

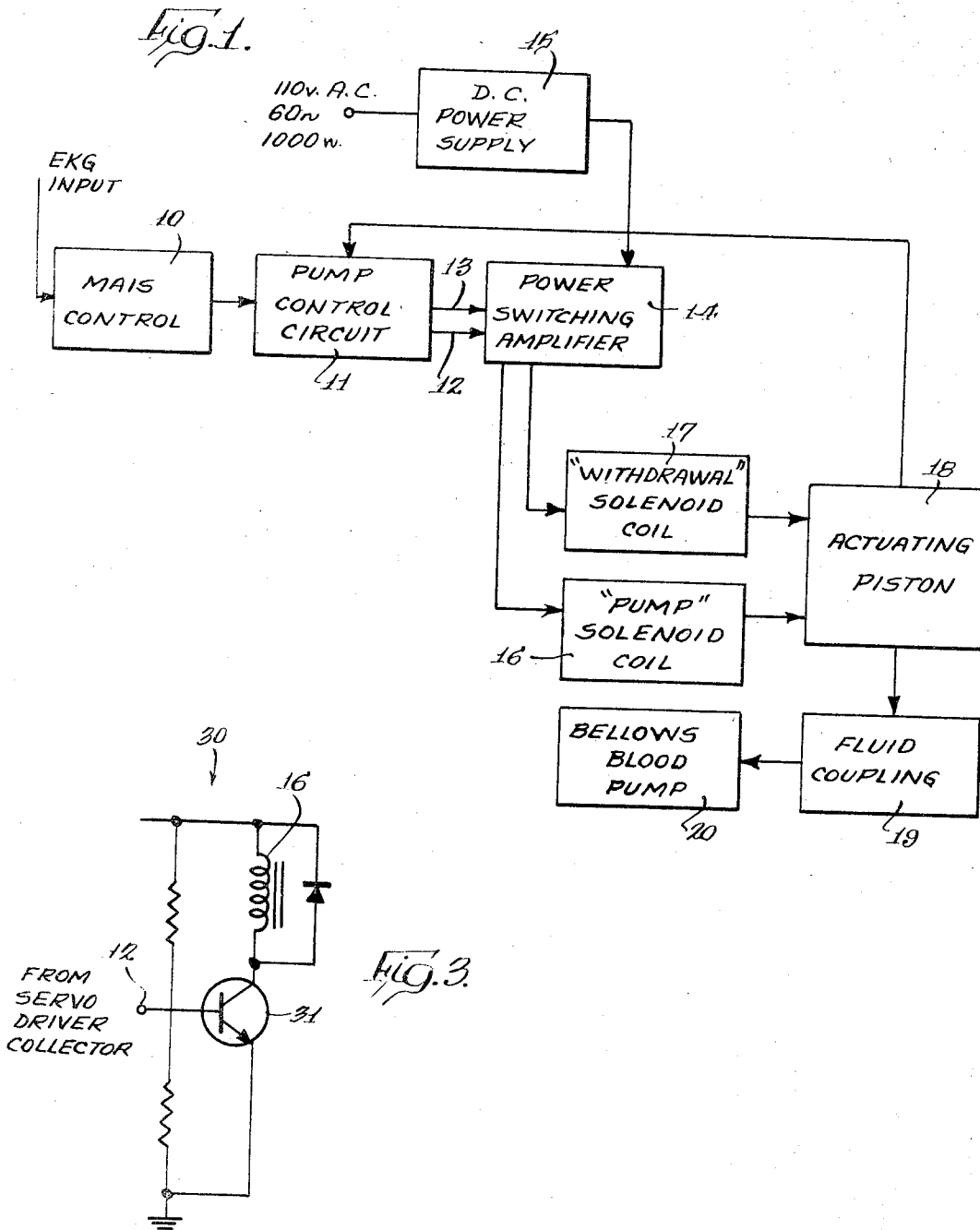
Feb. 18, 1969

M. G. CHESNUT
HEART PUMP ACTUATOR

3,428,042

Filed Aug. 10, 1964

Sheet 1 of 2



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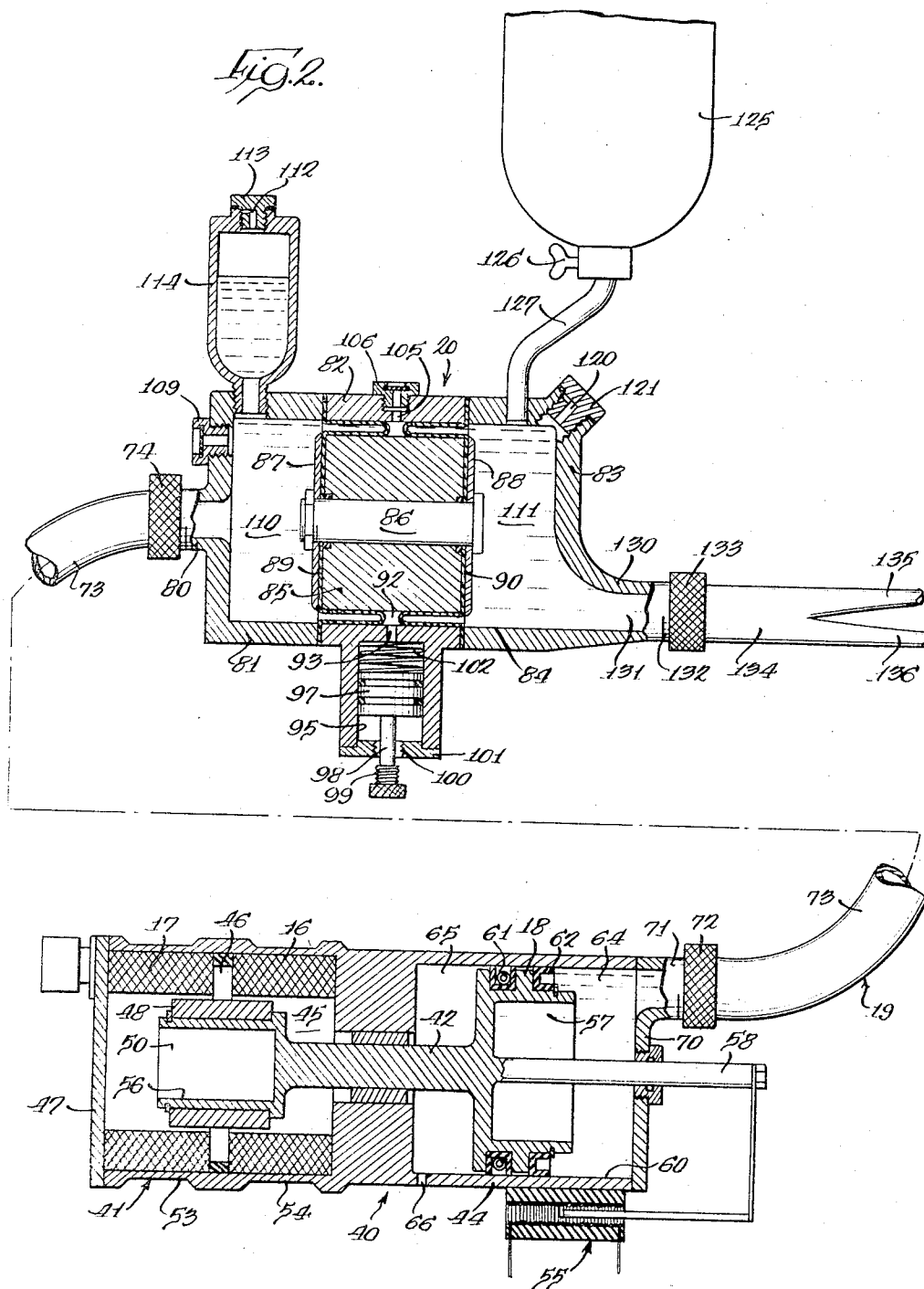
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HEART PUMP ACTUATOR

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10 Claims

Int. Cl. A61m 5/20; A61h 31/00; F04b 9/10

ABSTRACT OF THE DISCLOSURE

A catheter for insertion into a patient's circulatory system communicates blood from one chamber of a bellows pump, the other chamber of the pump driving the pump piston in response to fluid pressure communicated thereto from a positive displacement actuator pump which includes a pump (pressure) coil and a withdrawal (suction) coil mounted in one of two chambers, in magnetic communication with an armature reciprocally mounted in the other of said chambers. The armature has a stroke rate responsive to the magnitude of current in the coils, and is provided with a hollow recess so as to reduce its mass and, therefore, the delay time of the actuator pump. The other chamber has a pump piston reciprocally disposed therein which is rigidly connected to the armature, the piston also having a recess or cavity so as to reduce its inertia. Grooves provided in the housing of the pump adjacent the coils control the flux path between the coils and the armature so as to provide linear operation.

