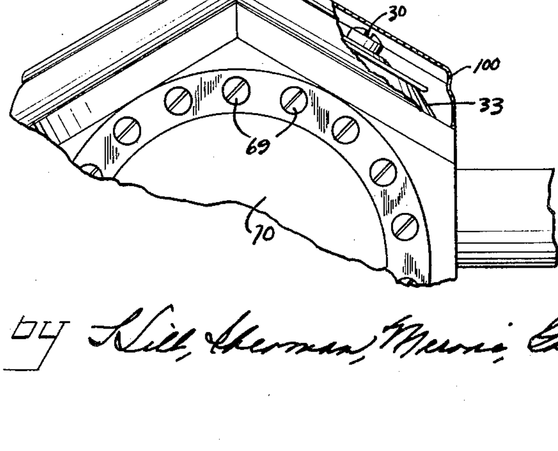


Fig 2



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Aug. 7, 1962 S. H. NORTON **3,048,165**

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3 Sheets-Sheet 2

Fig 3

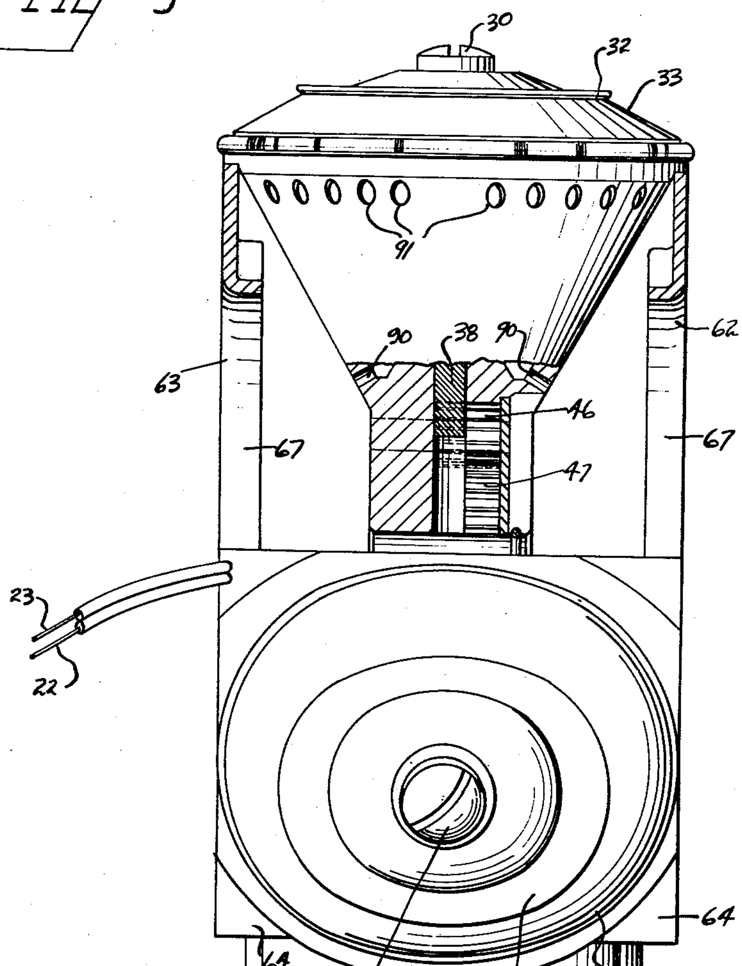

Fig 9

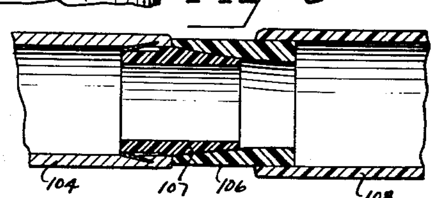

Fig 8

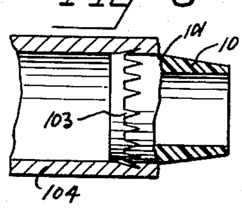

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Fig 4

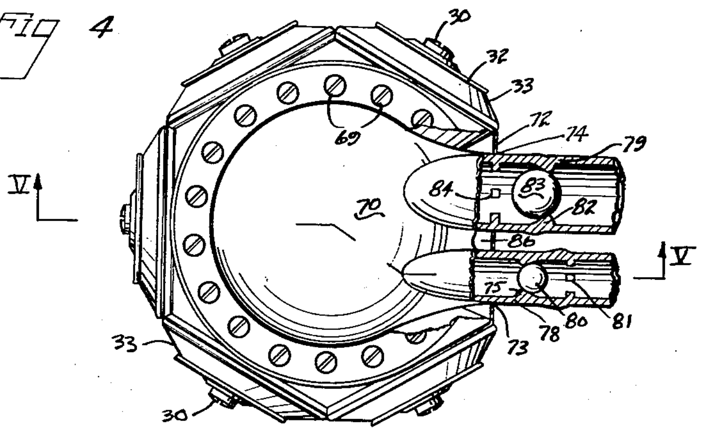
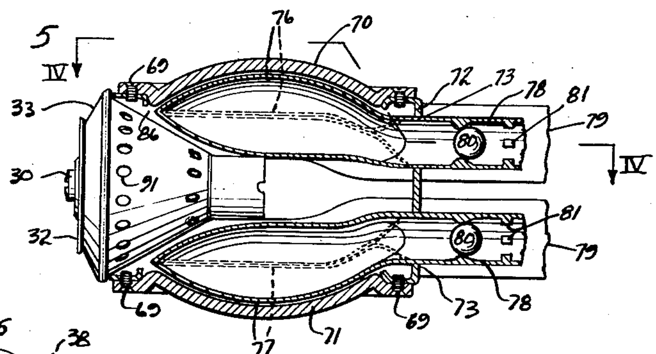


Fig 5



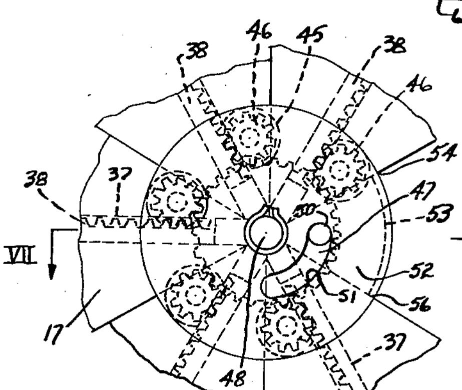


Fig 6

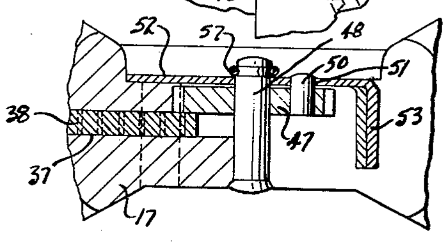


Fig 7

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United States Patent Office

3,048,165

Patented Aug. 7, 1962

3,048,165
PUMP FOR AN ARTIFICIAL HEART

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Filed Apr. 17, 1959, Ser. No. 807,192
8 Claims. (Cl. 128—1)

This invention relates generally to pumps and pumping processes. The principles of the present invention find a particularly useful application to a so-called "artificial heat" or pump for an artificial heart.

It is an object of the present invention to provide a pump which will not contaminate the pumping medium, which will occupy a small amount of space and which can be operated and regulated electrically.

Another object of the present invention is to provide a chambered pump operable in the manner of the human heart and regulated in accordance with the variable characteristics of heart operation.

Yet another object of the present invention is to provide a pumping device wherein one flexible chamber or chambers operates another flexible chamber or chambers.

A further object of the present invention is to provide a pump which will be chemically inert and which will not be destroyed by the substance it is pumping.

Still another object of the present invention is to provide plural pumping means synchronized for uniform unison action.

A further object of the present invention is to provide a pump using as an integral actuating device therein, a magnetic plunger having stop means to limit the travel thereof.

Many features, additional advantages and other objects of the present invention will become manifest to those versed in the art upon making reference to the detailed description and the accompanying sheets of drawings in which a preferred structural embodiment of a pump incorporating the principles of the present invention is shown by way of illustrative example. It is believed that the pumping methods disclosed herein will be clear to persons skilled in the art from a description of the structures used for practicing such processes.

