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Wortman

[11] **3,771,174**

[45] **Nov. 13, 1973**

[54] **ARTIFICIAL HEART UTILIZING BLOOD PULSING FLUID OSCILLATORS**

[76] Inventor: **Donald E. Wortman,** 609 Muriel St., Rockville, Md. 20852

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[52] **U.S. Cl.** ..... **3/1,** 3/DIG. 2, 128/1 D, 128/DIG. 3, 128/DIG. 10, 417/350, 137/81.5

[51] **Int. Cl.** **A61f 1/24**

[58] **Field of Search** ..... 3/1, DIG. 2; 128/1 R, 1 D, 214 R, DIG. 3, DIG. 10; 137/81.5; 417/350

[56] **References Cited**

UNITED STATES PATENTS

3,599,244	8/1971	Wortman	3/1
3,208,448	9/1965	Woodward	128/1 R

Primary Examiner—Richard A. Gaudet
Assistant Examiner—Ronald L. Frinks
Attorney—Edward J. Kelly et al.

[57] **ABSTRACT**

An artificial heart intended for supplementing or replacing the natural heart for circulating blood through the body. The heart relies on the dynamic flow properties of the blood for its operation, utilizing a pair of fluid oscillators in combination with nonpulsitive valveless pumps. The pumps have pressure-volume flow characteristics that simulate the natural heart and the pressure sensitive fluid oscillators increase their frequency in accordance with the flow of blood therethrough.

