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[54] SURGICAL PUMP

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[52] U.S. Cl. ....417/326, 128/DIG. 3, 128/214 R, 417/383, 417/385, 417/478, 417/479
[51] Int. Cl. F04b 35/02
[58] Field of Search ....417/383–389, 394, 417/395, 478, 326, 479; 128/1 D, DIG. 3

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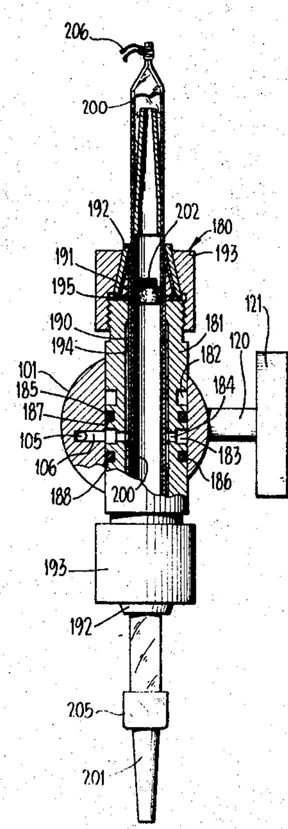
[57] ABSTRACT

This invention relates to a surgical pump primarily designed for the pumping of blood, as in open-heart surgery or for pumping blood through a "kidney machine," but also particularly adapted for other surgical uses, such as pumping dialycate in a "kidney machine," or the like; and is characterized by the fact that it provides direct and continuous volumetric adjustment from 0 to the maximum size of the pump even while in use; is small in size and light-weight; is readily adjustable as to the force applied to the liquid being pumped, and has independently adjustable timing of the diastole and sistole portions of a pumping cycle.

