

[54] MECHANICAL HEART SYSTEM

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Related U.S. Application Data

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No. 3,636,570.

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418/171, 137/106

[51] Int. Cl. F01c 1/10, F04c 1/06, F04b 21/00

[58] Field of Search.....3/DIG. 2; 418/32,
418/159, 166, 170, 171; 417/315, 383, 389,
310, 442; 137/104, 106

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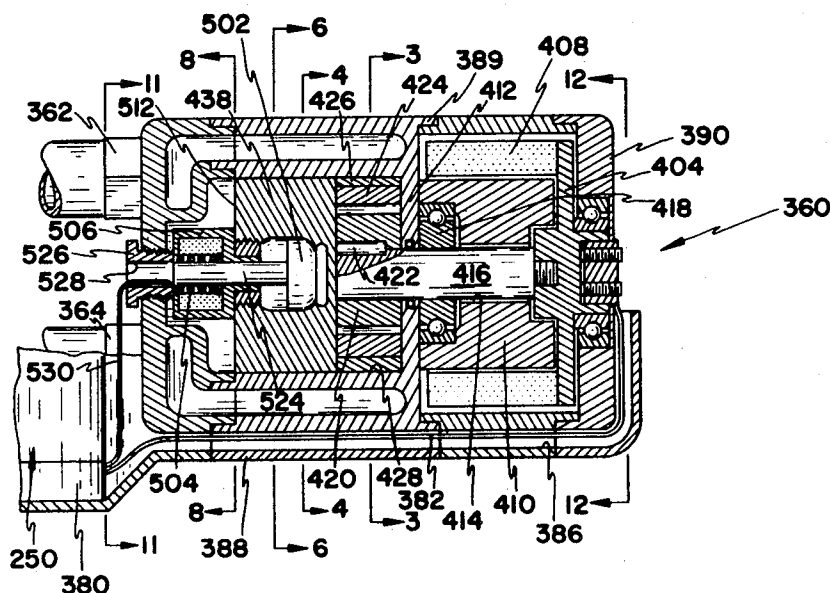
Attorney—Lynn G. Foster

[57]

ABSTRACT

A mechanical heart system including an artificial heart having a rigid exterior casing which is partitioned into two halves, each half being divided into chambers by a flexible diaphragm which collapses to pump blood out of the artificial heart when subjected to fluid pressure and which expands to withdraw blood into the artificial heart when the fluid pressure is removed therefrom. A mechanical driving pump forces driving fluid into and withdraws driving fluid from the artificial heart to control the operation of the diaphragm, the pump (a) forcing driving fluid into the artificial heart at a rate which is greater than the withdrawal of driving fluid from the artificial heart and (b) providing a more uniform rate of fluid flow between the pump and the artificial heart and modulating the transition between injection and withdrawal of driving fluid from the artificial heart. A pump regulator is connected to the power input of the mechanical pump, the regulator responding to the breathing rate of the user of the system to control the power input to the mechanical pump whereby the breathing rate of the user will determine the rate at which blood pumps from the artificial heart. In an alternative preferred embodiment, a fluid pump is substituted for the mechanical heart pump, the fluid pump accommodating injection of driving fluid into the artificial heart at a relatively constant rate and withdrawal of driving fluid from the artificial heart at another relatively constant rate. An alternate heart embodiment includes fluid-receiving cylinders and displaceable pistons alternately reciprocated in the cylinders due to fluid pressure developed by the fluid pump. An accumulator associated with the cylinders allows the pistons to travel in one direction at one rate and in the other direction at another rate.

