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ARTIFICIAL HEART CYCLING SYSTEM

Filed Oct. 15, 1964

FIG. 1

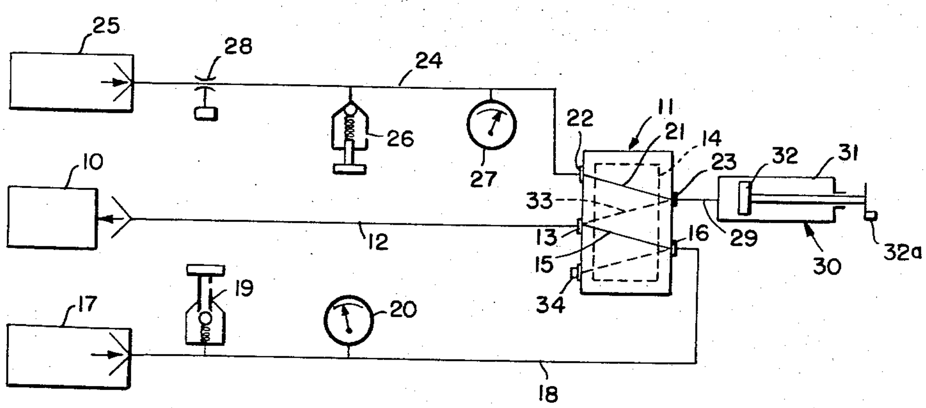
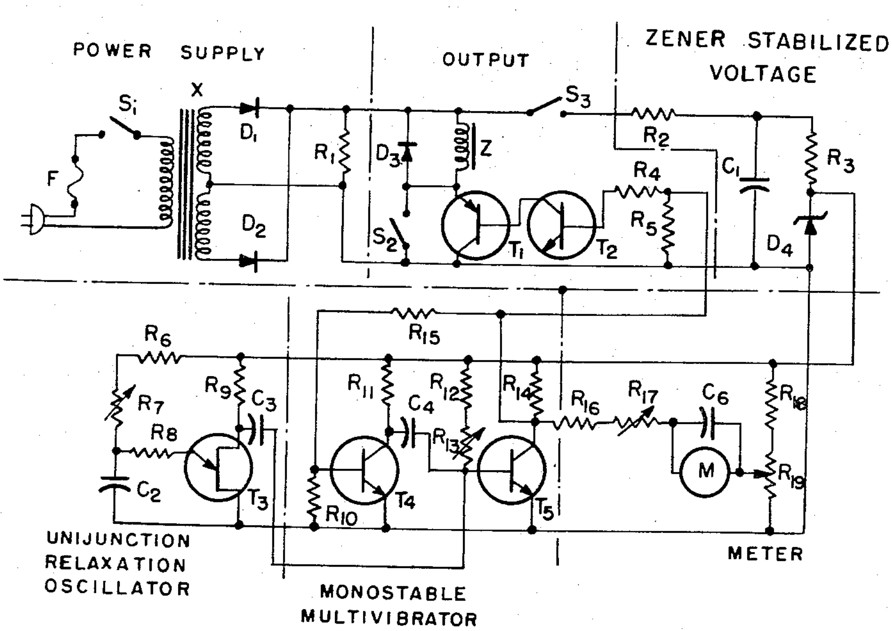


FIG. 2



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ARTIFICIAL HEART CYCLING SYSTEM
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ABSTRACT OF THE DISCLOSURE

An artificial heart pump apparatus which is not subject to valve-stiction catastrophe. The apparatus includes a pump, a pressure source, a reservoir, suction source, and a spring driven spool valve. When the valve is in the unactivated condition, the spool is urged by the spring to a first position which connects the pump to the suction source and the pressure source to the reservoir. The valve may be activated by means of a solenoid coil and an electrical circuit so that the spool is moved to a second position in which the pump is connected to the reservoir. The electrical circuit is adjustable to energize the solenoid at a desired repetition rate.

Background of the invention

This invention relates to artificial heart apparatus and more particularly to a heart pump including novel means for preventing valve-stiction catastrophe through pneumatic isolation of the high pressure source during systole.

Investigations leading toward the design of a chronic artificial heart have the important by-products of (a) developing a valuable tool for studying the physiological and pharmacological responses of the vascular system with a heart of rigidly controlled characteristics, (b) contributing to the growing knowledge of the hemodynamic characteristics of the mammalian heart through study and careful extrapolation of the properties of the simulation model, and (c) advancing the state of the art of perfecting materials and techniques for implanting and maintaining function internal prosthetic devices.

For some time, the workers in the art have supported the concept of transmitting the necessary hydraulic power to the blood by pneumatic methods. The advantages of using pneumatic methods to convert (but not transmit over long distances) primary power into mechanical power originate in large part from the energy storage density afforded by compressed gases. The energy storage densities of electric and magnetic fields rarely exceed 5000 joules per cubic meter with practical capacitors and inductors, whereas 10,000 times this amount can be stored easily in compressed air at 100 atmospheres. One of the main problems heretofore encountered in heart massage study was that the ordinary pneumatic method of metering compressed air into the housing enclosing the collapsible ventricle produced rapid catastrophic results if the valve stuck during systole. It is therefore an object of the invention to provide a pneumatic method for actuating a heart pump which overcomes this difficulty.