14 Claims, 8 Drawing Figures



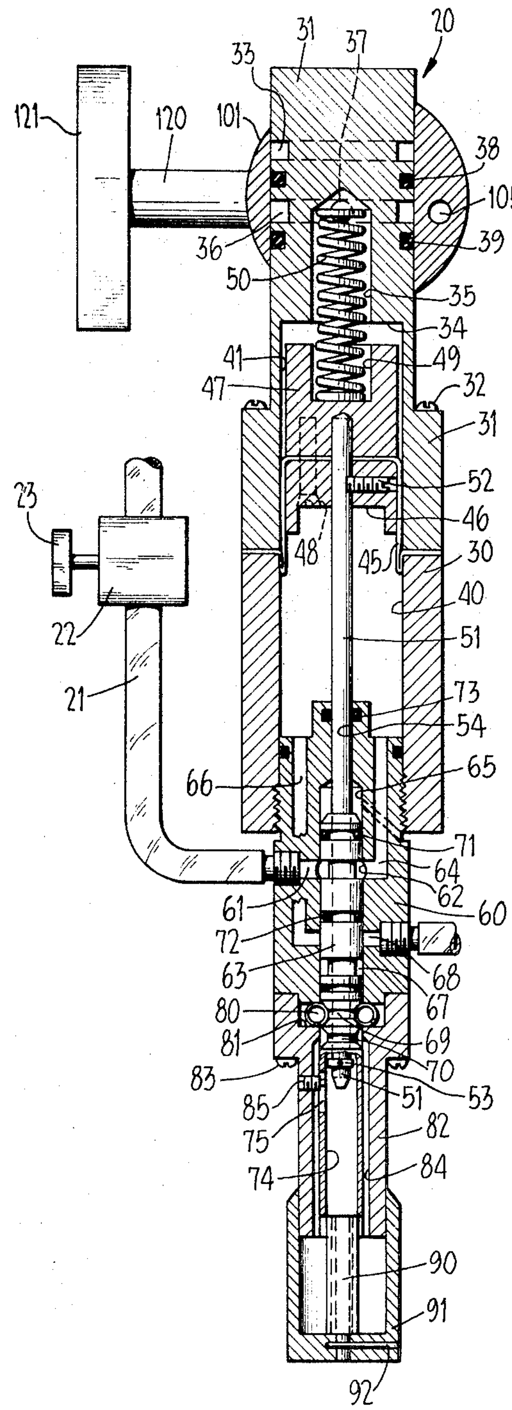


Fig_2

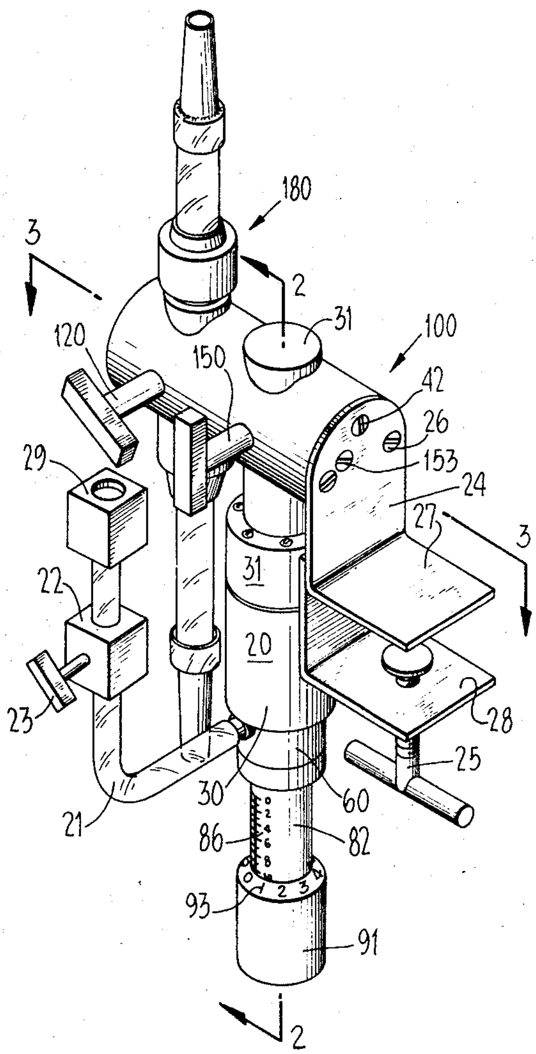


Fig_1

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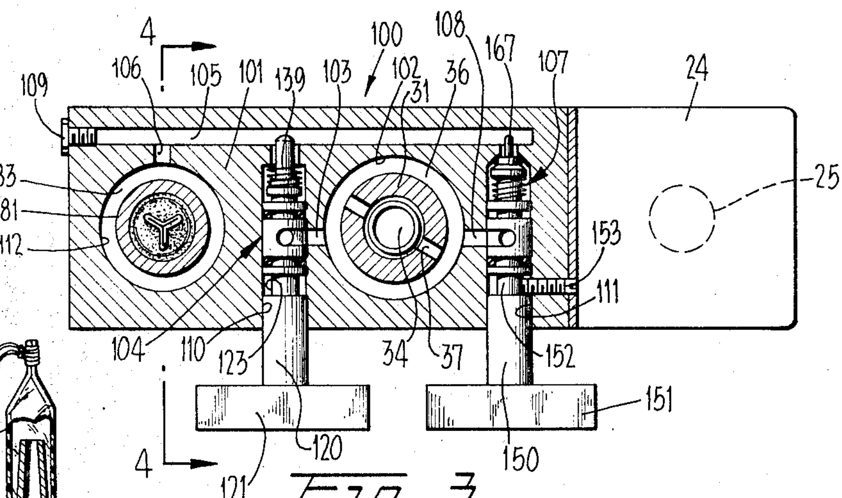