4 Claims, 28 Drawing Figures



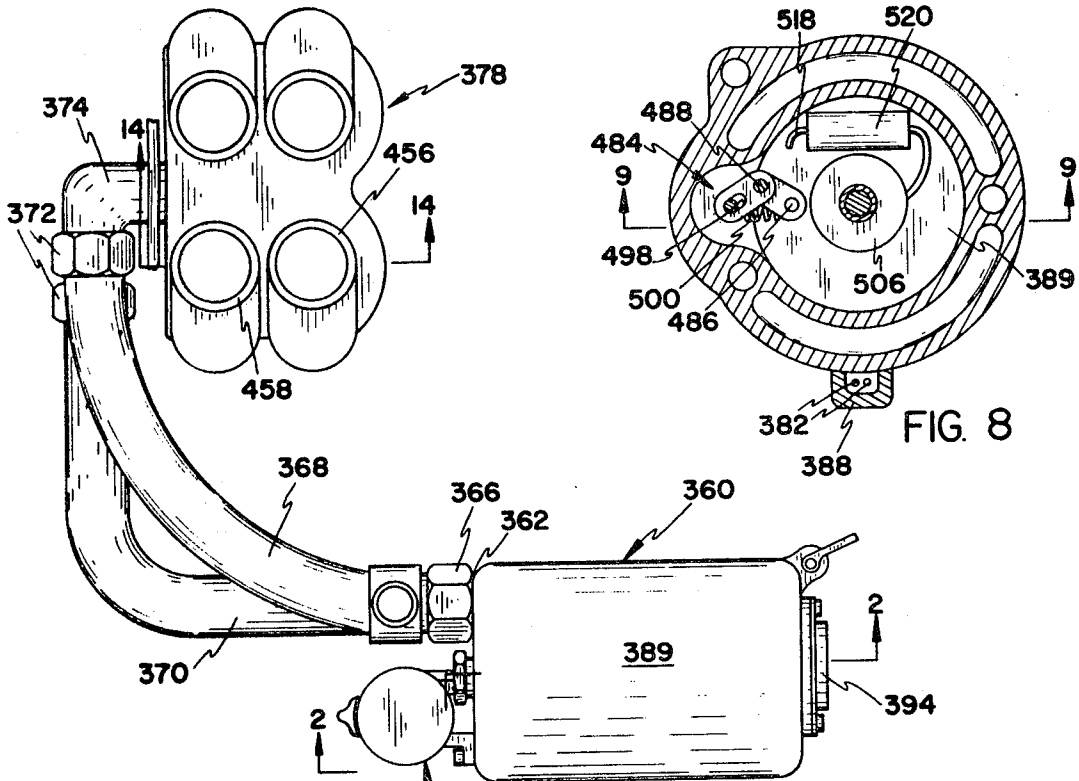


FIG. 1

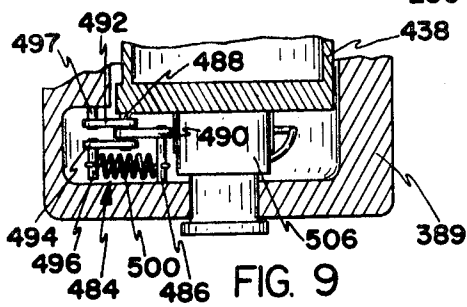


FIG. 9

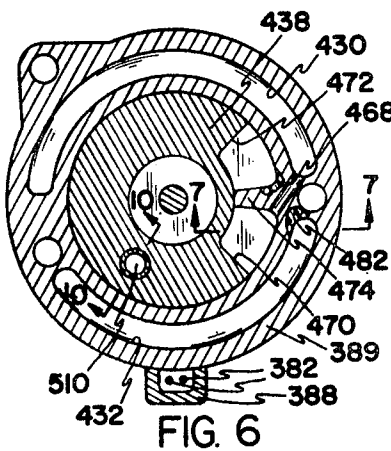


FIG. 6

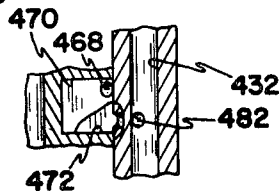


FIG. 7

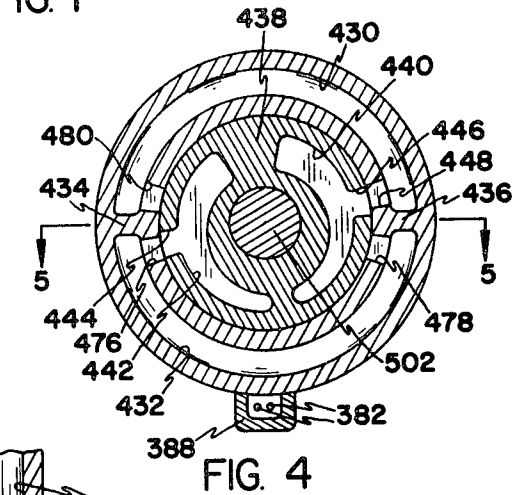


FIG. 4

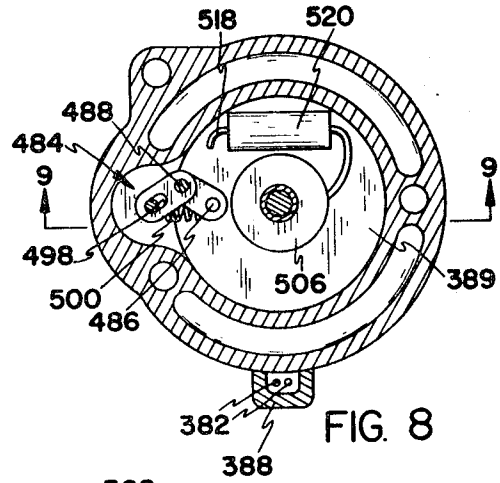
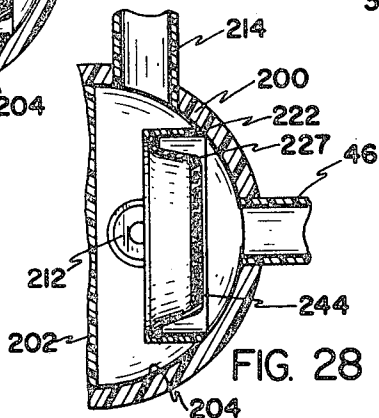
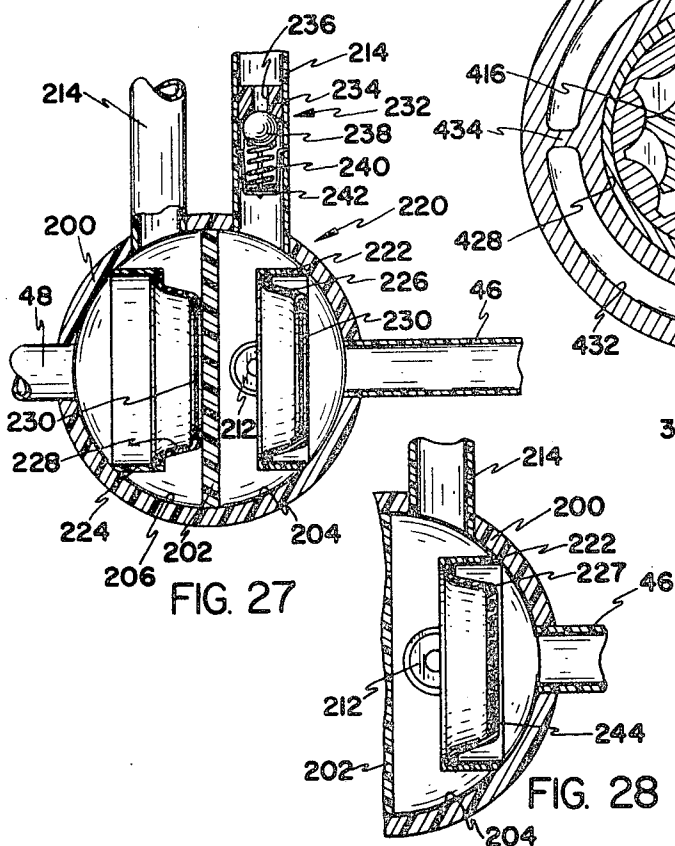
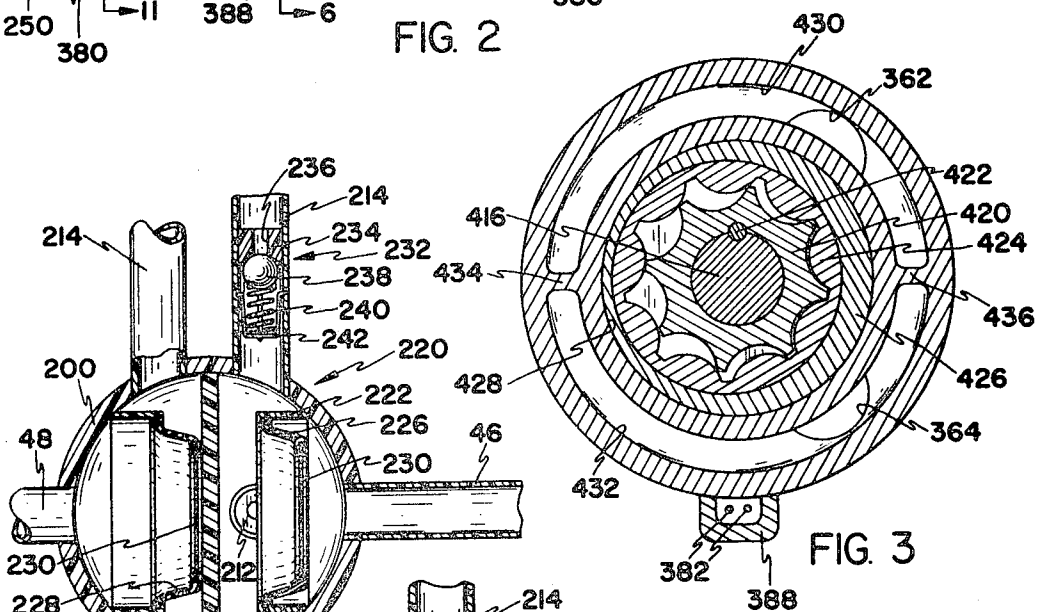
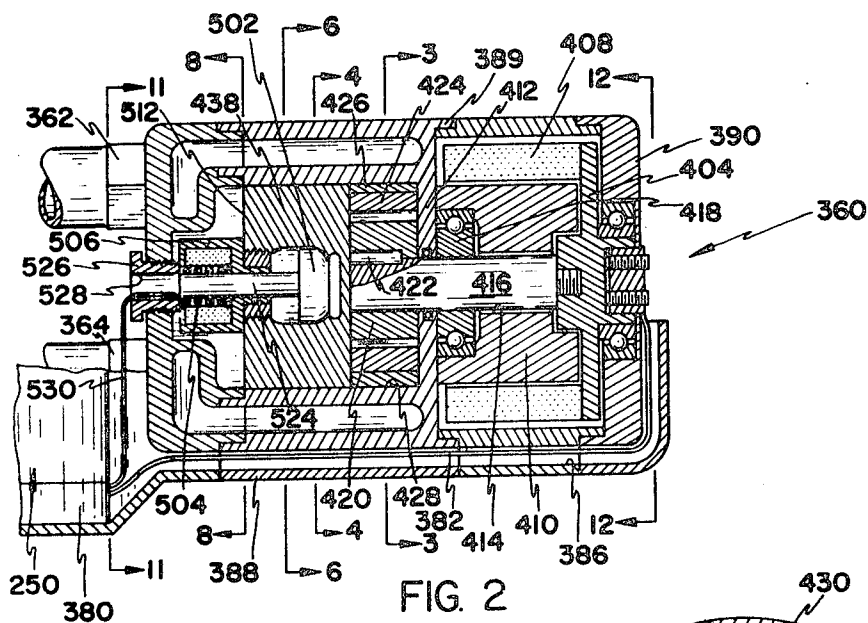
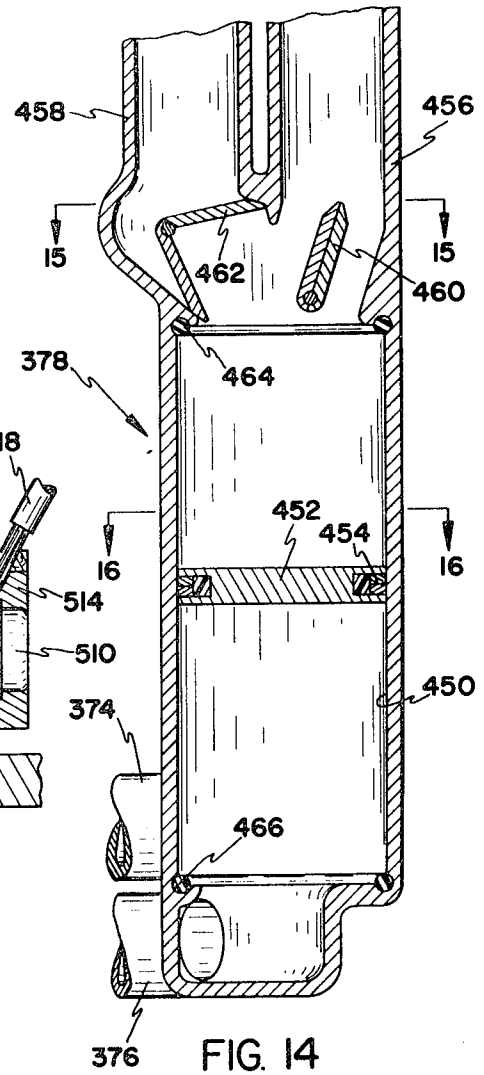
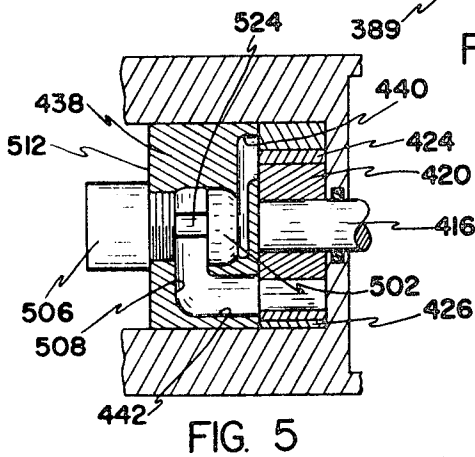
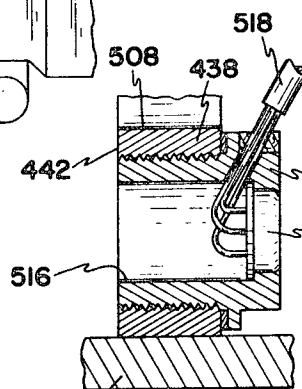
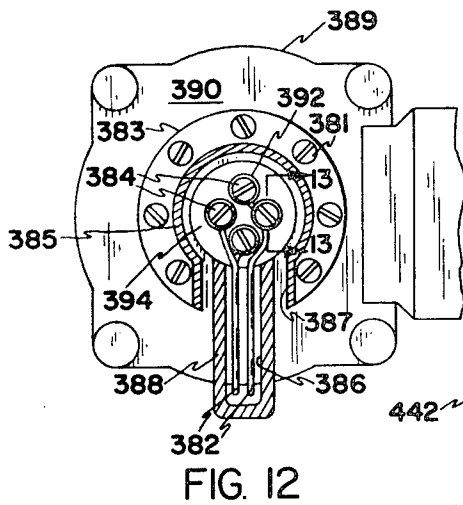
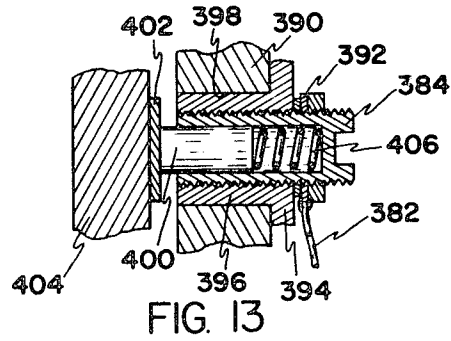
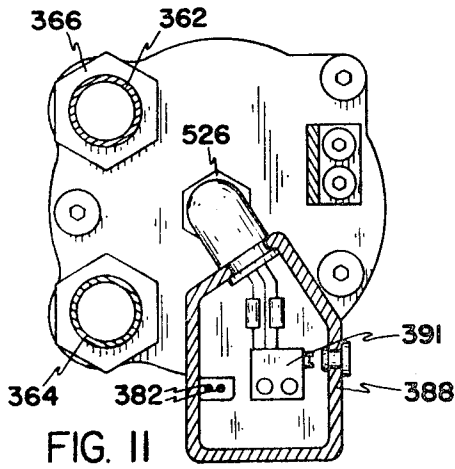