BACKGROUND OF THE INVENTION

Field of invention

This invention relates generally to a device for assisting the natural action of a defective heart. More particularly, it concerns an apparatus for assisting insufficient natural heart action by synthesizing the parameters of the patient's physical heart wave form.

The present invention relates to an improvement in the actuating mechanism shown in the copending application of Chesnut and Ball, Ser. No. 347,500, filed Feb. 26, 1964. This copending application relates to a heart-assisting system in which an open ended cannula is inserted into the descending aorta and expanded and contracted in timed relation to the patient's natural heart beat as derived from one of the patient's physiological parameters, such as the EKG wave form.

Description of the prior art

Heart pumps fall into two general categories; those which augment the natural heart action by operating in series with the natural heart, and those which either partially or totally bypass the heart. The present system, and that disclosed in Ser. No. 347,500, are of the augmentation type and in counter distinction to the bypass type system operate in series with the heart while the heart is actually beating and supplying blood to the arterial tree. The series or augmentation type systems reduce the work load of the heart by lowering the pressure head against which the ventricle must eject its contained blood, and aid the coronary circulation by increasing the blood flow during the correct phase of the natural heart cycle. This phase corresponds to the period of time when the resistance in the coronary circulation is at a minimum and has been found to be in, what is described as, a post systolic period. Consequently, in the augmentation system the flow and pressure developments are very accurately phased in timed relationships to the normal beating ac-

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tion of the heart, in counter distinction to the parallel or bypass systems which have been used in the past for by-passing blood from the veins to the arteries when the heart may be arrested.

In the augmentation or series system described in Ser. No. 347,500, a reciprocating piston pump, phased with the patient's EKG wave form, delivers fluid to and withdraws fluid from the patient's aorta to achieve a controlled pressure wave form in the patient's circulatory system. To achieve complete control over the patient's synthesized pressure wave form, it was found desirable to control the length of stroke, the speed of stroke, and the delay time of the reciprocating piston artificial heart pump. The present invention relates to an actuator for driving the reciprocating piston heart pump particularly designed for operating room use and combining the advantages of fast response time, accuracy, and simplicity of construction.

As utilized in the operating room, the augmentation type system consists of three basic physical components, the reciprocating pump, an actuator for the pump, and a control console for directing predetermined commands to the actuator for controlling the motion of the pump. As the catheters which supply and withdraw fluid from the aorta are most advantageously inserted into the patient's femoral arteries, the pump itself is usually placed between the patient's legs on the operating table during surgery or treatment. It has been found that when a hydraulic actuator is used, a plurality of hydraulic and electric control lines must run from the control component, which may house the source of hydraulic fluid, and the actuator located on the operating table, and this may, in some instances, result in there being too much apparatus and too many hydraulic lines around the operating table thereby interfering with the surgeon's and technicians' work which during the operation must be directed wholly to the patient rather than the equipment and apparatus.

Summary of invention

It is, therefore, a primary object of the present invention to provide a new and simplified actuator for a reciprocating pump heart augmentation system.

It is another object of the present invention to provide a new and simplified electric actuator for a reciprocating pump heart augmentation system permitting the reciprocating pump to be physically separated from the actuator and its associated circuitry so that only the reciprocating pump need be in the immediate vicinity of the operating table.

Another object of the present invention is to provide an electric actuator for driving a reciprocating heart pump in an augmentation type heart pump system which accurately controls all the pumping parameters.

A further object of the present invention is to provide an electric actuator for use in an augmentation heart pump system wherein the control circuit is responsive to the patient's physiological parameters.

According to the present invention there is provided a push-pull type reciprocating electric actuator pump and a fluid coupling for a reciprocating heart pump. By utilizing a fluid coupling, the electric actuator pump may be placed to the side of the operating room and a single fluid line may be connected between the actuator and the reciprocating piston pump thereby providing a simplified pumping apparatus with an extremely fast response time due to the utilization of hydraulic fluid having a high bulk modulus.

