

[54] **APPARATUS FOR PUMPING A FLUID**

[72] Inventors: **John Thomas Matthew Wright**,
Southport; **Alan Hilary Calvert**,
London, both of England

[73] Assignee: **National Research Development
Corporation**, London, England

[22] Filed: **June 12, 1970**

[21] Appl. No.: **45,780**

[30] **Foreign Application Priority Data**

June 13, 1969 Great Britain.....30,168/69

[52] U.S. Cl.....**417/394**, 128/1

[51] Int. Cl.**F04b 43/10**, F04b 45/00, A61b 19/00

[58] Field of Search.....417/53, 200, 36, 394, 389,
417/37, 346, 347; 128/1

[56]

References Cited

UNITED STATES PATENTS

2,212,667	8/1940	Mayer.....	417/394 X
2,772,543	12/1956	Berry.....	417/394 X
3,280,749	10/1966	Sennet et al.	417/394 X

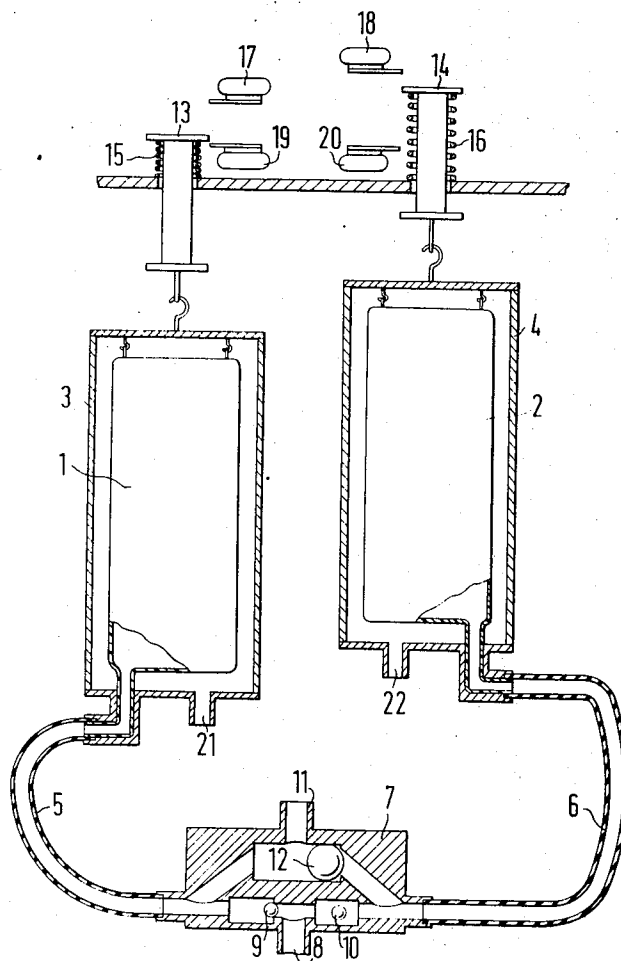
Primary Examiner—Robert M. Walker
Attorney—Cushman, Darby & Cushman

[57]

ABSTRACT

Apparatus for pumping a fluid comprises a plurality of vessels for the fluid, actuator means operable to charge and discharge each vessel, means for connecting each vessel to a common inlet for the fluid while the vessel is being charged and to a common outlet while the vessel is being discharged and control means for controlling the operation of said actuator means in phase sequence to effect substantially continuous pumping between said common inlet and outlet.