FIG. 8





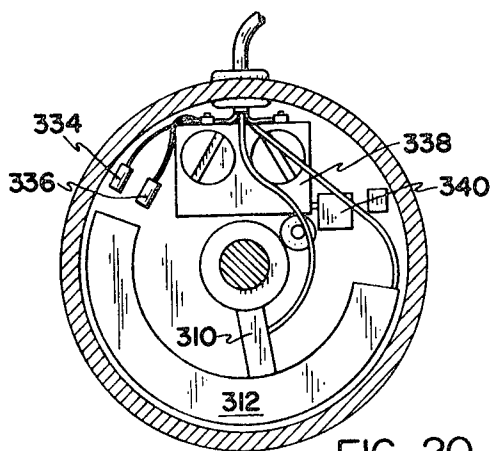


FIG. 20

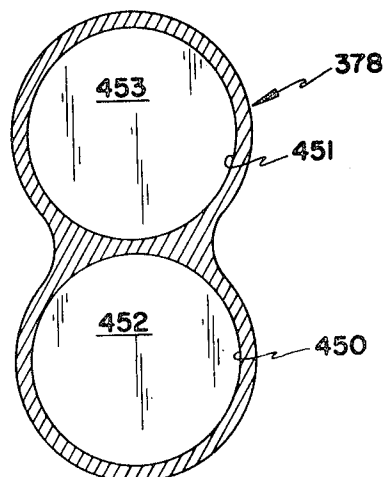


FIG. 16

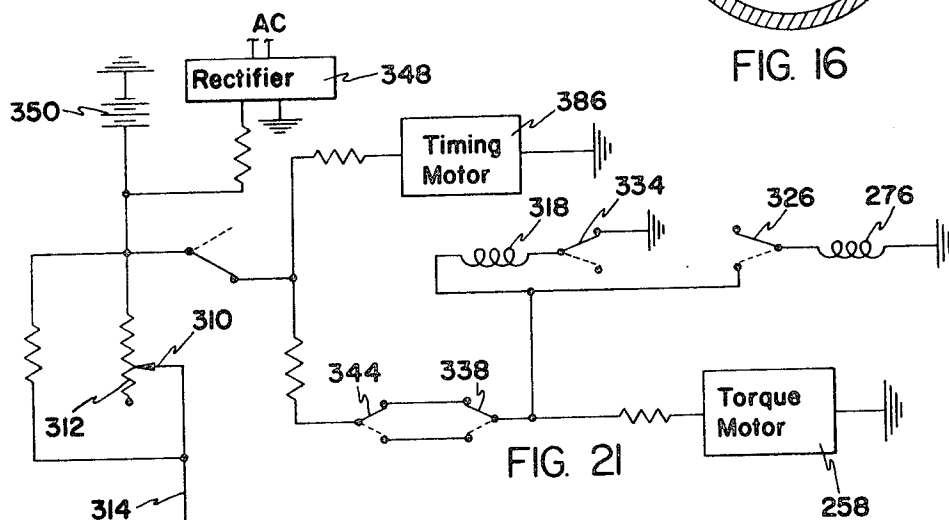


FIG. 21

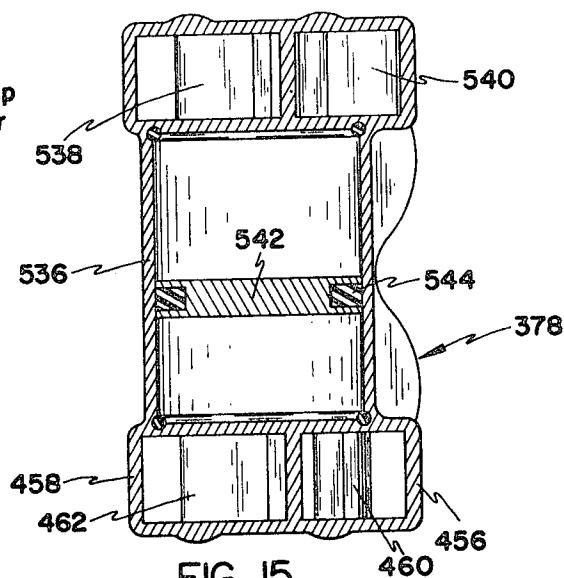
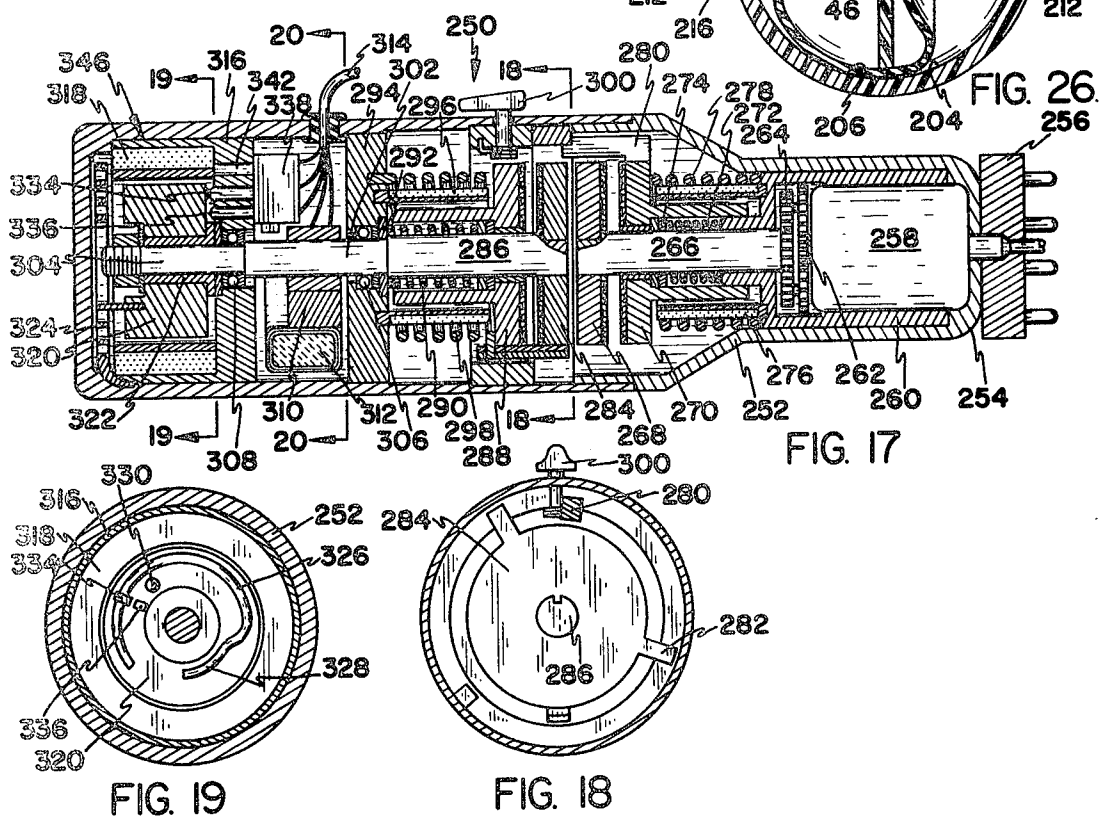
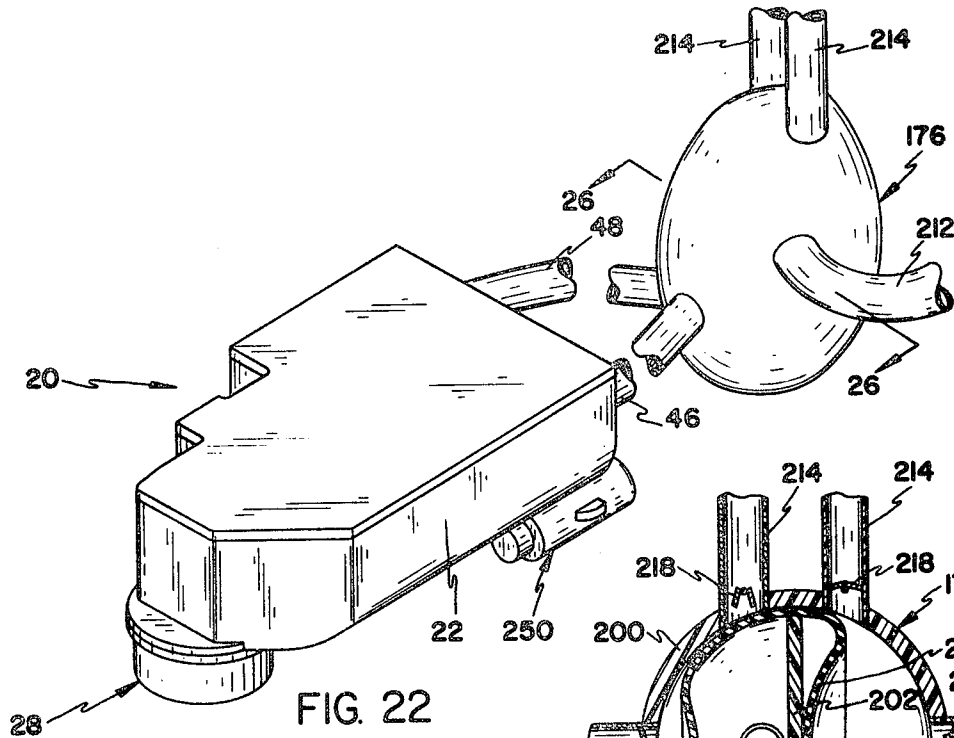
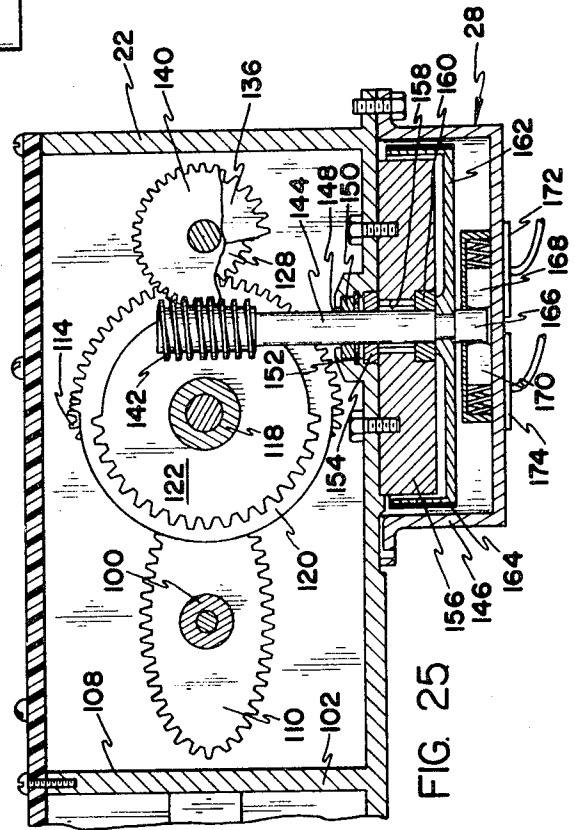
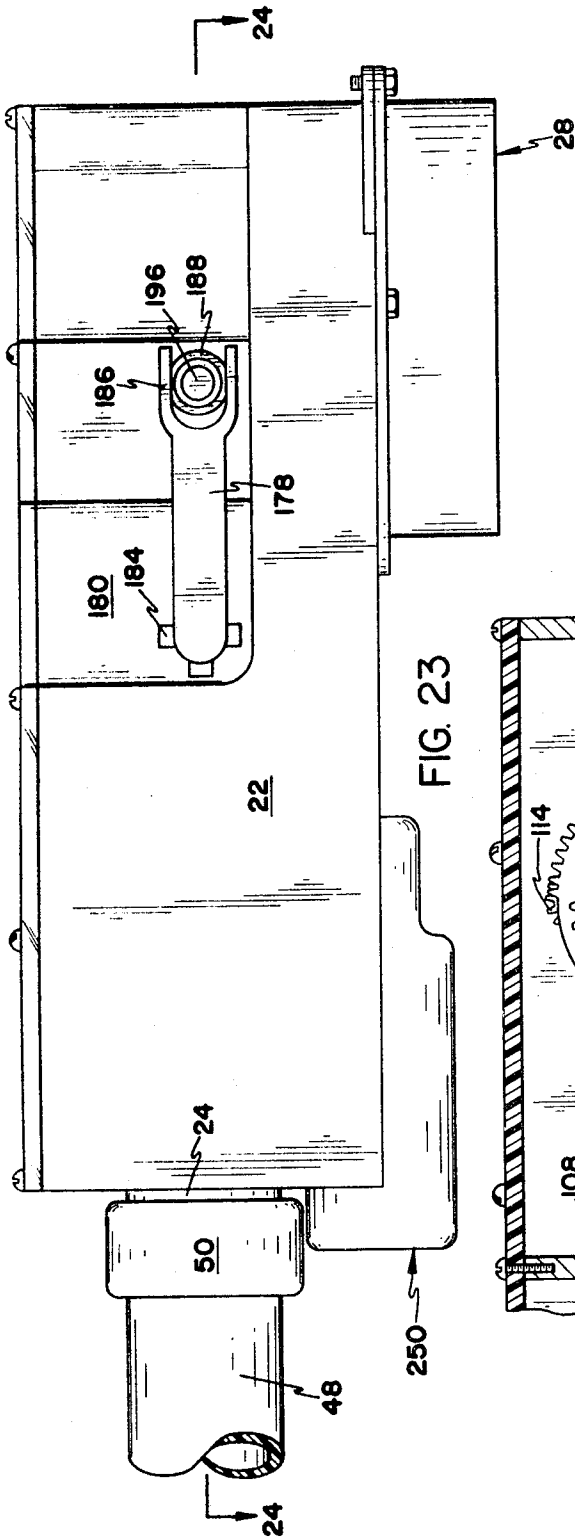


