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**3,406,633**

## COLLAPSIBLE CHAMBER PUMP

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**FIG. 1**

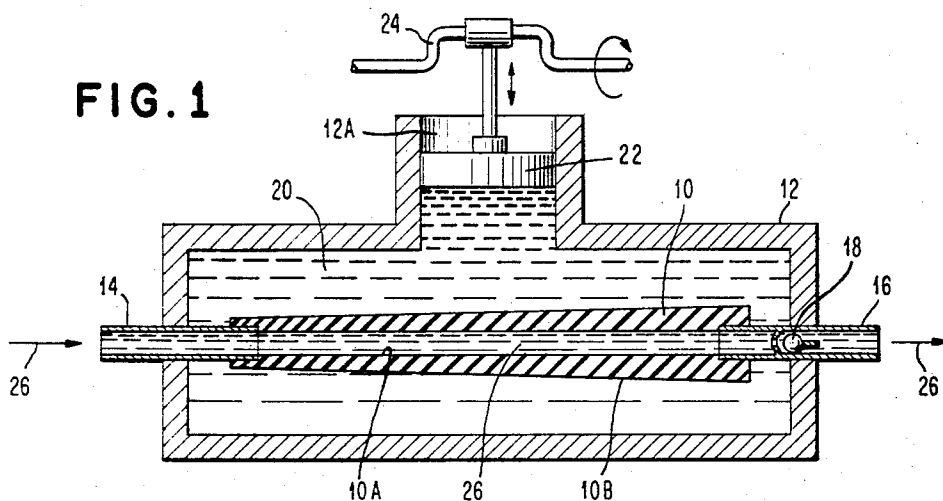


FIG. 2

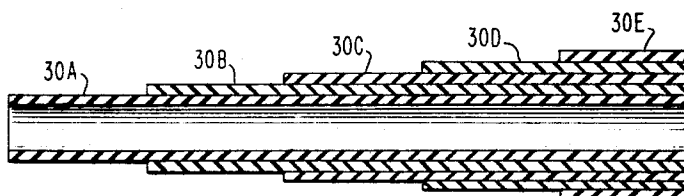


FIG. 3

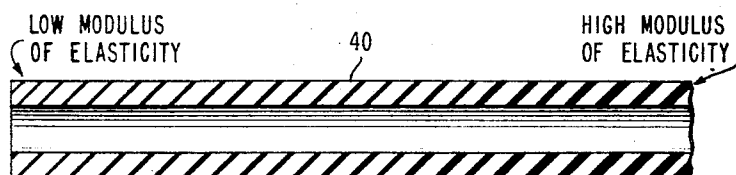


FIG. 4

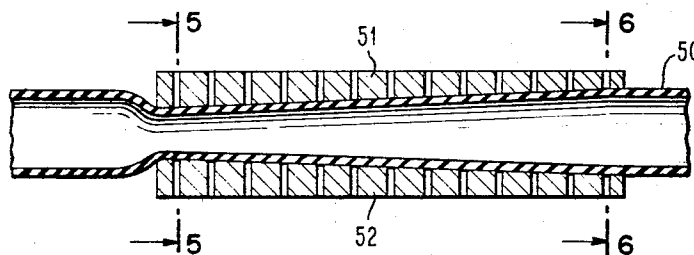


FIG. 5

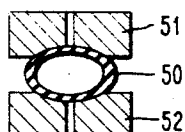
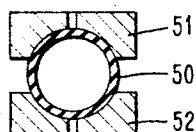


FIG. 6



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## COLLAPSIBLE CHAMBER PUMP

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### ABSTRACT OF THE DISCLOSURE

Fluid pumping action is obtained by surrounding an elongated collapsible chamber with a fluid capable of exerting varying pressure on the collapsible chamber. The chamber has a resistance to collapse varying along its length from a lesser resistance at its fluid inlet to a greater resistance at its fluid outlet. As the pressure of the fluid surrounding the chamber increases the chamber collapses progressively from its inlet to its outlet to thus expel the fluid contained therein.