5 Claims, 3 Drawing Figures



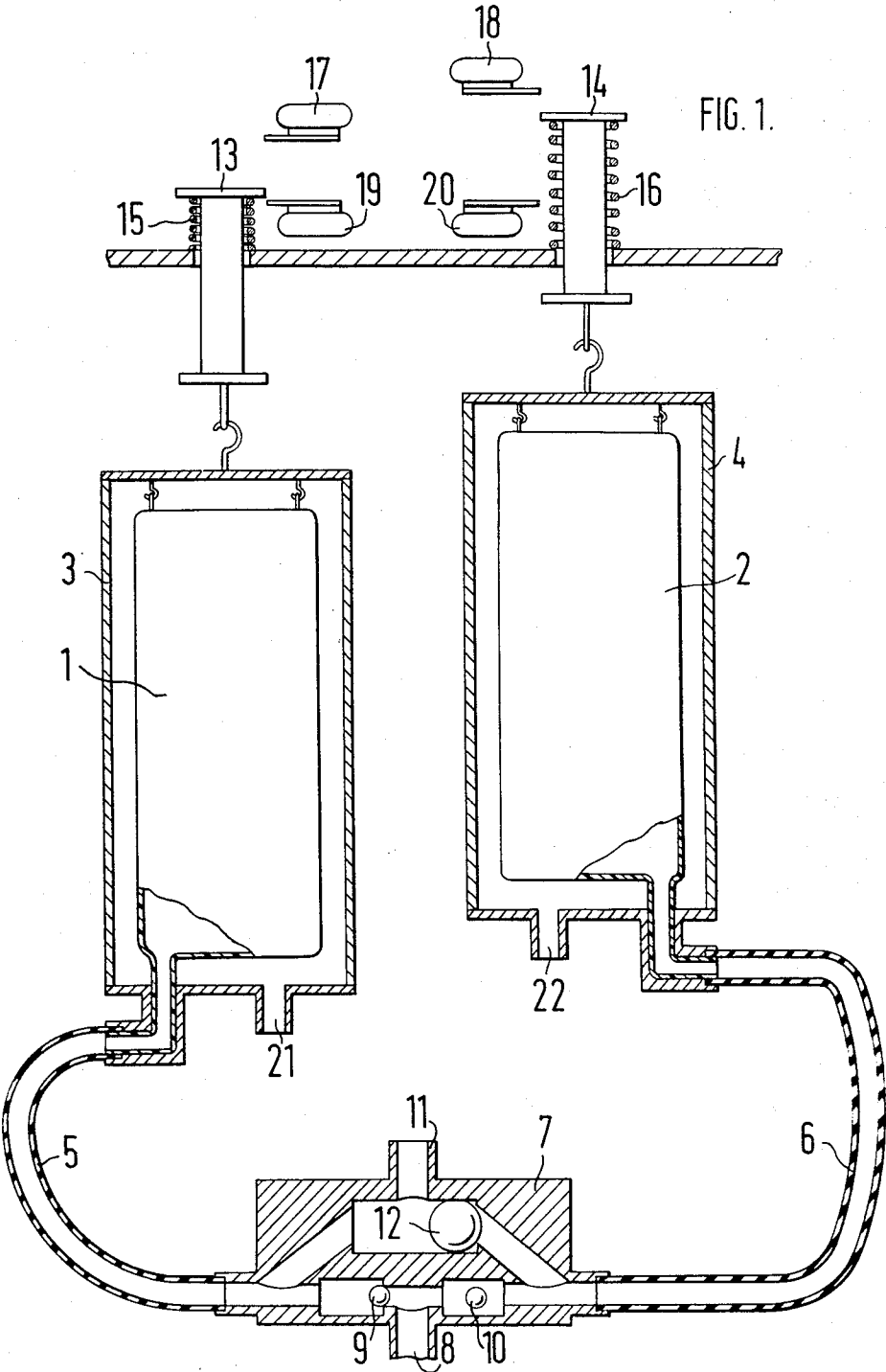


FIG. 2.