FIG. 15





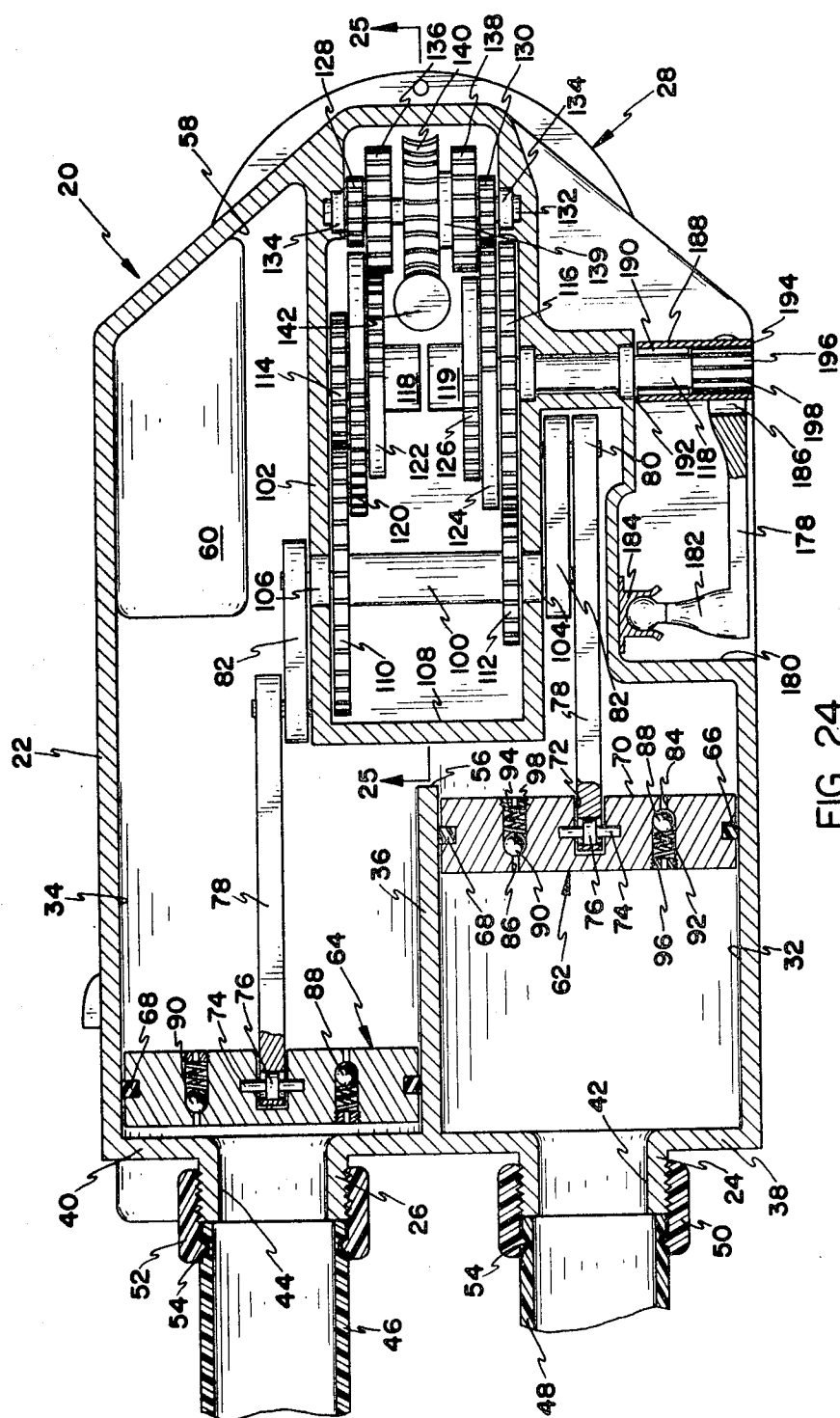


FIG. 24

MECHANICAL HEART SYSTEM

BACKGROUND OF THE INVENTION

This application is a division of my copending U. S. Patent Application Ser. No. 860,546, filed Sept. 24, 1969, now U. S. Pat. No. 3,636,570.

FIELD OF THE INVENTION

The invention relates to fluid regulators and pumps and more particularly to improved fluid pumps and regulators which can be used to more precisely duplicate the function of a natural heart.

THE PRIOR ART

The importance of providing a mechanical heart system which closely approaches the function of the natural heart system is well known in the art. It is critically important for the delicate tissues of the body to which blood is communicated that uniform systolic and diastolic pressures preserve the delicate tissue. Also, it is important that positive pressure be maintained upon the blood to keep the blood properly moving through the circulatory system.

Importantly, there often exists major changes in blood flow to the heart. These changes in blood flow must be compensated for by any suitable artificial heart system. Moreover, an important requirement for any acceptable artificial heart system includes a response mechanism which provides a greater output by the artificial heart during periods of physical or emotional stress or excitement.

Until the present pump and regulator inventions, a mechanical heart system accommodating the above features has not been successfully implemented.

BRIEF SUMMARY AND OBJECTS OF THE INVENTION

The present invention comprises improved pump and regulator structure accommodating, inter alia, an essentially constant pumping of blood out of an artificial heart and essentially constant flow of blood into the artificial heart through the circulatory system, the pumping and withdrawal rates being different in order to maintain proper blood pressure within the circulatory system. The speed regulator controls the speed of the pump as a function of the breathing rate of the user of the mechanical heart system so that an increased breathing rate due to physical and emotional stimulation result in increased blood flow.

It is a valuable object of the present invention to provide novel pumps.

Another important object of the present invention is a provision for novel pump regulator structure.

These and other objects and features of the present invention will become more fully apparent from the following description and appended claims taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a top plan view of one presently preferred system embodiment of the invention;

FIG. 2 is a longitudinal cross section taken along lines 2—2 of FIG. 1;

FIGS. 3 and 4 are transverse cross sectional views respectively taken along lines 3—3 and 4—4 of FIG. 2;

FIG. 5 is a cross section taken along lines 5—5 of FIG. 4;

FIG. 6 is a transverse cross section taken along lines 6—6 of FIG. 2;

FIG. 7 is a cross sectional view taken along lines 7—7 of FIG. 6;

FIG. 8 is a transverse cross section taken along lines 8—8 of FIG. 2;

FIG. 9 is a cross sectional view taken along lines 9—9 of FIG. 8;

FIG. 10 is a fragmentary cross sectional view taken along lines 10—10 of FIG. 6;

FIGS. 11 and 12 are transverse cross sections respectively taken along lines 11—11 and 12—12 of FIG. 2;

FIG. 13 is a fragmentary cross sectional view taken along lines 13—13 of FIG. 12;

FIG. 14 is a longitudinal cross section taken along lines 14—14 of FIG. 1;

FIGS. 15 and 16 are transverse cross sectional views respectively taken along lines 15—15 and 16—16 of FIG. 14;

FIG. 17 is a longitudinal cross sectional view of the presently preferred pump speed regulator of the invention;

FIGS. 18—20 are transverse cross sections respectively taken along lines 18—18, 19—19 and 20—20 of FIG. 17;

FIG. 21 is a schematic circuit diagram illustrating the electrical components of the regulator of FIG. 17;

FIG. 22 is a schematic perspective of another presently preferred system embodiment of the invention;

FIG. 23 is a side elevation of the embodiment of FIG. 22;

FIG. 24 is a cross sectional view taken along lines 24—24 of FIG. 23;

FIG. 25 is a fragmentary cross section taken along lines 25—25 of FIG. 24;

FIG. 26 is a longitudinal cross section taken along lines 26—26 of FIG. 22;

FIG. 27 is a longitudinal cross section of another heart embodiment which may be used with the system embodiment of FIG. 22; and

FIG. 28 is a fragmentary cross sectional view of still another presently preferred heart embodiment used with the embodiment of FIG. 22.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, the several presently preferred embodiments of the invention will be more completely described. In this specification, like parts are designated with like numerals throughout.