On the drawings:

FIGURE 1 is a plan elevational view with parts broken away and with parts shown in cross-section illustrating a pump incorporating the principles of the present invention;

FIGURE 2 is a reduced view similar to FIGURE 1, but showing a pump having a chemically inert covering thereover;

FIGURE 3 is a side view partly in section showing the pump of FIGURE 1 with the two covers removed and with one of the actuator units and the parts thereof in cross-section to illustrate additional details of construction;

FIGURE 4 is a somewhat reduced plan view similar to FIGURE 1 but with the covers in place and showing a bladder or pumping sack with its delivery and admission tubes and valves, the view of FIGURE 4 being taken substantially in the plane of line IV—IV, as shown in FIGURE 5;

FIGURE 5 is a side view taken in the plane of line V—V of FIGURE 4 and illustrating additional parts in cross-section to further disclose the details of construction of the present pump;

FIGURE 6 is a plan view fragmentary in part and showing additional details of the rack and gear construction and also the stop device incorporated in the structure of the present invention;

FIGURE 7 is a fragmentary cross-sectional view taken on line VII—VII of FIGURE 6; and

FIGURES 8 and 9 are somewhat diagrammatic fragmentary cross-sectional views showing quick connection means for connecting the pump of the present invention into the blood vessels of the human body.

As shown on the drawings:

Although the principles of the present invention are of general application to any pumping apparatus, the pumping construction and pumping methods disclosed herein are particularly useful in medical procedures for use as an artificial heart. Accordingly, to clarify the special advantages embodied in the structure of the present invention it would be useful to orient the features incorporated in the present invention to the corresponding components of the heart.

The heart is a muscular organ divided into four chambers and blood is brought into the heart by large veins with valves controlling the flow of blood through the various chambers. Arteries carry blood away from the heart. The heart is approximately the size of a fist, the adult average heart being approximatley five inches long, three and one-half inches wide and two and one-half inches thick with a man's heart weighing approximately eleven ounces and a woman's heart about nine ounces.

The upper chamber on each side of the heart is called an auricle and below each auricle is another chamber called a ventricle. The two ventricles pump the blood into the arteries with the right ventricle pumping blood only to the lungs and the left ventricle pumping blood through the entire body.

Blood in the right auricle chamber enters the right ventricle chamber through a so-called tricuspid valve and is discharged on its way to the lungs through a semilunar valve. Purified blood from the lungs passes from the left auricle into the left ventricle through the mitral valve and is discharged to the body through a second semilunar valve.

Because the right side of the heart takes blood from the body and pumps it to the lungs, while the left side of the heart collects blood from the lungs and pumps it to the body, the heart is really two pumps in one. The two sides of the heart, however, relax and fill and then contract and empty themselves at the same time. The relaxing and filling phase is called the diastole and the contracting and pumping phase is called the systole.

In accordance with the principles of the present invention, two flexible sacks serving as pumping chambers corresponding to the right and left ventricles are provided with separate valve controlled inlets and outlets. The flexible sacks are immersed in a confined liquid which, in turn, is acted upon by an annular row of magnetically operated flexible diaphragms. Thus, the flexible sacks may be electrically subjected to a cyclical pulsing action corresponding to a systolic and distolic cycle which causes the flexible sacks to alternately fill and contract in the manner of the human heart.

Referring now specifically to the drawings, a pump is indicated generally at **10** which comprises an annular row of separate actuators indicated generally at **11**, **12**, **13**, **14** and **15**. Each actuator **11–15**, inclusive, is essentially similar in structural and functional characteristics and, accordingly, only one will be described in detail, it being understood that like reference numerals apply to like parts insofar as all of the actuators **11–15** are concerned. It will be noted upon referring particularly to FIGURE 1, that the plurality of actuators selected in this particular embodiment of the invention total five and are disposed in an annular array or annular row so as to form a generally hexagonal device, one side of the hexagon being left blank as at **16**, the utility of which blank space will be evident from a further description of the pump **10**.

Each actuator **11** comprises specifically a frame member **17** which is generally conical in configuration having an inner apical portion 18 and an outer circumferential edge which is recessed as at 19.