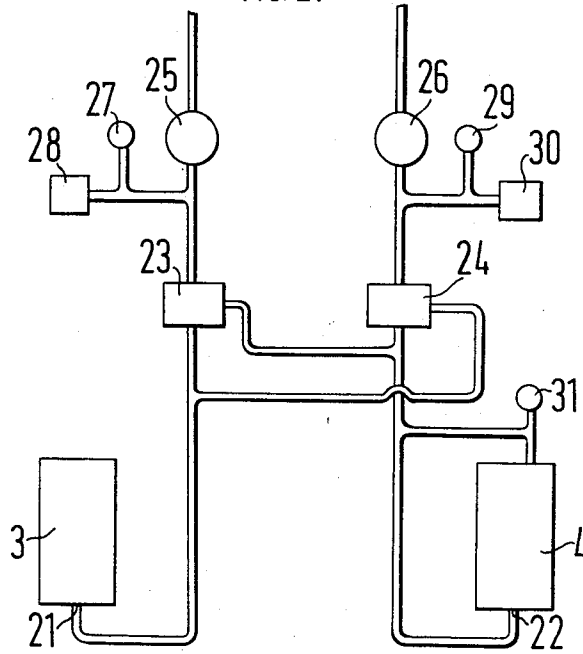
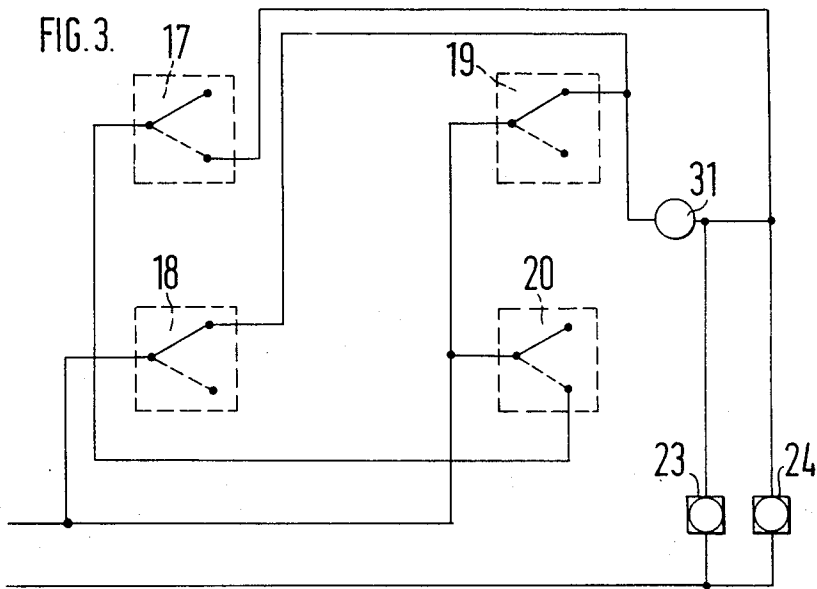


FIG. 3.



APPARATUS FOR PUMPING A FLUID

This invention relates to apparatus for pumping fluids, i.e., liquids or gases and in particular to blood pumps.

Blood pumps for use in the extra corporeal circulation of blood may cause trauma or damage to the blood being pumped. If the pumping time is short, as in open-heart surgery, this trauma, is not extremely critical. If, however, the pumping time is relatively long, as in left heart support following coronary thrombosis, it is important to avoid blood trauma as far as is possible. The pumps, according to the present invention, reduce blood trauma to a low level.

According to the present invention apparatus for pumping a fluid comprises a plurality of vessels for the fluid, actuator means operable to charge and discharge each vessel, means for connecting each vessel to a common inlet for the fluid while the vessel is being charged and to a common outlet while the vessel is being discharged and control means for controlling the operation of said actuator means in phase sequence to effect substantially continuous pumping between said common inlet and outlet.

According to one embodiment of the present invention, the actuator means operates to charge and discharge each vessel by respectively lowering or raising the vessel relative to a common inlet or outlet. When a vessel is raised with respect to the outlet, fluid contained therein flows under gravity to the outlet, with which the vessel is then connected. Simultaneously fluid passes under gravity into a second vessel connected to the inlet and situated at a lower level.