THE FLUID PUMP

The fluid pump shown in FIG. 1 and generally designated 360 preferably pumps isotonic saline or other biologically compatible fluid and has two vertically spaced ports 362 and 364 which are connected by suitable couplings 366 to tubes 368 and 370 respectively. Tubes 368 and 370 are respectively attached by couplings 372 to respective ports 374 and 376 in the mechanical heart embodiment generally designated 378 (see also FIG. 14). The fluid pump 360 is also electrically attached to a speed regulator 250 as best shown in FIG. 2.

With continued reference to FIG. 2, the speed regulator 250, which regulates the amount of power available to the pump 360, will subsequently be more fully described. A conventional plug-receiving socket 380

receives the power output from the speed regulator 250 and conducts the power through conductors 382 to terminal screws 384 (FIG. 12). The conductors 382 are confined within a passageway 386 defined by conduit 388. Conduit 388, integral with pump housing 389, envelopes the plug-receiving socket 380 and traverses the length of the fluid motor 360 to the trailing end 390 of the motor 360 (see FIGS. 2 and 12).

The terminal screws 384 threadedly engage collars 392 which, as shown in FIG. 13, are disposed over an insert 394. The insert has annular, outwardly projecting portions 396 (FIG. 13) adapted to be situated in annular bores 398 disposed in spaced locations through the end 390 of the motor housing 389. As shown in FIG. 13, each screw 384 is disposed in an interiorly threaded bore in the insert 394. The screws 384 are interiorly hollow and are adapted to receive a brush 400 which impinges upon a conductive element 402 attached to collector plate 404. The brush 400 is biased against the conductive element 402 with a compression spring 406. Although four screws 384 are shown, only two are required to effectively energize the pump 360. Thus, when necessary, pairs of brushes may be exchanged or repaired without stopping pump 360. The screws 384 are normally covered by an end cap 385 having a peripheral flange 383 and a slot 387 through which the conduit 388 passes. Cap 385 is secured to the housing 389 by screws 381 anchoring the flange 383 to the end 390.

With continued reference to FIG. 2, the collector plate 404 is united to an annular coil 408 which circumscribes a magnet 410. The magnet 410 is non-rotatably attached to a central partition 412 which divides the housing 389. The magnet 410 has a central bore 414 through which a drive shaft 416 is disposed. Drive shaft 416 is threadedly secured to the collector plate 404 so as to rotate with the collector plate and is mounted upon a bearing assembly 418 carried by the partition 412 and the magnet 410. Thus, as the power flows into the collector plate 404, the coil 408 is caused to rotate relative to the magnet 410. The shaft 416 is rotated with the collector plate upon the bearing assembly 418.

Drive shaft 416 is non-rotatably joined to a gear 420 such as with a key 422. As best shown in FIG. 3, the gear 420 is disposed adjacent the partition 412 opposite magnet 410 and forms part of a conventional gear rotor assembly such as model 8030, manufactured by Hydraulic Products, Inc., of Sturtevant, Wisconsin. The gear 420 is rotatably situated within a rotatable ring 424 which is internally configured complementary to the external configuration of the gear 420 as shown in FIG. 3. Notably, the gear 420 is off-set relative to the gear ring, the degree of off-set being determined by the eccentric ring 426. As shown in FIGS. 2 and 3, the gear rotor assembly is disposed in an interior chamber 428 within the motor housing 389. The chamber 428 is spaced from the exterior of the housing 389 by fluid reservoirs 430 and 432 which are separated one from another by partitions 434 and 436 (FIG. 3).

A porting plate 438 best shown in FIGS. 2 and FIGS. 4 through 7 is disposed in the chamber 428 adjacent to the gear rotor assembly. The porting plate 438, although disposed close to the face of the gear rotor assembly is not connected to the gear rotor assembly. While the gear rotor assembly rotates, the porting plate 438 oscillates back and forth as will now be described.

The porting plate 438 has a high-pressure port 440 which is in communication with the high-pressure output of the gear rotor assembly and a low pressure port 442 which conducts fluid to the intake portion of the gear rotor assembly. As shown in FIG. 4, both low and high pressure ports are respectively provided with openings 444 and 446. In the position shown in FIG. 4, the opening 446 is in register with an orifice 448 so that the high pressure fluid output from the gear rotor assembly is communicated into the reservoir 430 and thereafter conducted through the tube 368 (FIG. 1) to the heart 378. Low pressure fluid is simultaneously conducted from the heart 378 to the reservoir 432 and thereafter through orifice 476 and opening 444 into port 442 to function as intake for the gear rotor assembly.

In order to best appreciate the operation and function of the porting plate 438, the heart embodiment 378 of FIGS. 14-16 will now be described. The heart 378, best shown in FIG. 14, comprises two side-by-side, essentially identical cylinders 450 and 451 within which floating pistons 452 and 453 are reciprocally displaceable. Since the pistons and cylinders are essentially identical, only piston 452 and cylinder 450 will be described. Piston 452 is provided with annular seal structure 454 which divides the cylinder 450 into separate chambers. The upper chamber (as viewed in FIG. 14) is filled with blood and is in communication with the circulatory system of a man or animal through tubes 456 and 458. Each of the tubes is provided with a conventional one-way valve 460 or 462 which, for example, may be a butterfly valve. An annular ring 464 is disposed at the top of cylinder 450 and serves as a bumper for the piston 452. Similarly, an annular ring 466 is disposed at the bottom of cylinder 450 and serves as a lower bumper for the piston 452.

It is presently preferred that the diastole stroke of the heart 378 take twice as much time for completion as the systole stroke. To achieve this desirable result, the heart 378 is provided with an accumulator 536 integrally joined to the heart 378 above the cylinders 450 and 451 between valves 460, 462 and valves 538, 540.

The accumulator 536 has a displacement volume which is substantially equal to one-half the displacement volume of either cylinder 450 or 451. Also, the accumulator 536 is divided by floating piston 542 which is sealed in the accumulator with seals 544. When blood enters, for example, cylinder 450 on the diastolic stroke, blood is at the same time exhausted out of the cylinder 451, which exhaust comprises the systolic stroke. During the diastolic stroke, venous blood is drawn into the cylinder 450 from both the body and the accumulator 536 so that when the diastolic stroke is completed, the cylinder 450 has received blood volume substantially equal to the volume of the accumulator 536 and an equal volume from the body. During the same period of time, cylinder 451 is being emptied during the systolic stroke. As cylinder 451 is emptied of blood, the accumulator 536 is closed to the blood from cylinder 451 and expanded to receive blood from the body venous system. Thus, the quantity of blood pumped into the body is approximately twice the quantity received from the body during the same period of time. This occurs as a result of blood alternately entering the accumulator 536 and cylinder 451 from the venous system. Thus, blood flow rate is almost constant and uninterrupted from the venous system

whereas the blood flows to the lungs or body in interrupted intervals of flow during approximately half the time and no flow during the other half.

Returning again to the fluid pump 360, when the porting plate 438 is in the position shown in FIG. 4, high pressure fluid is communicated through the reservoir 430 and through tube 368 to the bottom of, for example, cylinder 450 so that piston 452 is displaced upwardly thereby forcing blood out through the tube 456 past the one-way valve 460. The one-way valve 462 in the tube 458 prevents outflow of blood through tube 458. When the piston 452 reaches the bumper 464, increased pressure is developed within the reservoir 430 and within the port 440. The increased pressure developed within the reservoir 430 is communicated through passageway 468 (FIG. 6) to pressure chamber 470. Pressure chamber 470 is separated from opposed pressure chamber 472 by a partition 474 comprising part of the housing 389. The pressure in chamber 470 will cause the porting plate 438 to rotate clockwise as viewed in FIGS. 4 and 6. The porting plate 438 will rotate only when the pressure in chamber 470 has reached a predetermined minimum level. The minimum level may be determined by toggle structure 484 hereinafter more fully described.

Upon rotation of porting plate 438, the opening 446 in the high pressure port 440 will be in communication with the reservoir 432 through orifice 478 (FIG. 4) and the opening 444 in the low pressure port 442 will be in communication with the reservoir 430 through orifice 480. Thus, the high pressure effluent from the gear rotor assembly will be communicated through the reservoir 432 and tube 370 to the other cylinder 451 (FIG. 16) to drive the corresponding piston 453 upwardly in the cylinder. Concurrently, the fluid in the reservoir 430 will be communicated to the intake of the gear rotor assembly. Thus, fluid will be drawn from beneath the piston 452 thereby displacing the piston 452 downwardly as viewed in FIG. 14.

Piston 452 may bottom out against bumper 466 and when this occurs, high pressure will develop in the reservoir 432, which high pressure will be communicated through a passageway 482 (FIG. 6) in the partition 474. Thus, high pressure will be developed in the pressure chamber 472 thereby causing the porting plate 438 to rotate counterclockwise as viewed in FIGS. 4 and 6 to the initial position previously described. In the initial position, the one piston 452 (FIG. 14) and the corresponding opposed piston 453 will commence displacement in opposite directions.

The amount of pressure required to oscillate the porting plate 438 from one position to another is determined by the toggle generally designated 484 and best shown in FIGS. 8 and 9. Toggle 484, shown in FIG. 8 in the over-center position, comprises a pin 486 anchored to the pump housing 389 and a pin 488 anchored to the porting plate 438. Pins 486 and 488 are connected by a link 490. Link 490 is interposed between links 492 and 494, link 492 being anchored to the housing 389 and link 494 being provided with a pin 496 which floats relative to the housing 389. Importantly, link 492 has an elongated slot 498 which accommodates lateral displacement of the link 492 relative to the pin 497.