This invention relates to hydraulic pumps, and more particularly to an improved collapsible chamber pump.

The pumping of body fluids, particularly blood, imposes severe restrictions on the design of a pump intended for this purpose. Not only must the sterility of the pumped fluid be preserved, but also the fluid, in the case of blood, must not be subjected to excessive mechanical forces that would cause the blood cells to rupture. A pump that has hitherto been used for this purpose is the peristaltic pump, wherein rollers move cyclically over a length of resilient tubing to cause a progressive localized flattening of the tube to propel the liquid therethrough ahead of the constriction, and to provide a reduced pressure behind the constriction to introduce more fluid into the tubing for propulsion by the next following roller. Another form of elastic chamber pump is one wherein the elastic pumping chamber, provided with inlet and outlet check valves, is surrounded by a hydraulic fluid which is subjected to a variable pressure to cause the elastic chamber to alternately collapse and expand to respectively expel the fluid therein and receive new fluid. The instant invention combines the features of the peristaltic pump and the fluid pressure actuated collapsible chamber pump. It employs an elongated collapsible pumping chamber with a check valve at its discharge end enclosed in a surrounding hydraulic fluid medium which is subjected to a varying hydraulic pressure, the collapsible chamber having a resistance to collapse which increases towards the discharge end thereof. When the pressure in the surrounding fluid is increased, the pumping chamber collapses first at the inlet end, the collapse progressing along the length of the chamber as the actuating pressure is increased. As the collapse of the chamber progresses along the length of the pumping chamber, the fluid therein is propelled through the chamber in advance of the advancing collapse. When the chamber is fully collapsed and the actuating pressure begins to decay, the check valve closes to prevent backflow of the discharged fluid. While the resiliency of the chamber tends to return the chamber to its non-collapsed condition, the reduced pressure within the chamber prevents this restoration until the pressure reduces to a level wherein the resiliency of the inlet end is sufficient to open the chamber to a new charge of fluid. This effectively breaks the vacuum within the chamber allowing it to fill with a new charge of fluid in preparation for the next pumping stroke.

By the foregoing arrangement the pumping chamber itself acts as a check valve at the inlet end. Additionally, because the pumping chamber is entirely surrounded

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by the activating fluid, the pumping pressure is not limited by the rupture strength of the collapsible chamber, as is the case in the peristaltic pump. Further, because of the progressive collapse of the pumping chamber, the flow of fluid out of the pump is non-turbulent and substantially free from pressure surges. The sudden expansion of the chamber to admit new fluid into the chamber produces a scrubbing or self-cleaning action which is particularly useful in continuous stream blood analyses to prevent cross contamination of successive blood samples. Since hydraulic actuation is inherently more gentle than mechanically applied forces, the problem of ruptured blood cells is obviated by the instant invention.

In accordance with the foregoing brief description it is an object of this invention to provide a collapsible chamber pump having a chamber with a variable resistance to collapse varying as a function of the length of the chamber with a unidirectional flow valve disposed within the flow path at the end of the chamber having the greater resistance to collapse disposed within a surrounding actuating fluid which is subjected to cyclical variations in pressure, to cause the collapsible chamber to alternately receive and expel fluid as the chamber expands and collapses.

A further object of the invention is to achieve the variable resistance to collapse in accordance with the foregoing object by forming the chamber with a variable cross-section progressively stiffer along the length of the chamber.

Yet another object is to achieve the variable resistance to collapse by fabricating the collapsible chamber with a material having a modulus of elasticity varying along the length of the chamber.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings.

In the drawings:

FIG. 1 is a schematic cross-sectional view of the collapsible chamber pump.

FIG. 2 is a cross-sectional view of an alternative form of pumping chamber.

FIG. 3 is a cross-sectional view of a further form of pumping chamber.

FIG. 4 is a cross-sectional view of yet another form of pumping chamber.

FIG. 5 is a cross-section taken on the line 5—5 of FIG. 4.