Fig_3

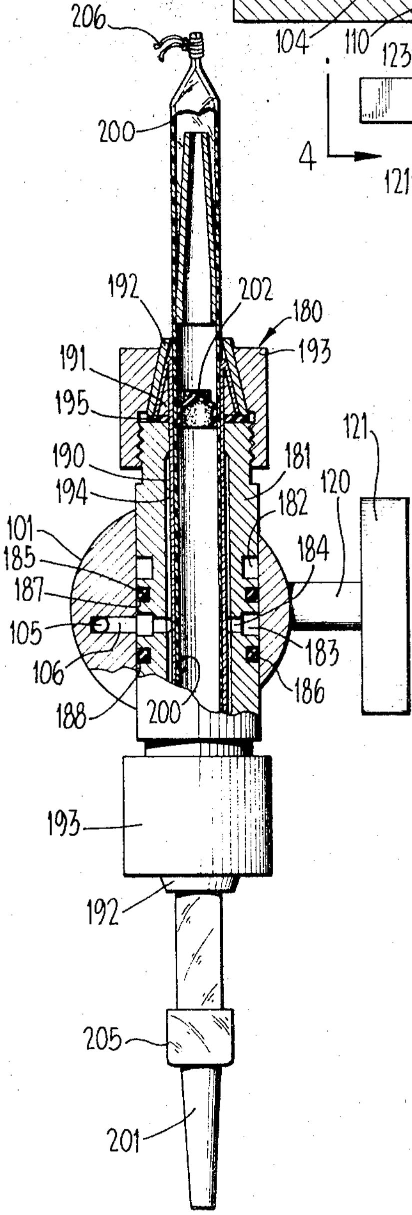

Fig_4

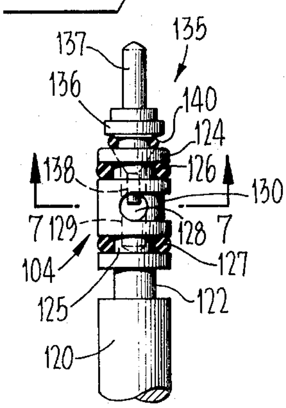

Fig_5

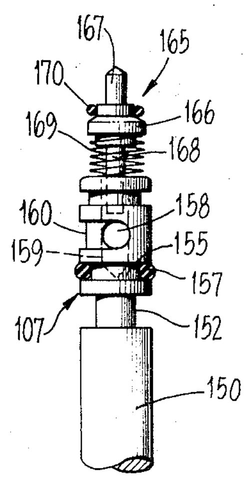

Fig_6

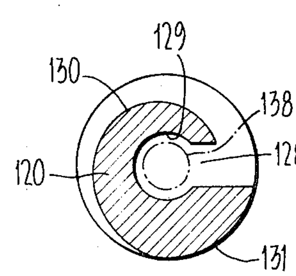

Fig_7

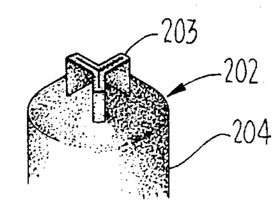

Fig_8

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SURGICAL PUMP

BACKGROUND OF THE INVENTION

One of the miracles of modern medical science has been the great development of open-heart surgery, a great deal of which requires the use of a heart bypass pump during the surgery. Another of the modern miracles is the artificial kidney machine, which passes blood through the artificial kidney where it is purified. One of the prime requisites of such a pump is that it have low platelet destruction and low hemolysis. The first pumps were quite destructive of blood cells, because there was a rubbing, or grinding, effect which burst the cells. This was overcome by passing the blood through a sterile tube, one end of which received blood from the body and the other end of which returned it to the body or treating apparatus; providing a short section in the tube delineated by one-way valves; and applying a pulsing pressure to the walls of the delineated section of the tube as by the periodic compression from a hydraulic source. Examples of this type of pump are shown in the patents to Birtwell, U.S. Pat. No. 3,099,260, Wilson, U.S. Pat. No. 3,551,076, and Huffman, et al., U.S. Pat. No. 3,550,162. The present invention utilizes a pump of this general nature in which an easily replaced and disposable sterile tube having a short pump section which is separated from the balance of the tube by a one-way flow valve at each end, each of which allows flow in the same direction, and systematically and continually applying a squeezing pressure around the tube and alternately applying a vacuum around the tube so as to suck in more blood. The present invention differs from the prior art in that the sterile blood tube is inserted through the pump and the hydraulic fluid which applies the pumping and vacuum pressure thereto does not come in contact with the tube, so that the pump and its contents does not need to be sterile; and the blood tube does not need to be sealed to the pump to complete the assembly. Also, preferably, an improved type of one-way valve is used which will do less damage to the blood cells.