The pins 496 and 486 are urged together with tension spring 500. In order for the porting plate 438 to be oscillated from one position to another, the pin 488 must

be moved relative to the housing 389 against the bias of spring 500. Thus, the amount of pressure required in chambers 470 or 472 to displace the porting plate 438 must be sufficient to overcome the tension exerted by spring 500. After toggle has passed over center, spring tension continues motion of porting plate 438 insuring complete closure of ports 448 and 476.

If, for some reason, pressure in the reservoirs 430 or 432 exceed a predetermined maximum level, the pressure will displace pressure relief valve 502 (FIGS. 2 and 5) against the bias of spring 504 carried within the solenoid 506. The pressure will then be allowed to vent past the valve 502 and through a passageway 508 to the low pressure, intake side of the gear rotor assembly.

It is desirable that the heart 378 pump into the body only that amount of blood which is offered by the veins at any given time and consequentially does not create excessive negative pressure in the venous system. This may be accomplished by controlling the output of the pump 360 so that fluid is pumped to the heart 378 only when a slight positive pressure exists at the intake side of the pump. When a negative pressure exists or, when a positive pressure below a predetermined set value exists, fluid will not be communicated to the heart 378 from the pump 360. This control mechanism is best shown in FIGS. 2, 5, 6 and 10.

Referring to FIG. 6, the porting plate 438 is provided with a pressure sensitive transducer 510, one side of which is exposed to the air adjacent the surface 512 of the porting plate 438. The opposite side is exposed to the low pressure chamber 442 (FIG. 4). Thus, the opposite side of the transducer 510 is exposed to the liquid or saline solution pumped by the pump 360. The transducer 510 is situated within a transducer retainer 514 which threadedly engages the porting plate 438 as shown in FIG. 10. The liquid pressure is in communication with the transducer 510 through an annular channel 516 so that the transducer 510 compares the fluid pressure in the low pressure port 442 with the air pressure interior of the pump 360.

When the pressure in the low pressure port 442 drops below a predetermined level, e.g. when less blood is being offered by the veins to the heart 378 than is being pumped into the heart 378, an electrical pulse will be developed by the transducer 510 and conducted through lines 518 (FIG. 10) to a reed switch 520, best shown in FIG. 8 and variable resistor 391, shown in FIG. 11. The reed switch 520 actuates the solenoid 506 (FIG. 8) causing the valve 502 to retract from the position illustrated in FIG. 5 so that the passageway 508 is in open communication with the high pressure port 440. Thus, the high pressure output in port 440 is communicated past the valve 502 into the low pressure port 442 through the passageway 508. It is therefore apparent that the output of the gear rotor assembly is recirculated through the porting plate to the input of the gear rotor assembly without being communicated to the heart 378.

When the pressure on the transducer 510 in the channel 516 (FIG. 10) is increased, the solenoid 506 will be deactivated closing valve 502 to the position illustrated in FIG. 5 so that fluid is once again conducted to the heart 378. Although any suitable transducer 510 could be used, it is presently preferred that the pitran model PT-2 manufactured by Stolab be used. As shown in FIGS. 2 and 5, the solenoid 506 is threadedly attached to the porting plate 438 and is interiorly hol-

low to receive the valve rod 524 in reciprocable fashion.

A bushing nut 526 (FIG. 2) is disposed in the housing 389 and impinges upon the solenoid 506 with sufficient pressure to force the porting plate 438 against the gear rotor pump assembly to prevent leakage while also avoiding excessive wear. The bushing nut has a hollow bore 528 through which wires 530 are disposed to communicate power from the regulator 250 to the solenoid 506. If desired, a conventional belville or like spring could be used to urge the porting plate against the gear rotor assembly.

While the use of a pressure differential to oscillate the porting plate has been described, it is also presently preferred that a mechanical driving mechanism (not shown) be used as an alternate embodiment. The mechanical driving mechanism would include a driving motor which drives the porting plate first in one direction and then in the opposite direction, at any desired sequence of flow reversals.

THE MECHANICAL PUMP

Referring now to FIGS. 22 - 25, in particular, a mechanical pump generally designated 20 is illustrated.

The mechanical pump 20 comprises a pump housing 22 which is preferably formed of metal and has fluid ports 24 and 26 (FIG. 24). The pump has a driving motor generally designated 28 and a speed regulator generally designated 250. The driving motor 28 and the speed regulator 250 will be hereinafter more fully described.

Referring now to FIG. 24, the interior of the pump 20 is illustrated and comprises side-by-side cylinders 32 and 34 which are separated by the cylinder wall 36. Each cylinder 32 and 34 terminates in a substantially flat cylinder head 38 and 40, respectively, each of which is integral with the housing 22. Each cylinder head 38 and 40 has an outwardly directed threaded boss comprising the ports 24 and 26, each boss defining a hollow bore 42 and 44 which communicates the cylinders 32 and 34 with the exterior of the housing 22. Cylinders 32 and 34 open into the interior cavity 58 of the housing 22.

The ports 24 and 26 are adapted to be secured to fluid conducting tubes 46 and 48 preferably formed of flexible material. The tubes 46 and 48 may be secured to the ports 24 and 26 by any suitable means which accommodates rapid attachment of the tubes 46 and 48 to the respective ports. In the illustrated embodiment, each of the tubes 46 and 48 is provided with an annular ring 50 and 52, respectively, such as with a key-keyway attachment 54 which accommodates rotation of the rings 52 relative to the respective tubes but prevents axial displacement between the rings and the tubes. Rings 52 and 54 are interiorly threaded so as to mate with the exterior threads on the ports 24 and 26. If desired, a fluid seal may be interposed between the ports 24 and 26 and the tubes 46 and 48, respectively, to prevent inadvertent fluid leakage at the connection.

The cylinders 32 and 34 each opens adjacent the end 56 of the cylinder wall 36 to the interior 58 of the pump housing 22. Also, notably, the open ends of cylinders 32 and 34 are in communication with one another. A bag 60, normally inflated with a gas such as air, is attached to the interior 58 of the housing 22 and is collapsible when subjected to elevated fluid pressure due

to increase in fluid volume within the housing 22 as will be hereinafter more fully described.

A piston 62 and 64 is disposed in each of the respective cylinders 32 and 34. Since pistons 62 and 64 are substantially identical, only piston 62 will be described, it being understood that piston 64 is similarly constructed. Piston 62 is essentially cylindrical in configuration and has an annular groove 66 disposed around the periphery of the cylinder. Seal 68 is disposed in the groove 66 so as to form a fluid-tight relation between the piston 62 and the cylinder 32. A laterally disposed blind slot 72 is disposed in the piston 62 and opens at the face 70. A wrist pin 74 is disposed transversely across the slot 72, wrist pin 74 having an enlarged portion 76 which outwardly presents a bearing surface. A connecting rod 78 is pivotally attached to the wrist pin 74 at the bearing 76 and is pivotally connected at the end 80 to a link 82. Link 82 is rotated in a manner subsequently more fully described in order to reciprocate the piston 62 within cylinder 32.

Piston 62 has opposed relief ports 84 and 86 which are selectively opened and closed by ball-check valves 88 and 90, respectively. The ball-check valves 88 and 90 are biased toward a closed position by springs 92 and 94. The bias exerted by springs 92 and 94 is selectively adjustable by set screws 96 and 98 so that the ball-check valves 88 and 90 will open only when subjected to a predetermined threshold fluid pressure.

With continued reference to FIG. 24 and with further reference to FIG. 25, the structure for driving pistons 62 and 64 will now be described. Links 82 are non-rotatably attached to a shaft 100 which is confined within a secondary housing 102. The secondary housing is integral with the housing 22 and completely encloses the gear structure hereinafter described to prevent contact between the fluid in chamber 58 from contacting oil or like lubricant surrounding the gears. The shaft 100 is supported within the housing 102 upon bearings 104 and 106 which both provide an anti-friction surface for rotation of the shaft 100 relative to the housing 102 and also a fluid seal to prevent fluid from entering the interior 108 of the housing 102. The shaft 100 is provided with elliptical gears 110 and 112 which are 90° out of phase one with respect to the other. In the position illustrated in FIG. 24, elliptical gear 110 has its longest axis in the plane of the drawing, and gear 112 has its longest axis normal to the plane of the drawing. Significantly, gears 110 and 112 are independently rotatable relative to one another and are fixed relative to the corresponding link 82.

Gears 110 and 112 respectively mesh with mating elliptical gears 114 and 116 each of which is oriented 90° relative to the respective mating elliptical gear 110 or 112. Gears 114 and 116 are non-rotatably attached to respective shafts 119 and 118, the shafts also being non-rotatably joined to respective segmented gears 120, 122 and segmented gears 124, 126. Significantly, gear 120 has a diametral dimension greater than gear 122 and has teeth disposed on only 180° of the periphery thereof. Gear 122 likewise has teeth disposed on 180° of the periphery and oriented so as to be diametrically opposite the teeth on gear 120. Similarly, gear 124 has a diametral dimension which is greater than gear 126 and has gear teeth disposed on 180° of the periphery thereof, the teeth on gear 124 being oriented diametrically opposite the teeth on gear 126. Significantly, the teeth on the diametrically enlarged gears 120

and 124 are disposed 180° out of phase one with another. The teeth on gears 122 and 126 are likewise aligned.

In the illustrated position of the gears (FIG. 24) gears 120 and 124 mesh with corresponding pinion gears 128 and 130 having substantially similar sizes and numbers of gear teeth, each of gears 128 and 130 being non-rotatably joined to a drive shaft 132. A one-way clutch assembly 139 is interposed between the pinion 138 and a worm gear 140. Clutch assembly 139 may be of the type manufactured by Towington, e.g. model No. RC061008). Drive shaft 132 is rotatably carried by the housing 22 upon bearings 134. Gears 128 and 132 are disposed in tandem with diametrically enlarged gears 136 and 138, respectively. Gears 136 and 138 are disposed opposite gears 122 and 126, respectively, and mesh with gears 122 and 126 only when gears 128 and 130 move out of engagement with the teeth on gears 120 and 124, respectively. Thus, the piston 62 will advance at a rate which is about twice as great as the retraction rate. Piston 64 will retract at a rate which is twice as great as the advancing rate.

Drive shaft 132 is integrally connected to a worm gear 140 which meshes with a worm 142 (best shown in FIG. 25). Worm 142 is integrally joined to a drive shaft 144 which is driven by the motor 28.