FIG. 6 is a cross-section taken on the line 6—6 of FIG. 4.

The basic principle of the invention is schematically illustrated in FIG. 1. The collapsible pumping member 10 is fabricated from a flexible elastic material such as synthetic rubber with a uniform internal bore 10A and a tapered exterior 10B such that the wall thickness increases from left to right, resulting in a minimum resistance to collapse at the left end and a maximum resistance to collapse at the right end. The pump chamber 10 is sealed in the pressure chamber 12 by fluid-tight connections with the tubular fittings 14 and 16 which are in turn led in fluid-tight connections through the housing 12 for external connection to the fluid supply and utilization device. Disposed within the tubular fitting 16 is a check-valve 18, shown as a ball valve, which permits unrestricted flow from left to right, but restricts flow in the opposite direction. Surrounding the pumping chamber 10 and completely filling the housing 12 is a fluid 20 which is cyclically pressurized by reciprocation of piston 22 within the cylindrical bore portion 12A of housing 12. Piston 22 is reciprocated by rotation of the crank 24.

With the pump in position shown in FIG. 1, the fluid 20 is at atmospheric pressure, and the chamber 10A by virtue of its inherent elasticity has expanded to fill the bore 10A with fluid 26 through the inlet connection 14, during which filling operation the check valve 18 remains closed to prevent backflow of fluid from the discharge pipe 16 into the pumping chamber. As the crank 24 rotates and the piston 22 descends to increase the pressure of the fluid 20 within the chamber 12, the pump chamber 10 begins its collapse at its left end causing the inner bore 10A to flatten and seal off the inlet. As the pressure increases the collapse of the chamber 10A progresses from left to right, thus forcing the fluid in the chamber 10A ahead of the collapse and out through the check valve 18 and the discharge tube 16. When the chamber is fully collapsed and the piston 22 begins its return stroke to reduce the pressure in chamber 12, the check valve 18 closes under the difference in pressure between the fluid in the discharge pipe 16 and the collapsed chamber 10A, now seeking to expand under its own resilience, but restrained by the sub-atmospheric pressure entrapped therein by closure of valve 18 and the collapse of the inlet side of the chamber. When, however, the pressure in the activating fluid 20 descends to a level at which the inherent resilience of the left end of the chamber is sufficient to break the seal to the chamber 10A and permit entry of a new charge of fluid into the pumping chamber, the member 10 now expands rapidly as the piston ascends to increase the volume in chamber 12 to permit the expansion of the resilient pumping member 10. It should be noted that when the pumping member 10 is fully collapsed and the piston 22 begins its ascent, the pumping member 10 retains its collapsed shape because of the sealing off of the chamber 10A at both ends. Since the activating fluid 20 is incompressible, any increase in the volume of chamber 12 results in an instantaneous pressure drop in the chamber to atmospheric pressure to break the seal at the left end of chamber 10A. The expansion of the pumping member 10 then follows the retrograde movement of piston 22 increasing in volume as permitted by a corresponding increase in volume in the chamber 12.

While in FIG. 1 the collapsible pumping chamber 10 has been shown with a uniform interior bore and a tapered exterior to yield a uniformly increasing wall thickness from left to right, it is equally possible to fabricate the pumping member with a tapered interior chamber and a uniform exterior configuration. Alternatively the pump member may have a stepped configuration such as that shown in FIG. 2 wherein the member 30 is fabricated from a plurality of closely fitting tubes 30A through 30E each progressively shorter than the preceding tube, cemented or otherwise molded together to form a unitary structure.

A further embodiment, as shown in FIG. 3, employs an elastic pumping member 40 having a uniform cross-section but a variable modulus of elasticity so as to produce a member which is relatively limber at its left end and increasing in stiffness toward the right end. This progressive change in the modulus of elasticity is indicated by the progressive shading in FIG. 3. This variable elasticity can be achieved by forming the member 40 with a uniform plasticity and then immersing the member in a solvent which will selectively leach out the plasticizer and slowly withdrawing the member in a vertical direction parallel to the axis of the member. By suitably adjusting the withdrawal rate each incremental volume of the member 40 will be subjected to a different amount of leaching. This produces the uniform variation in the modulus of elasticity throughout the length of the member. By a similar "candle-dipping" process the tapered structure of FIG. 1 may also be formed.