6 Claims, 5 Drawing Figures

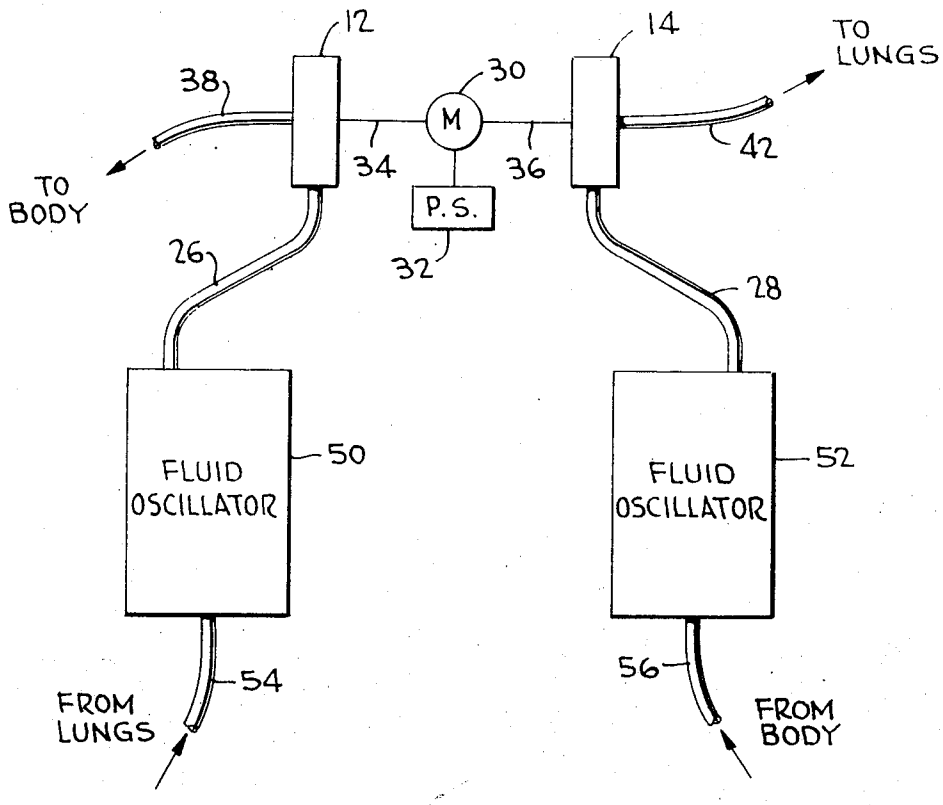


FIG. 1

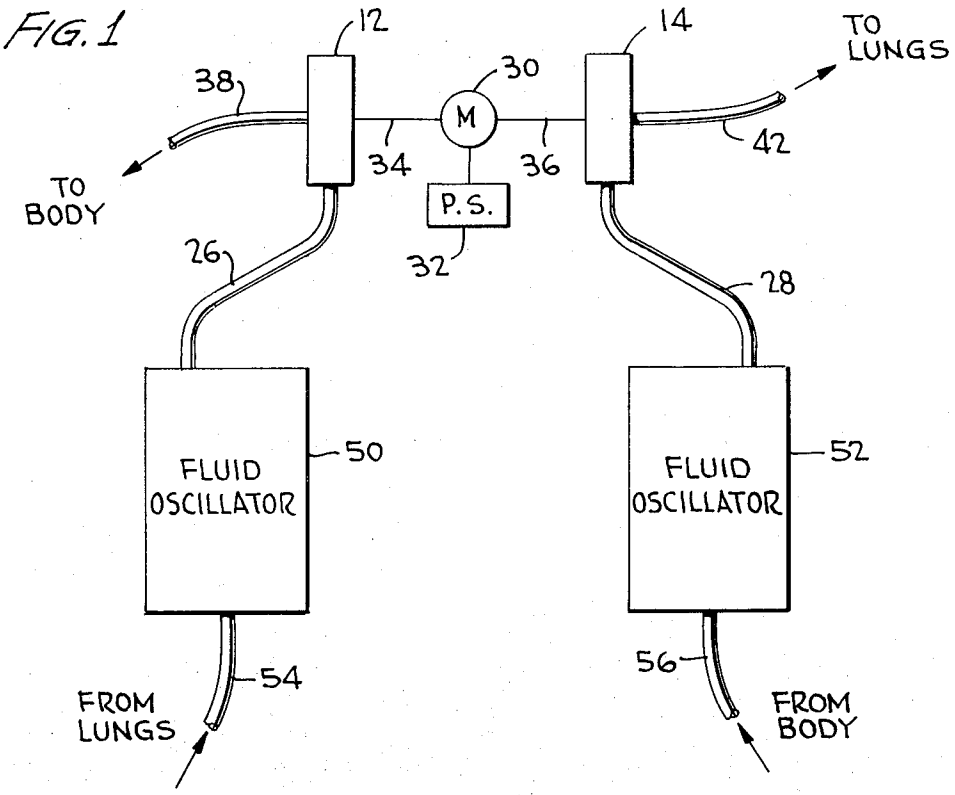

12
14
TO LUNGS
38
30
M
42
34
36
TO BODY
P.S.
32
26
28
FLUID OSCILLATOR
50
FLUID OSCILLATOR
52
56
54
FROM LUNGS
FROM BODY

FIG. 2

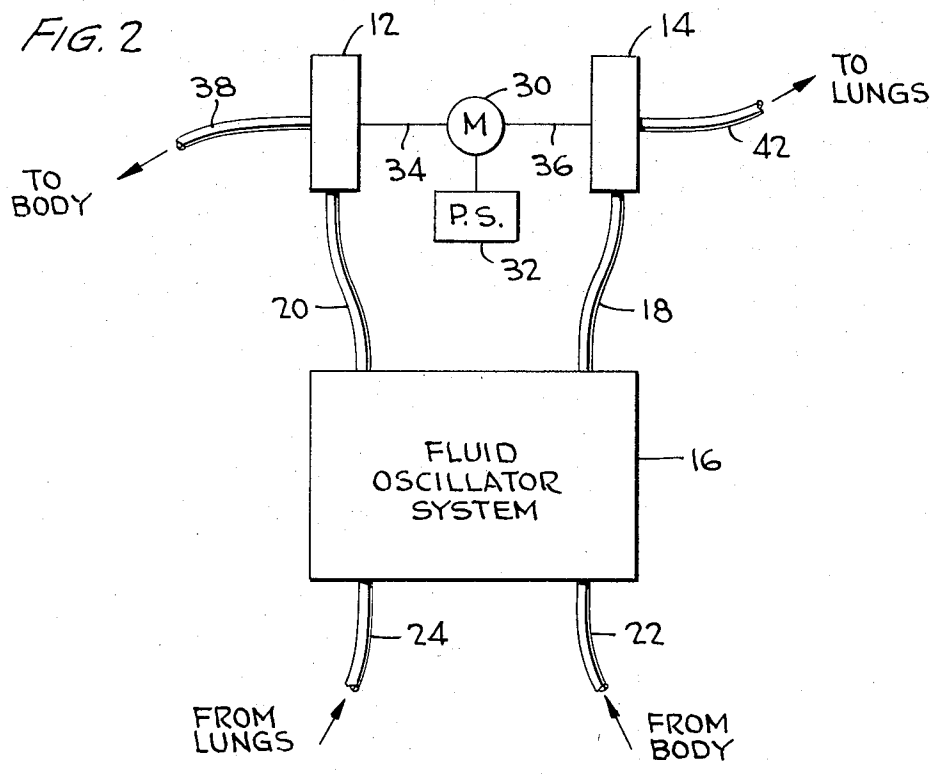

12
14
TO LUNGS
38
30
M
42
34
36
TO BODY
P.S.
32
20
18
FLUID OSCILLATOR SYSTEM
16
24
22
FROM LUNGS
FROM BODY

FIG. 3

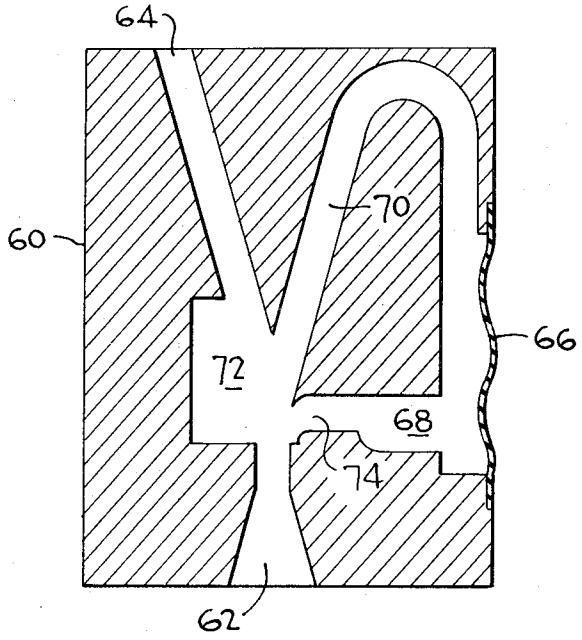


FIG. 4

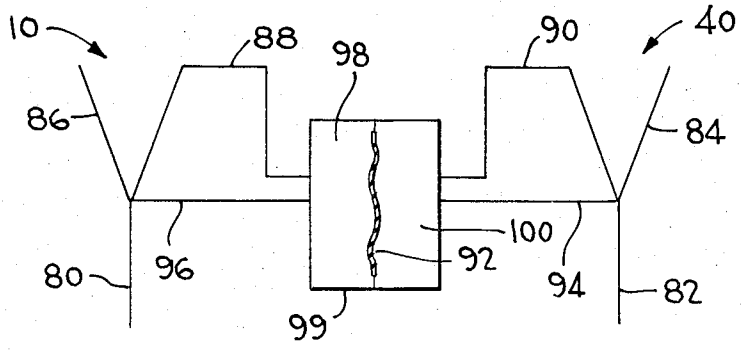
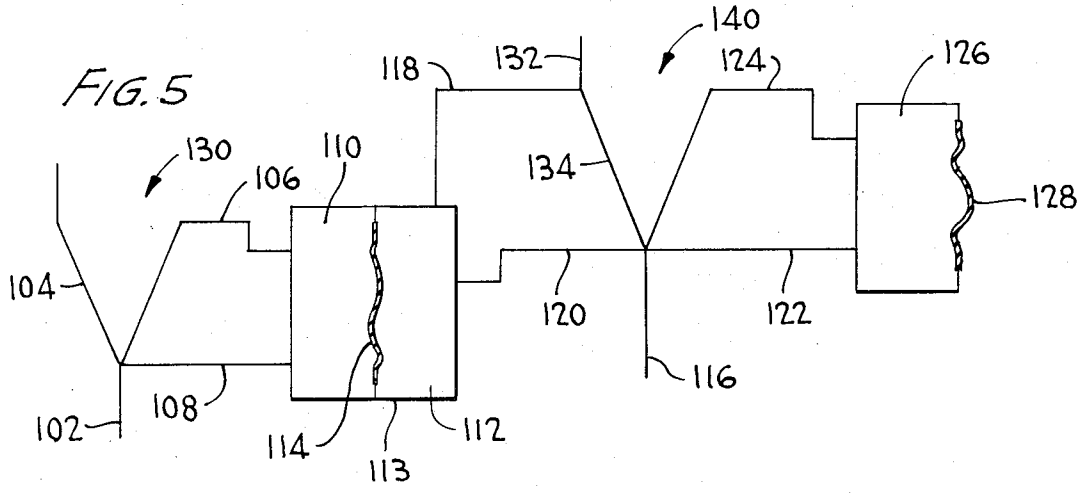


FIG. 5



ARTIFICIAL HEART UTILIZING BLOOD PULSING FLUID OSCILLATORS

RIGHTS OF GOVERNMENT

The invention described herein may be manufactured, used, and licensed by or for the United States Government for governmental purposes without the payment to me of any royalty thereon.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to an artificial heart and more particularly to an electromechanical system that incorporates the principles of fluidics to provide a device for use as a total replacement for or as an aid to the heart in circulating blood throughout the body.

2. DESCRIPTION OF THE PRIOR ART