One of the advantages of the present invention, in its preferred form, lies in the fact that the volume of blood, or other liquid, pumped in each stroke and thereby, indirectly, the blood pumped, is infinitely variable from 0 to the maximum capacity of the pump and adjustments can be made easily and accurately while the pump is in operation. Another advantage is that the force applied to the blood conduit is also variable over a considerable range, and adjustments may also be made while the pump is in operation. Additionally, both the duration of the diastole and the sistole strokes are independently adjustable and again the adjustments can be made while the pump is in operation. The pump is driven and controlled without electrical power, thereby reducing hazards from the breakdown of electrical equipment or a failure in the electrical system or power supply, and cumbersome equipment at the operating site. The pump is preferably powered by water pressure from the water system of the hospital. Water pressure taken directly from the cold water line is a more reliable source of power than electricity, as hospitals generally have an independent water storage tank on the roof to guarantee a supply of water at all times. The pressure exerted by water from this system is much greater than that needed for the operation of

the pump of the present invention, thereby avoiding the danger of electrical power failure. The unit is small and light and, therefore, may be clamped to the operating table, a gurney, or other equipment near the patient as may be required.

Since the pump of the present invention has adjustable timing, adjustable pressure and independently adjustable diastolic and sistolic timing, a single pump may be used for the full spectrum of surgical needs, from a newborn baby to a well-developed athlete. Since the adjustments can be made while the pump is in operation, the pump has built-in compensation for a change in the physical condition of the patient during an operation.

OBJECTS

It is a primary object of the invention to provide a small, light-weight surgical pump which can be used through a wide range of physical conditions.

It is a further object of the present invention to provide a surgical pump with an infinitely variable volumetric adjustment.

It is another object of the present invention to provide a surgical pump in which the pressure to be applied to the liquid to be pumped can be adjusted over a wide range, even while the pump is in operation.

It is another object of the present invention to provide a pump with independently adjustable timing of the diastole and sistole functions.

It is still a further object of the present invention to provide a pump suitable for heart bypass use which has low blood platelet destruction and hemolysis and which accordingly will do little damage to the blood being recirculated by it.

It is still a further object of the present invention to provide a surgical pump which, in itself, does not have to be sterilized, since only the tube through which the blood or other liquid passes needs to be sterile, and that tube is easily inserted through the pumping section of the present invention and may be disposed of after use.

These and other objects of the present invention will be apparent from the specification which follows, taken in conjunction with the accompanying drawings in which:

FIG. 1 is a perspective view on a reduced scale of the preferred form of pump of the present invention.

FIG. 2 is a cross-sectional view of the power section of the pump of FIG. 1, such as taken along the plane indicated by the line 2—2 of FIGS. 1 and 3.

FIG. 3 is a cross-sectional view of the control section of the pump, such as taken along the plane indicated by the line 3—3 of FIGS. 1 and 2.

FIG. 4 is a cross-sectional view of the pump section of the pump of the present invention, such as taken along the plane indicated by the line 4—4 of FIG. 3.

FIG. 5 is an enlarged view of the one-way control valve 104 which controls the flow of pressure liquid during the pumping stroke.

FIG. 6 is an enlarged view of the one-way control valve 107 which controls the flow of pressure liquid during the suction stroke.

FIG. 7 is an enlarged cross-sectional view of the control valve shown in FIG. 5, such as taken along the plane indicated by the line 7—7 of FIG. 5.

FIG. 8 is an enlarged perspective view of the preferred form of one-way valve in the blood tube.

The pump of the present invention comprises three major assemblies which are integrally connected by structure, passageways and functions. They are: (A) power unit **20**; (B) control section **100**, and (C) pump section **180**. It should be kept in mind that these three sections are contained in a single unit as shown in FIG. 1, but for ease of understanding, they should be discussed separately, and for purposes of construction, are built as three units which are readily assembled, or conversely disassembled for repair or modification.