According to the preferred embodiments of the present invention however, the actuator means comprises a rigid container enclosing each of the vessels, which are flexible, and means for decreasing and increasing the pressure of a working fluid (a liquid or gas) within each rigid container. Preferably two vessels are used, and in operation one of these is distended while the other is collapsed so that fluid moves from the inlet of the pump into the vessel which is distended, while fluid moves from the vessel which is collapsed to the outlet of the pump. When the first vessel is substantially full and the second substantially empty the operation of actuator means is reversed, to collapse the first vessel and distend the second, the connections of the vessels to the inlet and outlet being also reversed, so that the pumping action is continuous. The vessels can be in the form of bags whose walls are made of a flexible material, each bag being provided with a single opening. When blood is pumped, for example, air may be pumped in and out of the rigid container. Thus the movement of the walls of the flexible vessel takes place smoothly, and the blood is handled gently. The vessels should have as large a capacity as is convenient, so that the rate of changeover from one vessel to another is slow. For example, if two bags each having a capacity of 1 liter are used then the period between changeover is 30 seconds for a flow rate of 2 liters per minute.

When blood is pumped the flexible bags are preferably mounted so that the opening is at the bottom of the bag and is above the main inlet and outlet of the pump, so that any air which may enter the system will float to the top of the bag and be trapped there, and thus will not enter the blood-stream of the patient. It is

convenient if the bags and the surrounding rigid container and other blood-handling parts are made as far as possible of transparent materials, so that air bubbles can easily be seen.

When blood is pumped the increase and decrease of pressure within the rigid containers may be accomplished by means of an air pump arranged to supply pressure and an air pump arranged to supply suction and valves to connect one air pump or the other to each rigid container as appropriate. Pressure and suction regulating valves may be attached to the air pumps to control the rate at which air is pumped to and from the rigid containers, and this will, in turn, under normal running conditions, control the rate at which the blood is pumped and limit the delivery pressure and suction applied to the patient. A rise in the patient's arterial blood pressure will however cause the pumping rate to decrease and pumping will finally stop if the rise is sufficient.

The valves connecting the air pumps to the rigid containers must be controlled so that each of the flexible containers is distended and collapsed in the required manner. This may be done by suspending each of the rigid containers from a weighing device equipped with switches which are operated when the bag is relatively full and empty and which control the valves through a servo-mechanism.

The flexible containers may be connected to the outlet and inlet of the pump through pressure-responsive changeover valves arranged to open the connection to the inlet and block off the connection to the outlet while the container is being distended and vice versa when the container is being collapsed.

Preferably the blood handling parts of the pump are designed so that they can be separately sterilized.

A particular embodiment of the invention designed for pumping blood will now be described with reference to the accompanying diagrams, of which FIG. 1 represents the general arrangement of the apparatus, FIG. 2 represents the pneumatic circuit, and FIG. 3 represents the electrical circuit.

Referring to FIG. 1, two 1-liter P.V.C. bags 1 and 2 are each contained within a rigid airtight cylinder, respectively 3 and 4. The bags are connected by flexible pipes, 5 and 6, to a common valve block 7. An inlet 8 for the blood is connected to the pipes 5 and 6 through non-return valves 9 and 10 in the valve block 7, and an outlet for the blood 11 is connected to the pipes 5 and 6 preferably through a high pressure selector valve 12 in the valve block 7 or alternatively through two other non-return valves (not shown). The balls in the valves 9, 10 and 12 are made of soft silicon rubber. The cylinders 3 and 4 are suspended from sliding pillars 13 and 14, which are supported by calibrated compression springs 15 and 16. Four micro-switches 17, 18, 19 and 20, are arranged so that the switches 17 and 18 are operated by the pillars 13 and 14 respectively, when the pillars rise and switches 19 and 20 are operated by the pillars 13 and 14, when the pillars sink. Outlets 21 and 22 are provided opening into the cylinders 3 and 4.

Referring now to FIG. 2, the outlets 21 and 22 are connected through valves 23 and 24 to a suction pump 25 and a pressure pump 26, in such a way that when the solenoid valves 23 and 24 are not energized, cylinder 3

is connected to the pressure pump 26, and cylinder 4 is connected to the suction pump 25 and vice versa when the valves are energized. The partial vacuum provided by the suction pump 25 is indicated by a gauge 27 and controlled by a suction regulator 28, and the pressure provided by the pressure pump 26 is indicated by a gauge 29 and controlled by a pressure regulator 30. An electrical pressure switch 31 which is set to make at about 40 mm.Hg. (a lower pressure than the minimum pressure to be pumped), is connected to the line leading to cylinder 4.