Centrally disposed within the frame is a tube 20. Surrounding the tubular member or tube 20 and interiorly of the frame 17 there is provided wire windings indicated generally at 21. It will be understood that the wire winding 21 constitute a continuous winding, thereby forming a core for each separate actuator 11–15, inclusive, and the individual wires of the actuators 11, 12, 13, 14 and 15 are connected together in either series or parallel relationship, depending upon what current characteristics are used to power the pump 10. The wires may be brought out of the pump in the form of conductor wires indicated at 22 and 23 and will be connected to a suitable source of energization such as a power source regulated by a timer indicated diagrammatically and identified by appropriate legend.

It will be noted that the wire windings 21 are confined at a lower end by a flared flange 24 formed at one end of the tube 20 and at the opposite end the wire windings 21 are confined by a plate member 26 which is fastened in firm assembly within the interior of the frame 17, for example, by spinning a retainer flange 27.

A core or plunger 28 slidably fits within the interior of the tube 20 and is preferably made of a suitable magnetizable material so that the core or plunger 28 will be moved radially inwardly towards the apical portion 18 of the body frame 17 whenever the wire windings 21 are energized.

At the outer end, each core or plunger 28 is provided with a threaded aperture 29 in which is threadedly received a retainer screw 30 to hold an inner plate 31 and an outer plate 32 in supporting and clamping relationship to a flexible diaphragm 33 interposed between the plates 31 and 32.

The flexible diaphragm 33 spans the outer peripheral edge of the body frame 17 and overlies such edge so as to be positioned in the recess 19 whereupon the outer periphery of the diaphragm 33 envelops the upper rim of the body frame 17 and is held in firm assembly and in proper sealing relationship therewith by suitable retainer means such as a garter spring 34. The garter spring 34 may be made of a suitable spring wire, although it will be understood that any other form of fastening means such as a wire, cord or other fastener may be used.

Operatively disposed between the inner plate 31 and the plate member 26 is a compression spring 36 which preloads the diaphragm 33 and the core or plunger 28 to an extended position whenever the wire windings 21 are not energized. In extended position, the diaphragm 33 is positioned as shown in full lines in FIGURE 1, it being understood that the diaphragm together with the core or plunger 28 is movable to an inner position as shown in dotted lines in FIGURE 1.

The body frame 17 is provided with a centrally disposed passageway or guideway 37 in order to support and slidably guide a toothed rack member 38 fastened at one end to the core or plunger 28. To accommodate the rack member 38, the core or plunger 28 is provided with a passageway 39 receiving the end of the rack member 38 and a transverse intersecting passage 40 receives a locking pin 41 retaining the rack member 38 in firm assembly with the core or plunger 28.

The body frame 17 is further provided with an outwardly projecting portion 42 which cooperates with a recess 43 shaped to be of complemental configuration and provided in the inward end of the core or plunger 28, thereby providing a stop for limiting the relative inward movement of the core or plunger 28.

Each body frame 17 carries a pin 44 on which turns a gear 46 rotatably disposed within a recess 45 to mesh with the teeth on the rack member 38.

Additionally, there is provided at the center hub portion of the cooperating actuators 11–15, inclusive, a centrally disposed sun gear 47 pivotally mounted on a pin 48. Each pin 44 has a length equal to the thickness of the rack member 38 plus the thickness of the sun gear 47, thereby permitting each gear 46 to mesh not only with the rack member 38 at one end, but with the sun gear 47 at its other end. Thus, when the rack member 38 is moved in its guideway 37, the gear 46 will be rotated, thereby driving the sun gear 47. Since each of the actuators 11–15 has corresponding racks, gears and plungers, all of the racks mesh with their corresponding gears and all of the corresponding gears mesh with the sun gear 47 so that movement of any rack member 38 will cause a corresponding movement in all of the other rack members. It is thus impossible for any rack 38 and plunger 28 to move without causing every other plunger 28 and rack 38 to move an equal amount.