Devices heretofore developed and intended for use as artificial hearts have fallen far short of their expectations, one reason being their inherent complexity. Earlier embodiments of artificial hearts, while attempting to simulate as closely as possible the action of the human heart, were dependent for their operation upon a multitude of moving parts such as valves, flexible chambers, and displacement-type pumps, plus sophisticated synchronous control systems and sensors for either speeding up or slowing down the pumping action or "heartbeat." Such devices have been found to require relatively large power supplies and to occupy large volumes in addition to being prohibitively expensive, thus detracting from their usefulness as a total replacement organ. Additionally, such devices have not been suited for prolonged service: valves tend to wear out, leak, lose their efficiency and promote blood clots; pumps and collapsible chambers tend to exert large compressive forces upon the blood to the point where the blood would become damaged; and many other moving parts wear out or become inefficient.

It is therefore an object of the present invention to provide an artificial heart that is capable of replacing or aiding the natural heart by completely or partially taking over the operation of pumping blood through the circulatory system.

It is another object of the present invention to provide an artificial heart that is inherently pressure sensitive and thus does not require any external regulating mechanism for long term use.

It is an additional object of the present invention to provide an artificial heart which will be chemically inert and which will not destroy or be destroyed by the blood which it pumps.

A further object of the present invention is to provide a greatly simplified artificial heart that simulates the action of the natural heart to a high degree and yet is valveless and contains no collapsible chambers.

A still further object of the present invention is to provide an artificial heart that is economical to manufacture, has very few moving parts, and does not damage the blood in operation.

An additional object is to provide various embodiments of the artificial heart of the present invention which permits optimum matching of the components controlling the blood flow through the heart with the circulatory system so as to permit the present invention to be adaptable to the individualized requirement of the users.