Other objects and advantages will become readily apparent from the following detailed description taken in connection with the accompanying drawings.

Brief description of the drawings

FIG. 1 is a schematic diagram of the complete heart augmentation system;

FIG. 2 is a cross sectional elevation of the heart pump and the electric actuator connected by a fluid coupling; and

FIG. 3 is an electric circuit diagram showing a portion of the power switching amplifier in FIG. 1.

Description of the preferred embodiment

While an illustrative embodiment of the invention is shown in the drawings and will be described in detail herein, the invention is susceptible of embodiment in many different forms and it should be understood that the present disclosure to be considered as an exemplification of the principles of the invention and is not intended to limit the invention to the embodiment illustrated. The scope of the invention will be pointed out in the appended claims.

Referring to FIG. 1 wherein the overall augmentation system is shown in block diagram form, a myocardial augmentation instrumentation system (hereinafter referred to as MAIS) control, generally designated by numeral 10, receives an input signal from a suitable source, such as an electrocardiogram, which monitors one of the patient's physiological parameters. The MAIS control 10 shapes the input pulse, filters unwanted signals therefrom, and delays the input pulse behind a selected portion of the physiological input signal so that the pump cycle may be delayed therefrom in accordance with the surgeon's desired augmentation technique. An output pulse from the MAIS control energizes the pump control circuit 11 wherein suitable adjustments may be made by the surgeon to vary the length of pumping stroke and the speed of pumping on both pump and withdrawal strokes. The specific circuitry of the MAIS control 10 and the pump control 11 are described in detail in Ser. No. 347,500, and it is unnecessary to go into the circuitry therein as these components form no part of the present invention. However, it is important to note that the pump control circuit produces a signal on each of the pumping and withdrawal strokes of the heart pump, the duration of which dictates the length of stroke of the pump and the magnitude of which dictates the speed of the heart pump during each stroke. The pump control signal is indicated by the numeral 12 and the withdrawal control signal is indicated by the numeral 13, both of which are supplied to a power switching amplifier 14.

A D.C. power supply 15 of a suitable design delivers approximately 1,000 watts to the power switching amplifier 14 at a voltage level of approximately 50 v. D.C., these levels being merely exemplary. The power supply 15 may consist of an input transformer, a full wave rectifier, and conventional filtering if desired.

The power switching amplifier 14 drives alternatively the pump solenoid coil 16 and the withdrawal solenoid coil 17 in accordance with the values set by the surgeon or technician in the MAIS control 10 and the pump control circuit 11. The solenoid coils 16 and 17, described in more detail below, are responsive to both the magnitude and duration of the signal from the power switching amplifier 14 to drive an actuating piston 18 at a preselected speed to a preselected length of stroke. The actuating piston 18 delivers and withdraws hydraulic fluid from a fluid coupling 19 which is connected to drive a bellows blood pump 20.

Referring to FIGS. 1 and 3, the power switching amplifier 14 consists of two transistor circuits 30, one for the pump stroke and one for the withdrawal stroke, each having a power transistor 31 connected at its base to receive one of the pump or withdrawal control signals 12 or 13 from the pump control circuit 11. The pump solenoid coil 16 is connected to the collector of transistor 31 so that the amount of base current drive to the power switch-

ing transistor 31 dictates the collector current driving the solenoid coil 16 thereby controlling the magnitude and duration of the signal in the pump solenoid coil. While FIG. 3 is described with respect to the pump control signal, the identical operation applies to the withdrawal power switching transistor which is not shown. It is understood that the pump control circuit only energizes one of the power switching amplifier circuits 30 depending upon the direction in which the blood pump 20 is moving.