As pointed out, the inward travel of each plunger 28 is limited by the contact established between the conical projection 42 and the complementary surface 43. To limit the outward movement of each plunger 28 with some means other than the limitations imposed thereon by the diaphragm 33, which diaphragm 33 is subject to stretching, a stop means is incorporated in the mechanical movement of the plungers. Thus, as shown in FIGURES 6 and 7, there is provided a pin 50 which is carried in firm assembly with the sun gear 47 and which projects parallel to the axis of rotation into an arcuate slot 51 formed in a plate 52, which plate 52 is further characterized by an offset projection 53. The plate 52 is positioned so that the projection 53 is anchored between the opposite edges of the actuator 11 and the actuator 15, which opposite edges are indicated at 54 and 56 (FIGURE 7). The plate member 52 is secured to the pin 48 by means of a snap ring 57. Thus, the pin 50 can oscillate in the arcuate slot 51, but since the plate 52 is anchored against turning by contact against the actuators 11 and 15 as at 54 and 56, the ends of the slot 51 will operate as a stop for the pin 50 in the sun gear 47 and the limitation thus imposed upon the travel of the sun gear 47 will, in turn, limit the turning of the separate gears 46 and hence the outward movement of the corresponding rack members 38, as well as the plungers 28 and the diaphragms 33 associated therewith.

Each body frame 17 is firmly connected to an adjacent body frame 17 by suitable fastening means such as the rivets indicated in FIGURE 1 at 60 and 61. It will be understood that other means of fastening could be employed, for example, by sweating or brazing the actuator units together.

As shown in FIGURE 3, there is further provided supporting frame members on opposite sides of the annular row of actuators 11–15, inclusive, and such supporting frame members are indicated at 62 and 63. The supporting frames 62 and 63 have inwardly projecting portions shown at 64 which closely embrace the actuator units and along the portion of the unit corresponding to the blank wall 16, the supporting frames 62 and 63 are provided with wall portions indicated at 66. An offset flange extends inwardly on each of the supporting frames 62 and 63 and is indicated at 67. Each flange 67 surrounds a circular opening and the edges of each opening are characterized by the provision of a plurality of threaded apertures 68.

Dome-shaped covers preferably made of transparent chemically inert material are fastened to the support frames 62 and 63 by means of a plurality of fastening screws 69. The dome-shaped members are indicated at 70 and 71, respectively.

An end plate 72 (FIGURES 4 and 5) formed with suitable pairs of apertures 73, 73 and 74, 74 completes the box-like enclosure.

Disposed within the pump 10 and on opposite sides thereof are a pair of flexible sacks or bags indicated at 76 and 77, respectively. Each flexible sack or bag 76 and 77 comprises a bladder-like flexible enclosure made of a suitable chemically inert material. Each bag or sack **76** and **77** has two tubular snouts or conduits, a small sized conduit **78** being located in the opening **73** and a larger sized conduit **79** being located in the opening **74**. Thus, the smaller sized conduit **78** forms an outlet for the corresponding sack with which it is associated and is constructed with a valve seat **75** seating a ball check valve **80** retained in operative adjacency to the seat **75** by cage projections **81**.

The conduit **79** forms an inlet for the corresponding sack or bag and is also provided with a valve seat **82** seating a ball check valve member **83** retained in operative adjacency to the valve seat **82** by cage projections **84**. Thus, two tubes may be connected to each of the two plastic or flexible sacks serving as pumping chambers, one tube connected to the larger conduit **79** allowing fluid to flow into the sack or bag and the smaller conduit **78** handling the pressurized fluid as it is discharged from the sack or bag.

The box-like enclosure together with the two sacks or bags **76** and **77** form three separate compartments and for better identification, the chamber in which the sacks or bags **76** and **77** are positioned is indicated by the reference numeral **86**. The chamber **86** is preferably charged with fluid such as oil, thereby completely surrounding the magnetic actuators **11–15**, inclusive, and the sacks or bags **76** and **77** are, in effect, immersed in liquid fluid. Moreover, it will be understood that the chamber **86** is of variable volume since the outer wall thereof is comprised of the diaphragms **33** carried by the actuators. Thus, with a fluid such as oil, water or any other liquid medium located in the outside chamber **86** and with any substance or liquid it is desired to pump being permitted to enter the bags or sacks **76** and **77**, a pumping action will be developed.