Another means for varying the resistance to crushing along the length of the pumping member is shown in FIG. 4. In this form, an initial deformation is applied to the pumping member 50 by the opposed tapered

saddles 51 and 52 which are perforated to permit the activating fluid to have free access to the tubing walls. The most severe deformation is applied to the left end of the tubing to force it to occupy a nearly flattened condition. The progressive taper formed by the saddles 51 and 52 causes a less severe deformation of the tubing 50 along its length to the right, so that at the right end of the tubing will be substantially non-deformed. When progressively increasing pressure is applied to the activating fluid surrounding the pumping member the initial stress induced by the saddles 51 and 52 coupled with the fluid pressure causes the progressive collapse of the tubing. The cross-section of the progressive tubing deformation induced by the saddles 51 and 52 is shown in FIGURES 5 and 6.

Whatever form is adapted for the collapsible pumping chamber it is necessary that the collapse of the chamber under an increase of pressure of the actuating fluid progress along the chamber and that the chamber seal off the inlet duct as it collapses. By appropriate selection of chamber sizes and volumes, the delivery of a given pumping chamber may be chosen according to the needs of the particular application. So too by varying the cycle rate of the pressure variations in the chamber may the delivery rate be varied. In a multiple channel pump a plurality of collapsible chambers may be enclosed within the same pressuring chamber, each collapsible chamber being chosen for a specific rate of discharge. This is analogous to employing multiple tubes in a common roller peristaltic pump, wherein the diameter of each tube is chosen to deliver a measured volume of fluid for each stroke of the roller.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that the foregoing and other changes in form and details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A fluid pump comprising:

- (a) an elongated elastic collapsible pumping chamber means having a fluid inlet duct and a fluid discharge duct and having a resistance to collapse progressively varying along the length of said chamber from a lesser resistance at said fluid inlet duct to a greater resistance at said fluid discharge duct;
- (b) a unidirectional check valve means for preventing backflow in said discharge duct of fluid to be pumped;
- (c) pressure chamber means containing an immersing pumping fluid surrounding the exterior of said collapsible chamber means;
- (d) and means for cyclically varying the pressure of said immersing pumping fluid in said pressure chamber means to cause cyclic collapse of said pumping chamber means;
- (e) whereby as the pressure in said immersing fluid is increased the collapse of said pumping chamber means progresses along the length of said latter chamber toward the discharge end thereof to expel the fluid to be pumped from said chamber means, and when the pressure in said immersing fluid is decreased said pumping chamber means expands to receive fluid from said inlet duct, the said check valve means preventing the backflow of the pumped fluid from said discharge duct into said pumping chamber means.

2. The pump of claim 1 wherein said collapsible chamber means is fabricated from an elastic material in the general configuration of a tube having a uniform bore and a tapered exterior to provide a chamber means having a varying wall thickness which provides the variable resistance to collapse.

3. The pump of claim 1 wherein said collapsible chamber means is fabricated from an elastic material and the general configuration of a tube having a uniform

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internal bore and stepped external shape whereby the wall thickness of the chamber means increases in a plurality of discrete steps to achieve the variable resistance to collapse.

4. The pump of claim 1 wherein said collapsible chamber means is fabricated from an elastic material having a modulus of elasticity varying along the length of the chamber means to provide the variable resistance to collapse.

5. The pump of claim 1 wherein said collapsible chamber means is fabricated of an elastic material in tubular configuration and restraining means are provided to exert upon said chamber means a flattening force variable along the length of the chamber means, the chamber means being most flattened at the inlet end thereof

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and least flattened at the discharge end thereof, whereby the variable resistance to collapse under the influence of the pressure in the said immersing fluid is progressive along the length of the chamber means.

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