Another object is to provide a heart pumping system embodying a multi-port valve and a variable volume storage tank for supplying the required air pressure pulses in short, controllable, repetitive bursts with almost ideally sharp leading edges.

Still another object is to provide an artificial heart apparatus which can be driven at variable rates and duty cycles and still provide a stroke-limiting function.

Other objects and advantages of the invention may be seen in the details of construction and operation set down in this specification.

The invention is explained in conjunction with the accompanying drawing, in which—

FIG. 1 is a schematic representation of the mechanical portion of the artificial heart apparatus, and

FIG. 2 is a wiring diagram showing the electrical components of the apparatus.

In the illustration given and with reference first to FIG. 1 the numeral **10** designates a schematic representation of an artificial heart pump which may take the form of the chamber providing vessel and collapsible bags shown in detail in my copending application Ser. No. 261,426, filed Feb. 27, 1963, now Patent No. 3,182,335, issued May 11, 1965. The pump **10** is coupled to a four way valve generally designated **11** by means of a conduit **12**. The valve advantageously may be a five port solenoid-driven spring-return four-way valve such as is available commercially as Modernair No. BV 40602–B.

As seen in FIG. 1 the port **13** is coupled to the pump **10** by means of the conduit **12**. Further as seen in FIG. 1, the numeral **14** designates a spool movably positioned within the valve **11** and in the position shown has an internal passage **15** coupling the port **13** with a suction port **16**. The suction port **16** is communicated with a source of suction **17** by means of a conduit **18**. Suitably interposed in the conduit **18** is a suction adjustment device or regulator **19** and a meter **20**.

Also when the spool **14** is in the position shown (communicating ports **13** and **16**), a second way or passage **21** in the spool connects ports **22** and **23**. The port **22** is connected by means of a conduit **24** to a source of compressible pressure fluid **25** and also it includes a pressure regulator **26** and meter **27**. Still further, an adjustable restriction **28** is interposed in the conduit **24** and this may take the form of a screw driver-adjustable flow-control valve as marketed under the designation Schrader No. 3250A.

The port **23** is coupled by means of conduit **29** to an adjustably expansible or variable volume reservoir generally designated **30**. The reservoir **30** is seen in the illustrated embodiment to include a cylinder **31** equipped with a piston **32** slidably positioned therein. The piston is equipped with a crank fitting **32*a***.

In the alternative position of the spool **14**, a way or passage **33** (shown in dotted line) couples ports **13** and **23**. The bottom left hand port is closed by a plug **34**.

In the operation of the mechanical system just described, the positioning of the spool **14** as shown couples the compressible pressure fluid source **25** through the way **21** to the reservoir **30**. Simultaneously, the pump is coupled by means of way **15** to suction **17**. This causes a reduction of pressure in the pump allowing the ventricle-simulating means to expand. This is the situation which is contemplated upon power failure, i.e., absence of any actuation of the valve **11**, and thus absence of means whereby pressure fluid from the pressure input **25** can expand the ventricle beyond its failure limit. The spool is urged into the position shown in FIG. 1 by the spring provided as part of the valve.

During normal operation, however, the spool **14** is moved to the alternate position so that the reservoir **30** is coupled to the pump **10** by means of the dotted line way **33**. In this position of the spool **14** both the pressure fluid source **25** and the suction source **17** are disconnected from the pneumatic circuit.

The adjustable constriction **28** provides a means for varying the pressure in the conduit **14** and therefore contributes to the determination of the volume delivered to the pump **10**—by virtue of the extent to which the piston **32** is moved in the cylinder **31**.

The means for reversing or cycling the valve **11** will now be described in conjunction with FIG. 2. In FIG. 2 the central upper portion of the diagram represents an output circuit wherein the symbol Z represents a solenoid coil operatively associated with the valve spool **14**. When the solenoid is energized it moves the spool against the bias of the spring into the alternate position. In the illustration given, the solenoid coil or winding Z is rated at 20 ohms and requires a minimum DC current of 600 milliamperes for switching.

Referring now to the extreme upper left hand corner of FIG. 2, the components F, S, X, D_1, D_2, and R_1 comprise a power supply of rectified (but not filtered) 60 c.p.s. current (13.4 v. RMS). The diode D_3 prevents damaging transient voltage when the solenoid current is operated.

The push-button switch S_2 permits arbitrary manual operation of the valve solenoid, which is otherwise excited by the power-gating action of the PNP and NPN transistors T_1 and T_2 whenever the junction of resistors R_4 and R_5 is raised above its ground reference by a 6-volt step signal.

Such a signal is supplied on a repetitive basis by the remainder of the circuit if switch S_3 is closed.