SUMMARY OF THE INVENTION

Briefly, in accordance with this invention, an artificial heart is provided for use as either a total replacement for the natural heart to be implanted in the chest of the user or as an external supplement during surgery or the like. The device is characterized by a pair of valveless, non-pulsitive fluid pumps each connected to a pressure sensitive fluid oscillator. One set of oscillator and pump receives oxygenated blood from the lungs and directs a pulsed flow to the remainder of the circulatory system of the body. The other set of pump and fluid oscillator receives deoxygenated blood from the general circulatory system and directs a pulsed flow of same to the lungs of the body. The fluid oscillators may be either independent or interdependent, depending on the individualized needs of the user. The pumps are run continuously at a preselected speed and have pressure-volume flow responses which simulate the natural heart. The present invention provides great improvement over the prior art in that it simulates the action of the natural heart and yet has no valves to clog the blood and no collapsible chambers to squeeze or crush the blood, thus minimizing deterioration and wear of the device itself while allowing more efficient and dependable operation.

BRIEF DESCRIPTION OF THE DRAWINGS

The specific nature of the invention as well as other objects, aspects, uses, and advantages thereof will clearly appear from the following description and from the accompanying drawing, in which:

FIG. 1 is a schematic illustration of a preferred embodiment of an artificial heart in accordance with the present invention;

FIG. 2 is a schematic illustriative of another embodiment of an artificial heart in accordance with the present invention;

FIG. 3 shows a fluid oscillator that may be utilized in accordance with the present invention;

FIG. 4 is a schematic illustration of a dual fluid oscillator that may be utilized in the present invention; and

FIG. 5 is a schematic representation of another possible dual oscillator arrangement in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A brief review of the natural heart's pumping action will facilitate understanding of the efficiency with which the present invention simulates the actions of the natural heart.

The heart is a muscular organ divided into four chambers. The upper chamber on each side of the heart is called an auricle and below each auricle is another chamber called the ventricle. Deoxygenated blood from the body enters the right auricle of the heart through two large veins. The blood-filled right auricle then contracts, sending the blood into the right ventricle through the tricuspid valve. The right ventricle then contracts, which simultaneously closes the tricuspid valve and opens the semilunar valve leading to the lungs via the pulmonary artery. From the lungs, oxygen-enriched blood flows into the left auricle through the pulmonary vein. The filled left auricle contracts, forcing blood through the mitral valve into the left ventricle which in turn will contract and force the

flood through another semilunar valve into the aorta which is the main artery to the body.

It is evident that an artificial heart built to the above specifications to operate over an extended period of time would encounter many mechanical difficulties due to inevitable deteriorations of its numerous valves, chambers and contraction apparatus. The present invention, while efficiently carrying out the functions of the natural heart, does not attempt to duplicate its actions. Rather it employs well-known fluidic principles in pressure-sensitive fluid oscillators that provide alternate pulsing to a pair of fluid pumps that respond to pressure input variations as would be the natural heart.