Viewing FIG. 2, an electric actuator 40 supplies hydraulic fluid to the pump 20 and includes a push-pull type solenoid 41, a shaft 42 and the actuating piston 18. A housing 44 encloses all of the components of the electric actuator 40. The solenoid coils 16 and 17 are mounted within a cylindrical bore 45 in one end of the housing 44 and are separated by a suitable retaining ring 46. The coils are secured in the cylinder or bore 45 by an end cap 47 which closes one end of housing 44. An armature 50 is slidably mounted within the coils 16 and 17 and includes a cylindrical core 48 mounted on an enlarged end of shaft 42. Annular grooves 53 and 54 are formed in the housing 44 and define narrow saturating sections that direct the flux path to achieve approximately linear force versus stroke in the solenoid 41. These sections limit the gap flux when the armature reaches a position close to either end of the bore or cylinder 45. The amplitude of the signal in one of the coils 16 or 17 controls the speed of the armature 50 and thereby the rate of flow of fluid delivered by the actuator piston 18 to the pump 20. Also, the coils will continue to drive the armature 50 at the predetermined speed until the pump control circuit 11 switches the control signal to the other coil. This is in counter distinction to a positioning type system based upon the derivation of an error signal. A potentiometer 55 driven by a projection 58 on the shaft 42 produces a signal proportional to the length of stroke of the shaft which is fed back to the pump control circuit 11 for controlling the length of stroke of the piston 18. A linear variable transformer may be used equally well in place of the potentiometer 55.

The shaft 42 connects the armature 50 to the piston 18 and is constructed of a suitable nonmagnetic material, and has counterbores 56 and 57 adjacent the armature 50 and the piston 18 respectively, to eliminate weight which would otherwise cause mechanical time lags. Time lags are particularly undesirable in this system as the heart pump 20 must accurately be synchronized with the patient's selected natural physiological parameter.

The actuating piston 18, formed integrally with shaft 42, is reciprocally mounted in a cylinder 60 in one end of the housing 44 and carries suitable sealing rings 61 and 62. The piston 18 divides the cylinder 60 into a working chamber 64 and a venting chamber 65. Chamber 65 is in continuous communication with the atmosphere through a vent 66 to prevent any back pressure on the piston 18.

The cylinder 60 is closed by an end cap 70 fastened to one end of the housing 44 by suitable means and has formed thereon a threaded nipple 71 which receives a threaded fitting 72 of the hydraulic coupling 19. The hydraulic coupling 19 includes a suitable flexible hose 73 of a synthetic material such as one of the plastics, and carries a threaded fitting 74 at its other end fastened to a threaded nipple 80 formed on the end of a cup-shaped housing member 81 of the bellows pump 20.

The housing of the pump 20 includes the cup-shaped member 81, cylindrical housing member 82 and cup-shaped member 83 secured together by suitable clamps (not shown). Housing members 81, 82 and 83 form a cylinder 84 therein which reciprocally receives a cylindrical floating piston 85. A bolt 86 extending through the piston 85 holds clamping plates 87 and 88 against two rolling diaphragms 89 and 90 thereby sealing the diaphragms against both ends of the piston 85 and insures reliability in the pump. The diaphragms 89 and 90

form an annular chamber 92 between the piston 85 and the housing member 82. Communicating with the annular chamber 92 is a passage 93 formed in the housing 82 which communicates at its lower end with the interior of a cylinder 95 integrally formed with housing member 82. The cylinder 95 receives an evacuating piston 97 having a thumb screw 98 rotatably mounted therein. The lower end of the thumb screw 98 has a threaded portion 99 adapted to engage threads 100 on a cylinder end cap 101 fixed to the cylinder 95. A spring 102 urges the evacuating piston 97 downward. In the upper portion of the housing member 82 a passage 105 formed therein communicates with the annular passage 93 and a fill cap 106.

The evacuating piston mechanism serves to evacuate the annular chamber 92 and assures proper diaphragm rolling action. This mechanism is operated by threading the threaded portion 99 of the thumb screw 98 into the end cap 101 compressing the spring 102 thereby expelling air from cylinder 95, filling the chamber 92 with a blood compatible solution such as "Dextran" through passage 105, replacing the fill cap 106, backing out the thumb screw 98, disengaging the threads 99, thereby permitting the spring 102 to urge the piston 97 downward and thus maintain a low grade vacuum in chamber 93. The low grade vacuum applied by piston 97 insures proper diaphragm rolling action.

Piston 85 divides the cylinder 84 into chamber 110 and chamber 111. Chamber 110, fluid coupling 19 and chamber 64 in the electric actuator 40 are filled with "Dextran" or another blood compatible fluid so that the chamber 111 and the patient's circulatory system are isolated from any substance incompatible with the patient's system.