A. POWER UNIT

The power unit is best shown in FIG. **2**, which is a cross-sectional view through the length of the power unit **20**. As indicated above, the preferable source of power is the conventional water supply which may be conducted to the unit through a flexible tube **21**, coming from any suitable source, such as the tap water from the hospital piping, a storage tank on the roof, or the like. Since there may be many variations in pressure of fluid to be supplied to the unit, it is preferred that the tube **21** be provided with a suitable pressure-reducing valve **22** which can be adjusted by some suitable means, such as handle **23**. It is believed unnecessary to describe the construction of the pressure-reducing valve **22**, as many suitable devices are available on the market. It should be noted that the pump operates on only a small part of the normal available pressure, and that normal fluctuations in pressure from hospital usage still allows a much greater pressure than is needed for pump operation. However, in most procedures it is very important to have the pump operating consistently. Thus, while the pressure reducing valve is not necessary for pump operation, it can be assumed that it would be used in any surgical procedure. Further, since solids in the water supply could affect operation of the power unit, it normally would be advisable to provide a filter **29** somewhere in the water supply for the pump.

The power unit preferably comprises a cylinder **30**, the upper end of which is capped by a cap **31** that is rigidly held in the casing **101** of the control unit **100** to be described hereafter. The cap **31** is attached to the cylinder **30** by any suitable means, such as studs **32**. The cap section **31** can be rigidly held in the casing **101** of the control unit by any suitable means, but preferably by a dog pointed screw **42** extending through the end wall of the casing **101** and engaging an annular groove **33** in the cap **31**, thereby holding it tightly in the casing **101** but permitting it to be adjusted to any radial position desired. Incidentally, it can be noted that I prefer to connect the various assemblies together by means of a dog pointed screw engaging annular slots, with access to the slot by the screw from the nearest convenient surface, as such construction permits rapid assembly or disassembly by a technician without undue attention to the radial disposition of the parts, or adjustment thereof.

The pump of the present invention can be mounted on an operating table, a gurney, or any other suitable place, by means of a bracket **24** which has a pair of parallel flanges **27** and **28** and an adjusting screw **25** threaded into the flange **28**. The bracket **24** is affixed to the device in any suitable manner, but preferably is attached to one end of the casing **101** of the control section **100** (Section B) by suitable studs **26**, as shown in FIG. **1**. An adjusting screw **25** threaded into flange **28** and in opposition to flange **27** enables an operator to attach the pump to any convenient flat surface.

A shaped flexible diaphragm **45** is clamped between the cylinder **30** and its cap **31**, preferably being shaped to form a rolling contact with the interior walls **40, 41**, respectively, of the cylinder **30** and cap **31**. The diaphragm **45** is held against collapsing by providing piston-shaped followers **46** and **47** which are fastened together by some suitable means, such as studs **48**. As shown in FIG. **2**, the cap **31** adjacent to cylinder **30** is hollowed to form a cap section **31** of the same diameter as that of the interior wall **40** of the cylinder **30**. Thus, the piston-like member **46, 47**, which clamps the diaphragm **45** between them, can pass from the cylinder to the cap without difficulty and prevent collapsing or distortion of the diaphragm **45**. Since the pistons **46, 47** are almost the diameter of the cylinder, relatively little pressure is exerted against the diaphragm and it can be light and quite flexible. The upper piston member **47** is provided with an internal bore **49** which forms a spring seat for a compression spring **50**. The other end of the spring **50** is seated in a central bore, or flow passage, **35** formed in the end section of cap **31** and axially aligned with the bore **49**. This central bore **35** communicates with an annular groove **36** in the outer wall of the cap **31** by means of a diametric passageway **37** (see also FIG. **3**). It should be noted here that a force transmission liquid fills cup **34**, bore **35**, passageways **37** and annular groove **36** and other communicating passageways and chambers to be described in Sections B and C. Thus, when a superior force is applied against the piston member **46** and diaphragm **45**, the piston rises into the chamber **34**, thereby forcing liquid contained in the chamber **34** and bore **35** out through the passageway **37** and annular groove **36**. When the force below the piston is removed, the spring **37** forces the piston downwardly, thereby sucking previously expelled liquid back through the groove **36** and passageway **37** into the chamber **34**.