FIG. 1 illustrates in schematic form a preferred embodiment of the artificial heart of the present invention. The system of FIG. 1 is seen to be comprised of two fluid oscillators 50 and 52 which provide a pulsed flow of blood to two fluid pumps 12 and 14, respectively, by way of the conduits 26 and 28, respectively. The input to oscillators 50 and 52 is received from conduits 54 and 56, respectively, which deliver blood from the lungs and from the remainder of the circulatory system, respectively. The oscillators 50 and 52 oscillate at a frequency that varies directly as the flow of blood through the body varies. When the body is at rest, there exists a low blood flow and the frequency of oscillation will automatically lower. When the body is at work and more blood flows in the system, the oscillation will increase in frequency to pump more blood. In other words, the operation of the system is based on the dynamic properties of blood flow. The operation of fluid oscillators 50 and 52 is explained more fully below, but essentially they accept a stream of blood and emit a pulsed flow towards pumps 12 and 14. Pumps 12 and 14 have the characteristics that their outputs are directly related to their input pressure and inversely related to the pressure head against which they are pumping. The pumps thus respond to pressure variations at their inlets 26 and 28 and outlets 38 and 42 in a fashion analogous to the natural heart. One embodiment of a pump possessing such characteristics that could be utilized in the present invention is known in the art as a centrifugal pump. Centrifugal pumps have been shown to pump blood in a highly efficient and non-destructive manner, as evidenced by the F. Dorman et al paper in Volume XV of the TRANSACTIONS OF THE AMERICAN SOCIETY OF ARTIFICIAL INTERNAL ORGANS 1969 entitled "Progress in the Design of a Centrifugal Cardiac Assist Pump with Trans-cutaneous Energy Transmission by Magnetic Coupling." Pumps 12 and 14 are powered by a motor 30 which drives shafts 34 and 36, and a power supply 32. Much effort has been directed towards perfecting implantable motors and power supplies for the use as directed herein, whereas external equivalents are also well known in the art. It is noted in the embodiment presented in FIG. 1 that each fluid oscillator and its respective fluid pump is independent of the other pair. This allows considerable leeway to the engineer and physician in designing and providing the proper flow and pulse in the pulmonary and systemic circulatory systems for the particular user. Since there are an infinite number of selections of pulse rates and phase relations between the pulmonary and systemic circulatory systems and obviously only one such combination would be the optimum for any particular user, such design considerations are of extreme importance. FIG. 2 illustrates another embodiment of the present invention in which there is a single fluid oscillator system 16 that may comprise a pair of fluid oscillators that are coupled in some fashion to interrelate their frequencies and phase to provide a more tightly controlled system which may be desirable in some cases. FIG. 2 is essentially the same system as FIG. 1 with the exception of the interdependence of the fluid oscillators.

FIG. 3 illustrates at 60 a typical fluid oscillator that may be utilized in the embodiment depicted in FIG. 1. Oscillator 60 is comprised of an input 62, a resistance path 70, a capacitance chamber 68, a flexible diaphragm 66, a resistance conduit 74, an interaction region 72, and an outlet 64. In normal operation, fluid will enter input 62 and be biased by interaction region 72 to flow through resistance conduit 70. The fluid will come to rest in capacitance chamber 68. As chamber 68 is filling with fluid, diaphragm 66 will flex outwardly to accommodate a larger portion of fluid. When a certain predetermined volume of fluid is attained in capacitance chamber 68, diaphragm 66 will flex inwardly forcing the fluid in chamber 68 to exit along resistance conduit 74. The fluid exiting along resistance conduit 74 will impact with the stream entering input 62 and deflect said stream to output conduit 64 in the well knowm manner. The frequency of oscillation of oscillator 60 is dependent upon the rate of flow of fluid into the oscillator, the resistance of conduits 70 and 74, and the spring constant of the flexible diaphragm 66 which can obviously be varied for each patient's needs. It is understood that in adapting oscillator 60 to the system of FIG. 1, inlet 54 that receives blood from the lungs would be connected to input 62 and output 64 would be connected to conduit 26 that delivers the pulsed flow of blood to pump 12. A similar arrangement would exist for fluid oscillator 52. Individualized design of oscillator 60 to be adapted to fluid oscillators 50 and 52 presents distinct advantages in providing slight alterations between the frequency and phase of the dual circulatory system.