A fill cap 109 is provided in pump housing member 81. Blood compatible fluid may be injected into the system through the reservoir 114. Air entrained in the fluid is forced out through air vent 112 in a cap 113 threaded in the reservoir 114 mounted on the upper portion of housing member 81. Cap 113, must be unthreaded slightly to expose the vent 112, and may be threaded tightly so that during pumping no air may enter the system.

A vent 120 in a cap 121 threaded in the upper portion of housing member 83 permits air bubbles in the chamber 111 to be expelled from the system when the cap 121 is slightly unscrewed in a manner similar to cap 113. A blood supply reservoir 125 delivers blood through a valve 126 and a conduit 127 to working chamber 111 of the reciprocating pump 20, during priming of the chamber 111, but is normally shut off during the operation of the pump. Chamber 111 may be filled with blood compatible fluid instead of blood.

Housing member 83 has an elongated portion 130 defining an outlet for the pump with an outlet passage 131 for the pump having a threaded portion 132 engaging threads on catheter fitting 133. A flexible catheter 134 has branches 135 and 136 which are open ended.

In operation, the pump 20 is placed on the operating table between the patient's legs and the catheter branches 135 and 136 are inserted into the patient's femoral arteries and gently urged into the descending aorta. Other methods of insertion may be employed such as into the left sub-clavian artery. The desired length of stroke and speed of stroking are selected in the pump control circuit by the surgeon or technician and the MAIS control 10 is connected to receive the patient's physiological signal. The electric actuator 40 is conveniently mounted in the console containing the MAIS control 10, the pump control circuit 11, and the power switching amplifier 14, all of which may be placed away from the operating table. Only a single hydraulic line, i.e. conduit 73, runs from the console to the pump 20 located at the operating table. The pump control circuit energizes withdrawal coil 17 and the piston 18 withdraws fluid from pump chamber 110 at a rate dictated by the magnitude of current in the coil. The piston 85, of course, accurately follows movement of the piston 18 because of the rigid fluid coupling there-

between. When the piston 85 reaches its desired length of stroke, the pump control circuit switches the current through the switching amplifier 14 to the pump coil 16 thereby reversing the direction of travel of the piston 18 and the pump piston 25. The piston 18 then travels toward the right in FIG. 2 in a similar manner as in the withdrawal stroke until the pump control circuit 11 terminates the control signal 12. The pump control circuit 11 then awaits the next EKG input signal through the MAIS control before beginning a new pumping cycle. As the piston 85 reciprocates, it delivers and withdraws blood to and from the patient's aorta through the catheter 134 in the same manner as described in Ser. No. 347,500.

Having thus described an exemplary embodiment of my invention, what is claimed as new and desired to secure by Letters Patent of the United States is:

1. A heart augmentation system, comprising:

a free piston bellows pump having first and second chambers therein, said first chamber adapted for connection to a catheter for insertion into a patient and for communicating blood thereto;

a reciprocating pump having a piston working in a drive chamber, said pump having a suction stroke and pressure stroke adapted to draw fluid into and eject fluid from said drive chamber, respectively;

and a pressurized fluid communication line between the drive chamber of said reciprocating pump and the second chamber of said bellows pump, said line coupling the action of said reciprocating pump to said second chamber of said bellows pump so that blood is forced into and out of said first chamber of said bellows pump in response to fluid pressure communicated to the second chamber of said bellows pump by said reciprocating pump through said line.

2. In a heart augmentation system as defined in claim 1 means connected to said first chamber of said bellows pump for supplying additional blood to the circulatory system.

3. A heart augmentation system according to claim 1 additionally comprising:

a switching amplifier for controlling the flow of the current to said electric solenoid;

and a control circuit connected to said switching amplifier synthesizing the desired characteristics of said bellows pump.

4. A heart augmentation system according to claim 1 wherein said reciprocating actuator pump further comprises:

a housing of magnetic material having an armature slidably mounted therein;

first and second coils in said housing for moving said armature in respective first and second directions, said coils and said armature comprising the driving solenoid for said actuator pump, relative movement of the armature being responsive to the magnitude of the current in said coil;

said drive chamber comprising a cylinder located within said housing, said armature being rigidly connected to said piston;

said housing having annular grooves adjacent said first and second coils for maintaining a substantially linear relation between the force on the armature and the rate of movement of the armature.