Upon energization of the wire windings **21**, the respective cores or plungers **28** will be drawn inwardly. In order that any liquid trapped in the recess **43** in the area of the outwardly projecting portion **42** may be released, the flared portion **24** of the tube **20** is spaced outwardly of the projection **42** to afford clearance and a plurality of holes or apertures **90** (FIGURE 1) are formed in the body frame **17**, thereby permitting liquid in the tube **20** to escape to the chamber **86**.

In order that the fluid in the outer chamber **86** may have free movement from the diaphragm compartment in the head of the actuators **11–15**, the space inside of the frames **63** and **67** and the covers **70** and **71**, a plurality of apertures **91** are formed in the magnet frame.

In free position, all of the diaphragms **33** are biased outwardly by the coil springs **36**. Thus, when the wire windings **21** are energized all of the plungers **28** are biased inwardly and the force moving the plungers **28** inwardly increases as the respective plungers move inwardly within the tube **20**, the biasing force being much greater as each plunger **28** enters the end of its travel and contacts the outwardly projecting portion **42** of the corresponding body frame **17**. Thus, the pressure of the liquid in the chamber **86** will build up in proportion to the amount of travel of the plungers **28**, being small at the start and increasing greatly as the plungers **28** near the completion of the stroke.

It will be appreciated that it is impossible to make the friction and the strength of all of the magnetic actuators **11–15**, inclusive, identical. Whichever magnetic actuator **11**, **12**, **13**, **14** or **15** has the least friction and the greatest strength will move the fastest and the furthest compared to the other magnets if left to operate independently, however, in accordance with the principles of the present invention the synchronization apparatus provided by the rack and gear arrangement compels all of the plungers **28** to advance at the same speed. Thus, there is avoided the building up of pressure faster in one actuator than in the other, which pressure build up might actually detrimentally operate against the diaphragms of

the other actuators and prevent them from working properly. With the synchronized operation as provided by the structure of the present invention, all of the diaphragms **33** pull down uniformly from the full line position to the dotted line position as illustrated in FIGURE 1, and the consequent reduction of volume of the chamber **86** will cause the extended bags or sacks **76** and **77** to be contracted or collapsed, thus moving the walls of the sacks or bags **76** and **77** from the full line position shown in FIGURE 5 to the dotted line position shown in FIGURE 5. The bladder-like sacks or bags **76** and **77** are thus emptied of any liquid or substance they may have contained.

When the wire windings **21** are deenergized, the springs **36** force the diaphragms **33** outwardly, thereby sucking fluid through the openings **90** and **91** and rarefying the liquid around the bladder-like sacks or bags **76** and **77** causing them to expand and to, in turn, suck in a liquid or substance through the inlets provided by the conduit **79**. The check valve **83** in each inlet prevents the liquid from returning.

One of the advantages of the present invention resides in the fact that heat generated by the magnets will be conveyed to the liquid in the chamber **86** whereupon the heat will be dissipated to the outer surface of the pump **10** and to the liquid being forced in and out of the bladder-like bags or sacks **76** and **77** which function as secondary pumping chambers, thereby keeping the magnets at an optimum working temperature. It will be understood that continuous or cyclical opening and closing of a switch, for example, as through suitable electric timing mechanism indicated diagrammatically by the element identified by legend "timer" will keep the pump working and operating.

In some applications of the pump it may be necessary to protect the outside working parts from the atmosphere or from gases or liquids that might contaminate or destroy the metal parts. Or, the metal parts might contaminate the liquids or substances which are associated with the pump. Accordingly, a flexible thin covering of pliable and chemically inactive material indicated at **100** in FIGURE 2 may be placed around the exposed metal parts of the pump and extended under the cover plates **70** and **71**, thereby to be tightly clamped by the screws **69**.

The pump of the present invention is ideally suited to function as an artificial heart since the sacks or bags **76** and **77** correspond to the ventricles of the human heart. Assuming that the sack or bag **76** corresponds to the right ventricle and the sack or bag **77** corresponds to the left ventricle, it will be appreciated that the inlet valve **83** for the right ventricle corresponds to the tricuspid valve of the human heart, whereas the inlet valve **83** for the sack or bag **77** corresponds to the mitral valve. The outlet valve **80** for each of the sacks or bags **76** and **77** correspond to the semilunar valves for controlling the flow of blood from the ventricles to the outgoing arteries.