FIG. 4 represents my unique dual fluid oscillator that was first disclosed in my U.S. Pat. No. 3,599,244. The two back-to-back RCR fluid oscillators 10 and 40 are intended for use in the system depicted in FIG. 2. The oscillators are interdependent by means of the common diaphragm 92 encased in an inclosed chamber 99. Fluid oscillators 10 and 40 each basically operate in a manner similar to the fluid oscillator 60 of FIG. 3. Chamber 99 defines the two capacitance chambers 98 and 100 that are separated by diaphragm 92. In operation, consider the fluid to be entering oscillator 40 through input 82. The flow is initially biased to exit along conduit 90 and fill capacitance chamber 100. The initial emptiness of capacitance chamber 100 implies that capacitance chamber 98 of oscillator 10 is nearly full and diaphragm 92 is bulging to the right. As chamber 100 becomes filled with fluid, diaphragm 92 moves from the right to the left. The increased pressure on diaphragm 92 from the fluid in chamber 100 will help to force the fluid in nearly full chamber 98 to exit through resistance conduit 96 which acts as a control jet for fluid subsequently entering conduit 80. The control jet issuing from conduit 96 will impinge upon the fluid entering conduit 80 and divert it to conduit 86 to exit the system. In actuality, with reference to FIG. 2, conduit 80 will receive oxygen-rich blood from the lungs from conduit 24 and will deliver this blood in a

pulsed fashion from conduit **86** to conduit **20** of FIG. **2** to pump **12.** This emptying action of capacitance chamber **98** continues until chamber **98** is nearly empty and chamber **100** is nearly full. Once diaphragm **92** is fully expanded to the left of chamber **99** no force will be exerted on the fluid remaining in chamber **98** and thus the control jet will cease to issue from conduit **96.** Part of the fluid entering conduit **80** will then reattach to resistance conduit **88** and begin to fill chamber **98** once more. As chamber **98** fills with fluid, diaphragm **92** will move to the right in chamber **99** and exert pressure on the fluid in nearly filled tank **100** forcing the fluid to exit through resistance conduit **94** which now acts as a control jet to impinge upon the main stream of fluid entering conduit **82.** Again referring to FIG. **2,** it is immediately apparent that conduit **82** is connected to conduit **22** that receives deoxygenated blood from the body and conduit **84** sends this deoxygenated blood out conduit **18** to pump **14.** The stream of blood entering conduit **82** will thus be deflected and attached to conduit **84.** Once the fluid has been nearly emptied from chamber **100** and diaphragm **92** is fully expanded to the right, the control jet from conduit **94** will slow to a trickle and eventually cease. Part of the blood subsequently entering conduit **82** will reattach along conduit **90** and the above cycle will repeat itself. The foregoing description encompasses one cycle in the operation of this embodiment of the artificial heart; i.e. one pulse has issued from each oscillator to each pump. The duration of a single cycle is controlled in part by the dimensions of the resistance conduits and the capacitance chambers which can be varied for each patient's needs. It is apparent that the outputs from conduits **84** and **86** are approximately 180 degrees out of phase with one another.

FIG. **5** illustrates another possible configuration of two fluid oscillators **130** and **140** which are arranged so that their outputs from conduits **104** and **132,** respectively, are approximately in phase. This occurs by virtue of the weak coupling between oscillators **130** and **140** accomplished by means of conduits **118** and **120.** In basic operation, oscillators **130** and **140** are identical to oscillator **60** of FIG. **3,** each having an input conduit **102** and **116,** a resistance conduit **106** and **124,** a capacitance chamber **110** and **126,** a flexible diaphragm **114** and **128,** a resistance conduit **108** and **122,** and an output conduit **104** and **132.** In operation, we can assume that both capacitance chambers **110** and **126** are nearly filled with fluid and thus diaphragms **114** and **128** are flexed to the right. When the diaphragms reach their elastic limit and begin to flex to the left forcing fluid through resistance conduits **108** and **122,** the streams of fluid entering conduits **102** and **116** will be deflected through output conduits **104** and **134,** respectively. As this action commences, a small portion of the fluid exiting along conduit **134** will enter feedback conduit **118** that leads to chamber **112.** Feedback conduit **118** is a high resistance (small diameter) conduit that provides weak coupling between the two oscillators. The larger portion of fluid flowing through conduit **134** exits through output conduit **132** that will lead to a fluid pump as depicted in FIG. **2.** The partial filling of chamber **112** by fluid from feedback conduit **118** will reinforce the emptying action of diaphragm **114** by exerting pressure on its right side. When capacitance chamber **110** is nearly empty, the fluid exiting along with resistance conduit **108** will cease and fluid entering input conduit **102** will reattach to resistance conduit **106** and begin to fill capacitance chamber **110** once again forcing diaphragm **114** to the right. This will cause any fluid that has gathered in chamber **112** to exit along feedback conduit **120.** This flow from conduit **120** will impinge upon the fluid entering conduit **116** and re-enforce its natural shift to resistance conduit **124** such that capacitance chamber **126** begins to fill again. It is seen by the foregoing action that fluid will fill chamber **110** and **126** at approximately the same time and will subsequently exit along conduits **104** and **132** in phase. This is but one other example of two interdependent fluid oscillators that are adaptable within the system of FIG. **2.**