The lower end of the cylinder **30** is plugged by a plug **60** threaded into it, or otherwise rigidly secured thereto. This plug **60** will be drilled to provide the inlet and outlet passages leading into the interior of the cylinder **30** and an axial hole **54** to guide a piston rod **51** which carries a spool control valve **63** to be described shortly. Liquid from the tube **21** enters through an inlet passageway **61**, thence around an annular groove **62** in the spool valve **63**, and thence into passageway **64** leading into the interior of the cylinder **30**, assuming the spool valve is in the lower position shown in FIG. **2**, which is the position it will assume for the in-flow of liquid under pressure. At the proper time, when the spool valve **63** is forced upwardly, liquid within the cylinder **30** can flow from the power unit by means of a passageway **66**, annular groove **67** in spool valve **63** and outlet port **68** and is forced to do so by the spring **50** operating the piston **46, 47** and diaphragm **45**. The spool valve **63** moves within an internal bore **65** of the plug **60** and is slidably mounted on the piston rod **51**. It, the spool valve **63**, is adjusted to either its upper or lower operative positions only at the very extreme end of piston **51** by means of a collar **53** to be described more in detail hereafter. The spool valve **63** is provided with a pair of V-notches **69**, **70** which, when the spool valve is in the lower position shown in FIG. **2**, lie adjacent the end of the plug **60**.

A piston rod **51** is set in the diaphragm followers **46**, **47** which form the piston, being held rigidly therein by any suitable means, such as set screw **52** threaded through an aperture in the piston member **46** and set into an indentation in the piston rod **51**. The piston rod **51** extends through the suitable passageway **65** in the plug **60**, and is sealed against leakage by a suitable O-ring **73**.

The enlarged bore **65** within the plug **60** carries the loosely fitting spool valve **63** slidably mounted on the piston rod **51**, and is sealed against leakage between the inlet annular groove **62** and the outlet annular groove **67** by suitable O-rings **71** and **72**. A vent (illustrated by dotted lines) between the upper end of bore **65** and atmosphere permits escape of air trapped between the O-rings **71** and **73**.

Cooperating with the V-notches **69** and **70** in the lower end of the spool valve **63** is a garter spring **80** which lies within and is longitudinally restrained by annular cup **81** formed in the upper end of a cap **82**. Since the longitudinal, or axial, movement of the garter spring **80** is prevented by the lower end of the plug **60** and the lower wall of cup **81**, it cooperates with the notches **69**, **70** in the spool valve **63** to give a snap action of the spool valve **63** in its movement between its two operative positions. It is obvious that the garter spring **80** will hold the spool valve **73** in any adjusted position until overcome by some greater force. The adjusting force is supplied by the collar **53** pinned to the lower end of the piston rod **51**. When this collar engages the inner end of the bore **74**, it lifts the spool valve from the position shown in FIG. **2** to its raised position in which the passage of fluid between inlet port **61** and inlet passageway **64** is blocked by the spool valve, and the outlet passageway **66** is in communication with outlet port **68** through annular groove **67**. It is held in this position by the garter spring **80** until the downward movement of the piston rod **51** causes the collar **53** thereon to engage the upper end of a pin **90** carried by the lower end of the spool valve **63**, as hereinafter described, and thereby snap it to its lowermost position.

The cap **82** is attached to the lower end of the plug **60** by any suitable means, such as studs **83**, and is provided with a relatively large bore **84** which is large enough to loosely embrace the lower end of the spool valve **63**. The lower end of the spool valve is provided with a relatively large bore **74**, large enough to encircle the collar **53** pinned or otherwise rigidly secured to the lower end of the piston rod **51**, preferably without contact between the inner face of the bore **74** and the collar **53**. In order to provide the adjustments desired, it is necessary to prevent rotation of the spool valve **63** and this is readily accomplished by means of a slot **75** in the wall of the lower bore **74** with which registers a pin **85** threaded into the wall of the cap **82**. The pin permits axial movement of the spool valve **63** but blocks rotation thereof.