With continued reference to FIG. 25, the motor 28 comprises a motor housing 146 which is screw-secured to the housing 22 of the pump 20. The drive shaft 144 traverses from the interior 108 of the secondary housing 102 to the interior of housing 146 through a diametrically enlarged opening 148 in the housing 22. The shaft 144 is supported in the opening 148 by a bearing 150 held in place by a bearing retainer 152. Also, an oil seal 154 is disposed in the opening 148 and circumscribes the shaft 144 to prevent oil from passing between the shaft 144 and the seal 154.

An annularly shaped permanent magnet 156 is bolt-secured to the housing 22, the magnet 156 having a centrally disposed axial bore 158 through which the shaft 144 passes. A bearing 160 is interposed between the magnet 156 and the shaft 144 to accommodate smooth rotation of the shaft 144 as will now be described.

Shaft 144 is non-rotatably connected to a collector plate 162 which is generally U-shaped in cross section, the axially-directed periphery comprising a skew winding 164. Also, shaft 144 has an electrically-conducting tip 166 upon which electrical collectors 168 and 170 are disposed. Collectors 168 and 170 serve as brushes to conduct electricity to the motor 28 from the speed regulator 250. Significantly, each of the collectors 168 and 170 is, of itself, able to energize the motor 28 sufficiently to drive the worm 142. Also, each of the collectors 168 and 170 is individually removable by removing plates 172 or 174. Thus, in the event one of the collectors 168 or 170 should become damaged or worn out, the collector 168 or 170 may be replaced without causing the operation of the motor 28 to cease.

In the operation of the pump embodiment illustrated in FIGS. 22-25, the motor 28 is energized so that the shaft 144 and worm 142 rotate. Worm 142 drives the worm gear 140 so that shaft 132 is rotated. When gears 128, 120 and gears 130, 124 mesh, the corresponding gears 110 and 112 will drive piston rods 78 to displace the pistons 62 and 64 at one predetermined rate. When shaft has rotated so that the gears 136 and 138 respec-

tively mesh with gears 122 and 126, the pistons 62 and 64 will be displaced at a rate which is one-half the value of the previous rate as modified by the elliptical gear set.

Significantly, the elliptical gears 110, 114 and 112, 116 govern the rate at which the pistons 62 and 64 change from an advancing to a retracting stroke and vice versa and diminish the maximum velocity at mid-portion of the stroke. Due to the effect of the elliptical gears, when the pistons 62 and 64 reach the top or the bottom of the stroke, the rate at which the pistons are displaced is substantially increased. For example, when piston 62 is near bottom dead center (BDC), elliptical gear 116 will be disposed essentially horizontal as viewed in FIG. 24 and elliptical gear 112 will be disposed essentially vertical as viewed in FIG. 24. Thus, although the rate of rotation of the shafts 118 and 119 will be generally constant, the orientation of the elliptical gears 110, 114 and 112, 116 are such that a comparatively slow gear ratio of approximately 2:1 shall be in effect between the elliptical gears while the pistons 62 and 64 are mid-stroke and the elliptical gear ratios will be changed to approximately 1:2 while the pistons are at the end of each stroke. This tends to equalize the variation in forward motion of the pistons by maintaining the stroke of the piston at a relatively constant value through the majority of the stroke, peak velocities being reduced to approximately fifty percent of the velocity which would exist without the elliptical gear arrangement.

As the piston 62 is advanced in cylinder 32, fluid within the cylinder is forced out through the tube 48 to the mechanical heart generally designated 176 (FIG. 26). At the same time, piston 64 will be retracted within cylinder 34 to admit fluid from the heart 176 into the cylinder 34. Significantly, fluid exists on both sides of the pistons 62 and 64 so that in the event resistance to the advancing stroke of piston 62 becomes greater than a predetermined level, the check valve 90 will be opened to allow fluid to pass through the piston 62. The increased fluid volume in the interior 58 of the housing 22 is compensated by collapsing the gas-filled elastomeric bag 60. Similarly, if the pressure in the cylinder 32 goes below a predetermined level, valve 92 will bypass fluid to prevent excessive negative pressure. At the same time, the elastomeric bag 60 will expand to compensate for the change of volume. Piston 64 and the check valves therein operate in a similar manner.

Referring again to FIGS. 23 and 24, the pump embodiment 20 is provided with a mechanically operable hand crank 178 which is normally disposed within a recessed portion 180 of the housing 22. The hand crank is provided with a handle element 182 which, in the position illustrated in FIG. 24, is maintained immovable by a clip 184.

As can be appreciated by reference to FIG. 23, the hand crank 178 has a U-shaped connecting portion or clevis 186 which is pivotally connected to a vertically-extendable sleeve 188. The sleeve 188 has inwardly-directed splines 190 over slightly less than one-half the axial dimension of the sleeve adjacent the inward end 192 of the sleeve 188. The interior surface of the sleeve 188 adjacent the outward end 194 is substantially smooth.

Sleeve 188 is telescopically disposed over the end 196 of the shaft 118. The end 196 of the shaft 118 is diametrically enlarged and is provided with outwardly-

directed splines 198. Thus, when the hand crank 178 and sleeve 188 are displaced axially relative to the shaft 118, the splines 190 and 198 will engage so that the sleeve 188 then becomes non-rotatable relative to the shaft 118. Thereafter, the handle 182 may be rotated 180° around its pivotal attachment to the sleeve 188 and may be hand-rotated to revolve shaft 118 thereby driving the pump 20.

When the hand crank 178 is not needed, the sleeve 188 is axially displaced out of engagement with the splines 198 and the handle element 182 is attached to the clip 184 as illustrated in FIG. 24.

THE ARTIFICIAL HEART USED WITH THE MECHANICAL PUMP EMBODIMENT

Referring particularly to FIGS. 22 and 26, the artificial or mechanical heart embodiment generally designated 176 comprises a rigid exterior housing 200 which in the illustrated embodiment is essentially circular in cross section and is interiorly hollow. If desired, heart embodiment 176 may be cylindrical in configuration. A rigid partition 202 (FIG. 26) divides the hollow of the housing 200 into two chambers 204 and 206. Each of the chambers 204 and 206 is provided with an elastomeric, collapsible accumulator or diaphragm 208 and 210, respectively. Although the diaphragm is shown as rubber, the diaphragm may be formed of any suitable flexible material, such as titanium. If titanium is used, heart embodiment 176 should be cylindrical. Each diaphragm 208 and 210 forms a separate compartment or chamber within the chambers 204 and 206 so that the heart 176 has four distinct chambers.

Chambers 204 and 206 are respectively in open communication with tubes 48 and 46 connected to the pump 20. Also, each of the chambers 208 and 210 is respectively in communication with an outlet tube 212 and an inlet tube 214. One-way valves 216 and 218 respectively restrict movement in the tubes 212 and 214 to unidirectional flow. In the operation of the heart embodiment 176, and with particular reference to FIG. 26, fluid under pressure is communicated through the tube 48 into the chamber 204 so that the chamber 208 is collapsed. As chamber 208 collapses, blood disposed within the chamber 208 is forced out through the one-way valve 216 and through 212 to the body of a person using the system. At the same time, fluid is withdrawn from the chamber 206 through the tube 46 so that the chamber 210 is caused to expand. Expansion of chamber 210 causes blood to be drawn into the chamber 210 through the tube 212 and the one-way valve 218.

When pistons 62 and 64 (FIG. 24) reverse direction, fluid will be forced into the chamber 206 through the tube 46 to collapse chamber 210 thereby forcing blood out through the corresponding tube 212 and valve 216. Conversely, withdrawal of fluid through the tube 48 will cause the chamber 208 to expand and draw blood into the chamber 208 through the corresponding tube 214.

If desired, the artificial heart embodiment illustrated in FIG. 27 and generally designated 220 may be substituted for the heart 176. The heart embodiment 220 is similar in many respects to the heart 176, like parts having like numerals throughout. The heart embodiment 220 has chambers 204 and 206 which are divided by a cylindrically shaped partition 222 and 224 formed of rigid material. The cylindrical partitions 222 and 224 are interiorly hollow and each are attached to a flexible

hinge 226 and 228, respectively. Each hinge 226 and 228 is formed of rubber or rubber-like material and has a central hollow, the hollow being filled with a metal disk 230 integral with the disk. Preferably the disk is a thin titanium wafer.

Also, each blood input tube 214 and each blood output tube 212 is provided with a one-way ball-check valve 232. Ball check valve 232 comprises a valve seat 234 having a through bore 236 therein. A spherical ball 238, preferably formed of teflon or stainless steel is urged in seating-relation upon the valve seat 234 with a spring 240. Spring 240 is preferably coated with a protective material such as tetrafluoro ethylene and is maintained in position with a spring retainer 242.

When fluid under pressure is communicated through the tube 46 into contact with diaphragm 226, the diaphragm is moved toward the left as illustrated in FIG. 1 so that blood within the chamber 204 is forced out through the tube 212. At the same time, the ball check valve 232 in the tube 214 will prevent outflow of blood therethrough.

Conversely, the diaphragm 228 works in a substantially similar manner.

If desired, the hinge 226 may be substituted with a diaphragm 227 and the metal reinforcing plate 230 may be substituted with metal reinforcement 244 as illustrated in FIG. 28. The reinforcement 244 comprises a metal disk having a plurality of apertures therein. The metal disk 244 is embedded entirely within the diaphragm 227 and the apertures accommodate permanent cohesion between the disk 244 and the diaphragm 226.

THE SPEED REGULATOR

Reference is now made to FIGS. 17 - 21 which illustrate the presently preferred embodiment of the speed regulator generally designated 250. Speed regulator 250 has an exterior housing 252 which is generally annular in transverse cross-section and which has, at the leading end 254 a plug jack 256. The plug jack 256 is adapted to be received by the mating socket carried by the pump embodiments 20 and 360, above described.

Internally, the regulator 250 has an electric motor 258 a portion of which is carried within gear reducer housing 260. The output 262 of the motor 258 is reduced by gear train 264 and transferred at reduced velocity to shaft 266. Thus, shaft 266 is adapted to rotate at a relatively slow rate. The shaft 266 is keyed or otherwise non-rotatably attached to a clutch plate 268. An opposing clutch plate 270 is carried upon the shaft 266 and is rotatable relative thereto. Thus, in the position illustrated in FIG. 17, the shaft will rotate independent of the movement of the clutch plate 270.