During the alternate pulsing of the oscillators in the system of FIG. **1** or **2,** pumps **12** and **14** will run continuously at the same speed. The pumps will pump only that blood that is present at their inlet. Thus if the blood pressure increases or decreases and forces the frequency of oscillation to do likewise, the pumps would automatically adjust to the change in pulsatile flow. The entire heart can be constructed of a material that is noncorrosive, has nonoccluding surfaces, and does not damage the blood in any way.

From the foregoing it is apparent that I have provided a greatly improved artificial heart capable of assisting the natural heart by complete implantation within the body or for use as an external aid to circulation. The device heretofore described is simple and uncomplicated, relying on the dynamic flow properties of the blood for its operation. No valves or collapsible chambers are used, which makes the device less susceptible to wear and tear while ensuring further that the blood remains undamaged.

I wish it to be understood that I do not desire to be limited to the exact details of construction shown and described, for obvious modifications will occur to a person skilled in the art. For example, the positions of pumps and oscillators could be interchanged if greater compliance with the circulatory system could be attained.

I claim:

1. An artificial heart comprising:

a. first means for pumping oxygenated blood from the lungs of a body to the remainder of the circulatory system of said body;

b. second means for pumping deoxygenated blood from said remainder of said circulatory system to said lungs;

c. a first independent fluid oscillator for receiving oxygenated blood from said lungs and emitting said oxygenated blood in a pulsed fashion to said remainder of said circulatory system; and

d. a second independent fluid oscillator for receiving deoxygenated blood from said remainder of said circulatory system and emitting said deoxygenated blood in a pulsed fashion to said lungs;

e. said first pumping means connected in series with said first fluid oscillator and said second pumping means connected in series with said second fluid oscillator.

2. The artificial heart of claim **1,** wherein each of said fluid oscillators comprises:

a. an input conduit for receiving a mainstream of blood;

b. a capacitance chamber to store the blood received from said input conduit until a certain volume therein is attained;

c. a control conduit for transmitting the blood from said capacitance chamber to deflect said mainstream of blood; and

d. an output conduit for receiving said mainstream of blood after its deflection by the blood issuing from said control conduit;

e. said mainstream of blood re-entering said input conduit upon the cessation of flow of blood through said control conduit.

3. The artificial heart of claim **2** wherein each of said fluid oscillators further comprises a flexible diaphragm adjacent to said capacitance chamber, said diaphragm expanding as blood fills said capacitance chamber, said diaphragm contracting upon the attainment of said certain volume of blood in said capacitance chamber to help force blood through said control conduit, said expanding and contracting of said diaphragm tending to create a pulsed output of blood.

4. The artificial heart of claim **3** further comprising means for coupling each of said fluid oscillators to one another whereby their oscillations are approximately in phase with one another.

5. The artificial heart of claim **4** wherein said means for coupling comprises a feedback conduit for transferring blood from the output of one of said oscillators to the capacitance chamber of the other oscillator.

6. The artificial heart of claim **2** wherein each of said pumping means comprises a centrifugal pump.

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