The components R_2, R_3, C_1, and D_4 supply an 8-volt filtered-and-zener-stabilized, voltage to a unijunction relaxation oscillator and a monostable vibrator (see the bottom left hand and central portion, respectively, of FIG. 2). By means of the components R_6, R_7, R_8, R_9, and C_2, the unijunction T_3 delivers 1.0 msec., negative 7-volt pulses (at a repetition rate determined by the setting of the potentiometer R_7) through C_3 to the monostable multivibrator. The latter circuit, consisting of the components R_{10}, R_{11}, R_{12}, R_{13}, R_{14}, R_{15}, C_R, T_4, and T_5, delivers to the R_4–R_5 junction through C_5 a corresponding train of rectangular pulses, each having an amplitude of about 7 volts and a width determined by the setting of the potentiometer R_{13}.

The remaining components R_{16}, R_{17}, R_{18}, R_{19}, and C_6 allow the percent dutycycle of the pulse train to be displayed on the meter M. The circuit design is such that the range of the adjustable pulse repetition rate is 60–180 beats/minute and the duty cycle range is 0–50 percent.

As a further explanation of the above description of practicing the invention, Table 1 below sets forth a description of the circuit components.

Table 1

F—Fuse, 1.0 a., 150 v.
S1—Switch, 1.0 a., 150 v.
S2—Switch, 1.0 a., 150 v., push button
S3—Switch, 1.0 a., 150 v.
X—Transformer, Pri. 115 v.—60 c.p.s., Sec. 26.8 VCT—1.0 a., (Triad F–40X)
Z—Solenoid, 12 v. DC, 20 ohm (Modernair BV40602B)
M—Meter, DC 0–50 ma., Triplett, Model 221PL
D1—Diode, 750 ma., 30 v. (TI–1N2069)
D2—Diode, 750 ma., 30 v. (TI–1N2069)
D3—Diode, 750 ma., 30 v. (TI–1N2069)
D4—Diode, 8 volt zener
C1—Capacitor, 1000 μf., 15 v.
C2—Capacitor, 10 μf., 15 v.
C3—Capacitor, 1.0 μf., 15 v.
C4—Capacitor, 20 μf., 15 v.
C5—Capacitor, 100 μf., 15 v.
C6—Capacitor, 1000 μf., 15 v.
R1—Resistor, 4.7K, 0.25 w.
R2—Resistor, 120 ohm, 0.5 w.
R3—Resistor, 120 ohm, 0.5 w.
R4—Resistor, 22K, 0.25 w.
R5—Resistor, 22K, 0.25 w.

R6—Resistor, 47K, 0.25 w.
R7—Potentiometer, 250K, carbon
R8—Resistor, 100 ohm, 0.25 w.
R9—Resistor, 1K, 0.25 w.
R10—Resistor, 10K, 0.25 w.
R11—Resistor, 1K, 0.25 w.
R12—Resistor, 2.5K, 0.25 w.
R13—Potentiometer, 25K, carbon
R14—Resistor, 1K, 0.25 w.
R15—Resistor, 10K, 0.25 w.
R16—Resistor, 68K, 0.25 w.
R17—Potentiometer, 25K, carbon
R18—Resistor, 4.7K, 0.25 w.
R19—Potentiometer, 500 ohm, carbon
T1—Transistor, power, PNP, 3 a., 30 v., (Motorola 2N2138)
T2—Transistor, NPN silicon, 20 ma., 30 v., (TI–2N338)
T3—Unijunction, 450 mw., (GE–2N1671A)
T4—Transistor, NPN, silicon, 20 ma., 30 v., (TI–2N338)
T5—Transistor, NPN, silicon, 20 ma., 30 v., (TI–2N338)

While in the foregoing specification, a detailed description of an embodiment of the invention has been set down for the purpose of illustration, many variations in the details herein given may be made by those skilled in the art without departing from the spirit of scope of the invention.

I claim:

1. Artificial heart energy-supply apparatus comprising an artificial heart, a multi-port valve equipped with a spool arranged for movement between two positions, the artificial heart connected to one of said ports, an expansible reservoir connected to another of said ports, two other ports being coupled to sources of compressible pressure fluid and suction, respectively, said spool in one position coupling said compressible fluid pressure source with said reservoir and said artificial heart with said suction source, the other position of said spool coupling said artificial heart with said reservoir while blocking fluid pressure flow relative to said sources, and electromechanical means for positioning said spool, said positioning means in the absence of energization thereof being arranged to maintain said spool in said one position.

2. The structure of claim **1** in which a conduit is provided to couple said fluid pressure source with said valve, and means including a restriction in said conduit for varying the volume of pressure fluid delivered to said pump from said reservoir.

3. The structure of claim **1** in which said positioning means includes a solenoid for moving said spool, and means including pulse frequency and pulse width variation means coupled to said solenoid for varying the frequency and duration of pumping pulses.

4. The structure of claim **1** in which said positioning means includes a solenoid operatively associated with said spool for moving the same between said positions upon electrical signal to said solenoid, and means including a unijunction relaxation oscillator and monostable multi-vibrator for energizing said solenoid.

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