In order to duplicate the relaxing and filling phase called the diastole, the pump is permitted to assume its free position with the springs **36** biasing the diaphragms **33** outwardly. The contracting and pumping phase called the systole is duplicated by energizing the wire windings **21** whereupon the compression of the hydraulic fluid in the chamber **86** will contract the flexible plastic bags **76** and **77** to pump the fluid contents of the bags outwardly.

Conventional electromagnetic pumps are not satisfactory for use as artificial hearts since the magnets in the pump are continually charged and discharged and the charging phase is generally utilized to suck the pumping medium into the pump. In duplicating the action of the human heart, of course, the reverse is required since only weak suction stroke is needed to get blood into the heart, but a strong pressure stroke is required to discharge blood to the points of utilization.

The present pump with its characteristic of an increasing pulling force as the plunger is drawn inwardly permits the pressure in the chamber 86 to build up in proportion to the amount of travel of the plunger 28, thereby insuring a strong delivery force.

The entire structure of the present invention lends itself to the compactness required of an artificial heart since the six sided unit shown herein is approximately four inches in diameter. Furthermore, since the operation of the pump is electrical, the conductor wires 22 and 23 can be connected to any suitable external controls for duplicating the variable characteristics in a typical heart action.

In order to facilitate quick connection of the pump 10 into the circulatory system of the human body, suitable conduit connection means may be provided for the conduits 78, 78 and 79, 79. For example, as shown in FIGURE 8, a bushing 101 is provided having a tapered portion 102 and a connecting portion provided with an annular row of spikes 103. A vein or artery shown at 104 is quickly attached to the bushing 101 by merely inserting the spiked end into the blood vessel.

A mating bushing 106 having an oppositely tapered connecting portion 107 is fastened to a conduit member 108, as shown in FIGURE 9. Thus, the artificial heart can be quickly incorporated into the circulatory system of the human body so that one of the ventricle-like sacks or bags 76 and 77 can take blood from the body and pump it to the lungs, whereas the other ventricle-like sack or bag 76 and 77 can collect blood from the lungs and pump the same outwardly to the body. Thus, the pump 10, like the human heart, really comprises two pumps in one, both operable simultaneously in a positive pulsing action accomplished by a uniformly applied hydraulic pressure.

Although minor modifications might be suggested by those versed in the art, it should be understood that I wish to embody within the scope of the patent warranted hereon all such modifications as reasonably and properly come within the scope of my contribution to the art.

I claim as my invention:

1. A pump for an artificial heart comprising a plurality of magnets disposed in an annular row, each magnet having an outside conically-shaped body frame and a centrally disposed tubular member, wire windings inside of said frame around said tubular member, a plunger slidably fitted in said tubular member and biased inwardly when said wire windings are energized, means forming a flexible diaphragm wall on said body frame and connected to one end of said plunger, a compression spring operatively disposed between said body frame and said diaphragm to normally preload said diaphragm outwardly to an extended position when said wire windings are not energized, a toothed rack connected to and movable with said plunger, an idler gear rotatably carried by said body frame and meshing with said rack, and a sun gear rotatably mounted at the center of said plurality of magnets and meshing with all of said idler gears to synchronize the respective movements of said magnets, means forming dome-shaped covers extending across opposite sides of said body frame and together with said diaphragms forming an enclosure adapted to be charged with liquid, and a pair of liquid-impervious flexible bags in said enclosure immersed in the liquid contained in said enclosure, each of said flexible bags having a separate valve-controlled inlet and outlet, whereby temporary energization of said magnets will move said diaphragms inwardly to contract said flexible bags under pressure and develop a pumping action.

2. A pump for an artificial heart comprising first and second plastic sacks corresponding to the right and left ventricles of the human heart, an inlet for said first sack having a check valve therein corresponding to the tricuspid valve of the right ventricle in the human heart, an inlet for said second sack having a check valve therein corresponding to the mitral valve of the left ventricle in the human heart, separate outlets for each of said first and second sacks each having a valve therein corresponding to the semilunar valves of the human heart for controlling the outward flow of fluid from the sacks, means forming a variable volume chamber confining said first and second sacks and said chamber being charged with a liquid to surround said sacks therewith, said variable volume chamber means including movable wall means temporarily reducing the volume of said chamber to contract said sacks under liquid pressure and forcing fluid within said sacks outwardly under increased pressure through said valves corresponding to the semilunar valves of the human heart, and conduit means connected to said inlets and to said outlets for joining the pump to the blood vessels of a human being.