5. In a heart augmentation system for assisting natural heart action; a catheter adapted to be inserted into the patient's circulatory system, a pump connected to said catheter having a pump and a withdrawal stroke for supplying blood to the circulatory system; an electric actuator for controlling movement of the pump including a housing having two chambers therein, a pump coil and a withdrawal coil mounted in one of said chambers, an armature having windings thereon reciprocally mounted in said one chamber, the other of said chambers defining a cylinder, an actuator piston mounted in said cylinder, a

shaft rigidly connecting the armature and the actuator piston, saturation means for controlling the flux path, and an outlet in said other chamber adjacent said piston; and a flexible conduit connecting said outlet to said pump having hydraulic fluid therein thereby providing a rigid fluid coupling between the actuator and the pump.

6. In a heart augmentation system a catheter adapted to be inserted into the patient's circulatory system, a blood pump connected to said catheter having a reciprocating piston; an actuator for controlling movement of the pump piston including a housing having two chambers therein, a pump coil and a withdrawal coil mounted in one of said chambers, an armature reciprocally mounted in said one chamber within said coils, said armature having a stroke rate responsive to the magnitude of current in said coils, said armature also having a hollow section to reduce the delay time of the actuator, the other of said chambers defining a cylinder, an actuator piston mounted in said cylinder and adapted to deliver and withdraw fluid from said reciprocating pump, said actuator piston being rigidly connected to said armature, a hollow section within said piston to reduce the delay time of the actuator, grooves in the housing adjacent the pump and withdrawal coils for controlling the flux path between the coils and the armature, and an outlet fitting in said other chamber adjacent said actuating piston; and a fluid coupling connecting said outlet fitting and said blood pump.

7. In a heart augmentation system the combination of; a catheter adapted to be inserted into the patient's circulatory system; a pump for supplying blood to the circulatory system including a housing having a first end member, a central member, and a second end member fixed to said central member, a cylinder in said housing, a floating piston slidably mounted in said cylinder, a first diaphragm mounted between said first end section and said central section on one side of said piston, a second diaphragm mounted between said central section and said second end section on the other side of said piston, means on the housing for evacuating the space between the diaphragms thereby effecting a rolling of the diaphragm reciprocation of the piston, a fitting member on said second end section connected to the catheter adjacent the working end of the piston, a second fitting on said first section of the housing adjacent the driven end of the piston; an electric actuator for driving the blood pump piston including a housing having two chambers, pump and withdrawal coils mounted in one of said chambers, an armature slidably mounted in said one chamber adjacent said coils, an actuator piston connected to said armature and adapted to deliver fluid to one end of the blood pump piston, said actuator piston being rigidly connected to said armature; a fluid coupling connecting said actuator piston and said second fitting whereby the pump piston is driven by the actuator, and control circuit means for alternatively energizing said coils and controlling the magnitude of current to said coils to vary the speed of movement and length of movement of the armature and the pump.

8. A reciprocating pump for a heart augmentation system comprising a housing, a piston reciprocally mounted in said housing, a first diaphragm mounted in said housing covering one end of said piston, a second diaphragm spaced from said first diaphragm mounted in said housing and covering the other end of said piston, and means to evacuate the space between said diaphragms, said evacuation means comprising a piston and cylinder mounted adjacent said housing.

9. A reciprocating pump for a heart augmentation system as defined in claim 8 wherein said means to evacuate the space between the diaphragms includes an opening through said housing communicating with said space permitting fluid to be injected in said space, a closure for said opening, a cylinder mounted on said housing communicating with said space, an evacuating piston slidably mounted in said cylinder, resilient means urging said piston toward one end of the cylinder in a direction to evacuate said cylinder, and means for holding said piston at the other end of said cylinder so that the space between the diaphragms may be filled with fluid and closed before the resilient means evacuates the space.

10. A reciprocating pump for a heart augmentation system as defined in claim 8 wherein said means to evacuate the space between the diaphragms includes an opening through said housing communicating with said space permitting fluid to be injected in said space, a closure for said opening, a cylinder mounted on said housing communicating with said space, an evacuating piston slidably mounted on said cylinder, a spring mounted in said cylinder engaging said piston to one end of the cylinder in a direction to evacuate the cylinder, a member rotatably mounted in one end of the piston and having a threaded portion engaged with said one end of the cylinder, said threaded portion being spaced from said one end of said piston whereby when the threads are engaged, the spring is compressed and air is exhausted from the cylinder.

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