A spring 272 circumscribing the shaft 266 and interposed between the reducer housing 260 and a spring retainer 274 normally urges the clutch plate 270 against the clutch plate 268 so that joint rotation of the clutch plates 268 and 270 results. However, an annular solenoid 276 is selectively energized, as will be hereinafter more fully described, to retract the clutch plate 270 relative to the clutch plate 268 against the bias of spring 272. Clutch plate 270 is illustrated in the retracted position.

A torsion spring 278 is secured both to the clutch plate 270 and to the gear reducer housing 260. When the clutch plate 268 is engaged by the clutch 270 and as clutch plate 270 rotates with the clutch plate 268,

the torsion spring 278 will develop a bias counter to the rotation of the clutch plate 270. When clutch plate 270 is subsequently displaced out of engagement with clutch plate 268 by the solenoid 276, torsion spring 278 will cause clutch plate 270 to rotate relative to the shaft 286 to its initial, predetermined position. Significantly, the clutch plate 270 is provided with an axially extending arm 280. Arm 280, integral with the clutch plate 270, engages a dog 282, which dog comprises part of the clutch plate 284 (see FIG. 18.) Thus, when clutch 270 is rotated, the arm 280 will engage the dog 282 to simultaneously drive the clutch plate 284. A central shaft 286 is keyed or otherwise non-rotatably secured to the clutch plate 284 so that the shaft 286 rotates with the clutch plate 284. It is important that shaft 286 be maintained in the position to which it is rotated due to the force exerted by the dog 280 upon the clutch plate 284. One such position is illustrated in FIG. 18.

In order to maintain the shaft 286 in the predetermined position, another clutch plate 288 is provided. Clutch plate 288 is configured and operated in substantially the same way as clutch plate 270. That is, clutch plate 288 is biased toward a position of engagement with the clutch plate 284 by spring 290 which is concentric with shaft 286. The spring 290 exerts an opposing force upon a bearing retainer 292 carried within an annular central partition 294. The solenoid 296, when energized, exerts sufficient force to draw the clutch plate 288 away from clutch plate 284 against the bias of spring 290. When the clutch plate 288 is removed from clutch plate 284, a torsion spring 298 which is anchored between the partition 294 and the clutch plate 284 causes the clutch plate 284 to rotate toward an initial at-rest position.

Significantly, in the operation of the regulator 250, the clutch plate 288 holds clutch plate 284 in its last position until the arm 280 reaches its end point. If the end point of displacement of arm 280 is a greater angular distance from the starting position illustrated in FIG. 18, than the existing position of the dog 282, arm 280 will rotate the dog 282 and clutch plate 284 to a new angular position. However, if the end point of the arm 280 is less than the previously set position of the clutch plate 284, the torsion spring 298 will cause the clutch plate 284 to rotate (e.g. counterclockwise in FIG. 17) until the dog 282 engages the arm 280 at the new end point. The clutch plate 288 is then allowed to re-engage the clutch plate 284 to hold the clutch plate in the last-mentioned position so that the arm 280 may return to the start position illustrated in FIG. 17. Accordingly, the position of the shaft 286 will readjust with each displacement of the arm 280 to the end point.

If desired, the starting position of the arm 280 may be adjusted by arcuately displacing the stop bar 300 to any one of a variety of selected positions. The position of the stop bar 300 determines the minimum rotation shaft 286 can assume. Thus, the position of stop bar 300 determines the lowest possible power output of the speed regulator 250 as will be subsequently more fully described.

Shaft 286 is stepped to define a reduced diametral portion 302 and a diametrically reduced end 304. The shaft 286 is supported upon bearing assemblies 306 and 308 so that the shaft 286 easily rotates. Significantly, the shaft portion 302 is integrally joined to a brush assembly 310 (see also FIG. 20). Brush assembly 310 is

disposed adjacent a portion of rheostat 312, as best shown in FIG. 20. The relative positions of the brush 310 and the rheostat 312 determine the power output through line 314. Line 314 is electrically connected to plug jack 256 which is in electrical communication with the pump motors 20 and 360 above described.

Having described the structure and method accommodating rotation of the shaft 286 to position the brush 310 relative to the rheostat 312, the timing structure which governs the proper movement of the components will now be described. Referring particularly to FIGS. 17, 19 and 21, a torque motor housing 316 is disposed concentrically within the housing 252. A coil 318 is carried by the housing and, when energized, develops a rotational force in the torque motor armature 320. Significantly, the armature 320 revolves independent of the shaft 286 upon bearings 322. A torsion spring 324 is anchored to the housing 316 and is also anchored to the armature 320 so that when current ceases to flow in the coil 318, the torsion spring 324 returns the armature 320 to an initial starting position.

As best illustrated in FIG. 19, an electrical conductor 326 is disposed around the periphery of the armature 320 and has a laterally off-set portion 328. The armature is also provided with a pin 330.

A pair of spaced electrical brushes 334 and 336 are disposed in the housing 316 so that brush 334 normally engages the conductor 326 as shown in FIGS. 17 and 19. Brush 336 is positioned so as to engage the off-set portion 328 of the conductor. A micro-switch 338 is provided with a switch arm 340 (FIG. 20) which selectively controls the source of power to the coil 318 through the conduit 342.

When the coil 318 is energized, the armature 320 is rotated against the bias of torsion spring 324 which controls the speed of rotation of the armature. During the initial rotation of the armature 320, the brush 334 is in contact with the conductor 326 so that the coil 318 is energized (see FIG. 19). When the armature 318 rotates sufficiently so that the brush 334 disengages from conductor 326, there is a time lapse before brush 336 engages the offset portion 328 of the conductor. The time lapsed is sufficient to allow the solenoid 296 to de-energize and to allow the clutch plate 288 to engage clutch plate 284. When the off-set portion 328 is brought into contact with the brush 336, the coil 276 is energized to allow arm 280 to return to its initial position to reset the timing cycle. Continued rotation of the armature 320 causes the pin 330 to strike the switch arm 340 of micro-switch 338 (FIG. 21) thereby deenergizing the coil 318 and allowing the torsion spring 324 to return the armature 320 to its initial starting position.

The micro-switch 338 is reset to the start position when a switch 344, shown schematically in FIG. 21, is moved against a bias into the closed position. Although the switch 344 may be operated in any suitable manner, it is presently preferred that switch 344 be operated by a loop of flexible though inelastic material (not shown) wrapped around the chest of the user of the apparatus. Thus, when a breath is inhaled, the switch 344 will be closed and when a breath is exhaled the bias on the switch will return the switch to the open position. Accordingly, the rate at which the timing motor 346 operates the speed regulator 250 is determined by the rate of breathing of the user.

Referring now to the schematic circuit illustrated in FIG. 21, it can be appreciated that power from a conventional AC power source may be rectified by a rectifier 348 and, thereafter, conducted to the rheostat coil 312. Also, if desired, a conventional 12-volt battery 350 may be coupled into the rheostat 312. The brush or wiper 310 adjacent the rheostat is electrically connected by a line 314 to the pump motor 20 or 360 above described. The amount of power through the line 314 to the pump motor is determined by the position of the brush 310 and, in turn, the position of the brush 310 relative to the rheostat 312 is determined by the position of shaft 286 (FIG. 17). The position of the shaft 286 is controlled by the clutch engagement with constant speed motor 258 as modified by the interaction of the clutch plates in turn controlled by switches 334 and 336. Thus, the switch 334, controlled by the breathing of the user, also controls the magnitude of the torque motor output which is communicated to the brush 310.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore to be embraced therein.

What is claimed and desired to be secured by United States Letters Patent is:

1. a reversible fluid pump comprising:

a casing;

a unidirectionally rotating shaft journaled in said casing;

a pair of toothed rotors, one of said rotors drivingly engaged by said shaft, an inner one of said rotors disposed eccentrically within an outer one of said rotors as a result of said outer rotor being disposed for rotation in fixed eccentric relationship with respect to said casing, said inner rotor having a series of outward teeth and said outer rotor having a series of inward teeth complementary to and one more in number than said outward teeth, said teeth having diametrically opposed full mesh and open mesh positions as said one rotor rotates and drives the other rotor through interengagement of the respective teeth, each of said inner rotor teeth remaining in contact with said outer rotor during rotation, thereby defining pumping chambers which expand between full mesh and open mesh and which contact between open mesh and full mesh; porting means including a low pressure port and a high pressure port, said porting means disposed for rotation coaxially with said shaft between two positions angularly displaced from one another by substantially less than 90°, at any position of said port-

ing means between said two positions, said low pressure port being in substantial fluid communication with said expanding chambers rotating between full mesh and open mesh and said high pressure port being in substantial fluid communication with said contracting chambers rotating between open mesh and full mesh, each of said ports having an opening, said openings being mutually diametrically oppositely disposed;

a pair of fluid passages fixed in relation to said casing, each of said passages having a pair of orifices, one orifice of each pair being in fluid communication with one of said openings with said porting means disposed at one of said positions, and the other orifice of each pair being in fluid communication with an opposite one of said openings with said porting means disposed at the other one of said positions; and

means for rotating said porting means alternatively between said two positions thereby to cause said two passages to correspondingly alternate between communication with said high pressure port and said low pressure port.

2. A pump according to claim 1 further comprising: pressure relief means including a pressure relief passageway disposed within said porting means and directly interconnecting said high pressure port and said low pressure port and a fluid pressure responsive relief valve disposed in said relief passageway and opening so as to bypass fluid between said ports in response to pressure in said high pressure port in excess of a given pressure.

3. A fluid pump according to claim 1 wherein said pair of fluid passages comprise fluid reservoirs integrally cast within said casing.

4. A fluid pump according to claim 1 wherein said means for rotating said porting means comprises:

a pair of pressure chambers, each in fluid communication with a respective one of said fluid passages at any position of said porting means between said two positions, each of said pressure chambers including one radial wall formed by said casing and at least one radial wall formed by said porting means such that fluid pressure in one of said chambers, resulting from said porting means being in a related one of said two positions so that said high pressure port is in communication with the corresponding one of said passageways, drives the related one of said radial walls formed by said porting means to rotate said porting means toward the other one of said positions; and

a spring-biased toggle means connected between said casing and said porting means to positively drive said porting means to said other one of said positions.

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