Referring now to FIG. 3, the connections made by the micro-switches 17, 18, 19 and 20, when the switches are in their normal positions, are shown in unbroken lines, and the connections made when the switches are operated by the pillars 13 and 14 are shown in broken lines. It will be seen that when the switches are in their normal positions the solenoid valves 23 and 24 are not connected to the power source and thus are not operated unless the pressure switch 31 is made. When both the switches 17 and 20 are operated a direct connection by-passing the pressure switch 31 is made. When both the switches 18 and 19 are operated the connection via the pressure switch 31 is broken.

The pump operates as follows:

Assume that both of the bags 1 and 2 are half full of liquid when the pump is switched on. All of the switches 17, 18, 19 and 20, will be in their normal positions, and the pressure switch 31 will not be made so that the solenoid valves 23 and 24 will not be energized. Thus the cylinder 3 will be connected to the pressure pump 26 so that the bag 1 is compressed, and cylinder 4 will be connected into the suction pump 25 so that the bag 2 will be distended. The pressure transmitted through the pipe 5 and the suction transmitted through the pipe 6 will cause the ball valve 9 to close off the pipe 5 from the inlet 8 and will cause the valve 10 to open the tube 6 to the inlet 8, and will also cause the valve 12 to open the tube 5 to the outlet 11 and close the tube 6 to the outlet 11. Thus liquid will be forced out of the bag 1 causing the cylinder 3 and the pillar 13 to rise, and liquid will be drawn into the bag 2 causing the cylinder 4 and the pillar 14 to sink.

When the pillar 13 has risen sufficiently it will operate the switch 17, and when the pillar 14 has fallen sufficiently it will operate the switch 20. The solenoid valves 23 and 24 will then be energized so that the pressure pump 26 will be connected to the cylinder 4 compressing the bag 2 and operating the pressure switch 31, and the suction pump 25 will be connected to the cylinder 3 distending the bag 1. The suction transmitted through the pipe 5 and the pressure transmitted through the pipe 6 will cause the positions of the valves 9, 10 and 12 to be reversed so that liquid will be drawn into the bag 1 and forced out of the bag 2. Thus cylinder 3 will begin to sink and cylinder 4 will begin to rise. The pillars 13 and 14 will therefore no longer operate the switches 17 and 20 which will return to their normal positions. However, the solenoid valves 23 and 24 will remain connected to the power source as the pressure switch 31 is operated.

When the pillar 13 has fallen sufficiently it will operate the switch 19, and when the pillar 14 has risen sufficiently it will operate the switch 18. The connec-

tion of the solenoid valves 23 and 24 to the power source via the pressure switch 31 will then be broken and they will no longer be energized. Thus the cylinder 3 will again be connected to the pressure pump 26, and the cylinder 4 will again be connected to the suction pump 25. The pressure switch 31 will not be made and the cycle will be repeated.

When a pump according to the invention is used for pumping fluids other than blood the working fluid can be either a liquid or a gas. Particular applications include the pumping of gases at very high pressures, in which case the working fluid may be oil or water and the pumping of liquid oxygen and other fluids which are manipulated with difficulty.

We claim:

1. A blood pump comprising:

a plurality of flexible vessels to contain blood;
a plurality of rigid containers each enclosing a respective one of said vessels, said vessels and containers being transparent so as to allow visual monitoring of the blood in the vessels;

an actuator means to apply and withdraw a working fluid to and from each of said containers to respectively collapse and distend said vessels, said actuator means providing a pressure of working fluid such that the pressure of the pumped blood is of a similar order to human blood pressure;

a plurality of blood flow conduits having a common inlet and a common outlet and connections therebetween with an opening disposed at the base of each of said vessels and above at least one of the common inlet and common outlet so as to avoid the formation of stagnant areas in the vessels and prevent transfer of air to the outlet;

a plurality of valves respectively associated with said vessels forming part of said connections and each having two states to respectively communicate the associated vessel with said inlet and said outlet when such vessel is distended and collapsed;

a sensor means to detect the amount of blood in at least one of said vessels; and

control means responsive to said sensor means to control said actuator means and said valve states in predetermined phase sequence to effect substantially continuous pumping between said common inlet and outlet.