3. A pump comprising a variable volume casing having a flexible enclosure means therein forming a pumping chamber, said flexible enclosure means having a valve-controlled inlet and outlet, and a plurality of actuating members disposed in an annular row in said casing, each of said actuating members being radially movable and connected to a casing wall means for temporarily reducing the volume of said casing, and liquid means in said casing acting on said flexible means upon radial inward movement of said actuators and said casing wall means to reduce the internal volume of said pumping chamber, thereby to forcibly pump the contents thereof outwardly through said valve-controlled outlet, and synchronizing means for operating all of said actuating members in unison through a cycle comprising a pumping stroke and a return stroke.

4. A pump comprising casing having a flexible enclosure means therein forming a pumping chamber, said flexible enclosure means having a valve-controlled inlet and outlet, and a plurality of actuating members disposed in an annular row in said casing, each of said actuating members being radially movable, and means acting on said flexible means upon radial inward movement of said actuators to reduce the internal volme of said pumping chamber, thereby to forcibly pump the contents thereof outwardly through said valve-controlled outlet, and synchronizing means for operating all of said actuating members in unison through a cycle comprising a pumping stroke and a return stroke, said synchronizing means comprising a center sun gear rotatable in said casing, a rack connected to each actuating member and a gear in said casing for each actuating member simultaneously meshed with said sun gear and with a corresponding rack, thereby to synchronize the actuating members for unison movement.

5. A pump comprising a casing having a flexible enclosure means therein forming a pumping chamber, said flexible enclosure means having a valve-controlled inlet and outlet, and a plurality of actuating members disposed in an annular row in said casing, each of said actuating members being radially movable, and means acting on said flexible means upon radial inward movement of said actuators to reduce the internal volume of said pumping chamber, thereby to forcibly pump the contents thereof outwardly through said valve-controlled outlet, and synchronizing means for synchronizing all of said actuating members in unison through a cycle comprising a pumping stroke and a return stroke, said synchronizing means comprising a center sun gear rotatable in said casing, a rack connected to each actuating member and a gear in said casing for each actuating member simultaneously meshed with said sun gear and with a corresponding rack, thereby to synchronize the actuating members for unison movement, said sun gear and said casing having pin and recess means affording relative rotational movement but forming a stop to limit the length of stroke of said actuating members.

6. A pump comprising a casing having an annular row of movable diaphragms formed in the outer wall thereof, a pair of flexible sacks in said casing each having a separate inlet and a separate outlet, magnetic actuating means in said casing each connected to a corresponding dia-

phragm, synchronizing means interconnecting said magnetic actuating means for unison operation, and a charge of liquid in said casing surrounding said sacks and acted upon by said diaphragms to transfer pressure evenly to said sacks, thereby to contract said sacks for a pumping action.

7. A pump comprising a casing having an annular row of movable diaphragms formed in the outer wall thereof, a pair of flexible sacks in said casing each having a separate inlet and a separate outlet, magnetic actuating means in said casing each connected to a corresponding diaphragm, synchronizing means interconnecting and actuating means for unison operation and a charge of liquid in said casing surrounding said sacks and acted upon by said diaphragms to transfer pressure eventy to said sacks, thereby to contract said sacks for a pumping action, and a thin flexible covering of chemically inert sheet form material around the outside of said casing.

8. A pump comprising flexible means forming an expansible and contractible pumping chamber having a valve controlled inlet and outlet, and variable volume casing means confining and acting upon said flexible means in cluding a plurality of movable diaphragm members forming the walls of said casing for pressuring fluid aginst said flexible means, and actuating means including an electromagnet for each diaphragm member and return spring means for actuating said diaphragm members through a cycle of strokes including successive electrically biased pumping and mechanically biased return strokes,

and synchronizing means to insure unison operation of said electromagnets, thereby to alternately contract and expand said flexible means.

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