2. Apparatus according to claim 1, comprising a plurality of weight-sensing devices, each one coupled with a respectively different one of said vessels, each operable to switch said control means from one phase to another in said sequence in response to a predetermined weight of fluid in the respective vessel.

3. A blood pump for extra corporeal circulation of blood, comprising:

a plurality of rigid fluid-tight cylinders;

a flexible fluid-tight container received in each cylinder;

a plurality of first conduits, each communicating through each respective cylinder with the inside of the flexible container received in such cylinder;

a plurality of second conduits, each communicating through each respective cylinder with the exterior of the flexible container received in such cylinder;

a pump means communicating with each of the second conduits for selectively pressurizing and partially

5

evacuating the region within the respective cylinders, exteriorly of the flexible containers received in such cylinders;

a blood inlet conduit for receiving blood flowing extra-corporeally;

a valve block;

all of said first conduits, said blood inlet conduit and said blood outlet conduit being connected to the valve block;

first check valve means in the valve block for selectively automatically communicating the blood inlet conduit with such of said first conduits as serve a said flexible container received in a said cylinder undergoing partial evacuation induced by said pump means and for stopping communication of the blood inlet conduit with such of said first conduits as serve a said flexible container received in a said cylinder undergoing pressurization induced by said pump means;

second check valve means in the valve block for selectively automatically communicating the blood outlet conduit with such of said first conduits as serve a said flexible container received in a said cylinder undergoing pressurization induced by said pump means and for stopping communication of the blood outlet conduit with such of said first conduits as serve a said flexible container received in a said cylinder undergoing partial evacuation induced by said pump means;

means for sensing the amount of blood in each flexible container;

control means controlling said pump means to alternately pressurize and partially evacuate said regions within the respective cylinders, through the respective second conduits;

and signalling means functionally interconnecting the sensing means with the control means for signalling the control means to

a. partially evacuate said region within each respective cylinder whose flexible container does not yet contain a first, predetermined, larger amount of blood until such first, predetermined amount is contained in such flexible container, and then to

b. pressurize said region within each respective

6

cylinder whose flexible container contains in excess of a second, predetermined, smaller amount of blood until such second, predetermined amount is contained in such flexible container;

and means for staggering the operation of said pump means to generally continuously provide filling of at least one said flexible container and emptying of at least another said flexible container;

the means for sensing the amount of blood in each flexible container being constituted by:

a fixed support;

means independently securing each cylinder, for support, to the fixed support and being configured to provide for limited movement of the respective cylinders vertically toward and away from the fixed support;

spring means associated between each cylinder and the fixed support for permitting gravity induced vertical movement of each respective cylinder in one sense when the flexible container received therein is one being filled with and emptied of blood and for permitting spring restoration force-induced vertical movement of each respective cylinder in the opposite sense when the flexible container received therein is being the other of emptied of and filled with blood;

first sensing means for each respective cylinder mounted to move therewith;

and second stationarily-mounted sensing means for each respective cylinder,

respective of said first and second sensing means being juxtaposed to activate said signalling means when the respective first and second sensing means become collocated.

4. The blood pump of claim 2 wherein the flexible containers are constituted by synthetic plastic film bags.

5. The blood pump of claim 2 wherein the connection of the blood outlet conduit to the valve block lies below all the cylinders, and the first conduits connect with the respective flexible containers at the lower extents thereof to reduce the possibility of transferring air from within the flexible containers to the blood outlet conduit.

* * * * *

50

55

60

65