The interior wall **74** of the bore at the lower end of the spool valve **63** is threaded to receive a threaded pin **90** which is rigidly secured in a cup member **91** by any suitable means, such as pin **92**. Preferably, as shown in FIG. **1**, the cap **82** is provided with an axially extending indicia **86** and the cup **91** is provided with a circumferential series of indicia **93**. Preferably, the pin **90** is hollow to receive the end of the piston rod **51**, so that the piston rod does not engage the pin **90**, but the collar **53** on the rod will.

It is thus seen that the spool valve, which is slidably mounted on the piston **51**, and contains the inlet groove **62**, the outlet groove **64**, the two V-notches **69**, **70**, will operate with the garter spring **80**, to give "-snap" movement only to the spool valve **63**. The garter spring **80** and its cooperating grooves **69** and **70** prevent slow movement of the spool valve **63**, and thereby avoid the possibility of the valve being held in an intermediate position in which both the inlet and outlet ports are partially open. The combination of the garter spring and its associated V-notches causes a snap action of the spool valve, so that it is snapped from either operative position. It will be readily seen that the adjustment of the cup **91** will control the position of the piston assembly to move from the outlet position to the inlet position, and that the position of the collar **53** will determine when the spool valve is raised from the outlet position to the inlet position. Thus, an operator is readily able to determine the length of the power stroke and consequently the amount of liquid that will be pumped by each stroke.

B. CONTROL SECTION

The control section **100** is contained in a casing **101** which preferably is mounted perpendicularly to the power section **20**, the upper cap **31** of the power section being located in a bore **102** in an intermediate location in the casing **101**. The bore **102** has a passageway **103** leading from the annular groove **36** in the cap **31** through a one-way control valve **104** described in connection with FIG. **5**, and thence into a passageway **105** which extends lengthwise of the casing **101**. The passageway **105** communicates with an annular groove **183** formed in the pump body to be described in Section C by a suitable cross-passage **106**. As shown in FIG. **3**, the passageway **105** extends almost to the opposite end of the casing **101**, and likewise communcates with a one-way control valve **107**, and thence through passageway **108** leading back into the annular groove **36** previously mentioned. It should be noted that the one-way valves **104** and **107** operate in opposite directions, so that during the pumping, or diastolic, stroke the entrapped force transmitting liquid will pass from chamber **34** in the pumping section to passageway **105** and thence into the pump section **180**, but cannot go into passage **108** and through the check valve **107**; and on the suction, or systolic, stoke, the one-way feature of the valve **104** prevents return of the fluid through it, but permits it through the control valve **107**. The construction of the check valves is quite similar and will be described respectively in connection with FIGS. **5** and **6**. At this point it should be noted that liquid is sealed in the control section which, in effect, comprises the chamber **34** in cap **31**, groove **36** in the cap, passageways **103**, **108**, **105** and **106** and the two control valves, and is sealed by any suitable means, such as a cap **109** threaded into the end of the passageway **105**. Obviously, the amount of liquid in this control section can be changed from time to time by removing the cap **109** and either removing or adding fluid to this section. It should also be noted that both of these valves are adjustable in order to control the rate of flow through them, so that either a rapid or a slow movement of the pump can be secured in either the pumping or suction portion of a cycle.

The control valve **104** is shown in FIG. **5**. It comprises a stem **120** at the outer end of which is a handle **121**. The valve stem **120** rather tightly fits in a transverse bore **110** in the control casing **101**. The stem has an angular groove **122**, which is adapted to receive a dog pointed set screw **123** which enables the stem **120** to be turned in the bore **110** but to prevent its axial adjustment therein. The stem **120** is also provided with a pair of small grooves **124** and **125**, in which are seated flexible O-rings **126** and **127** which firmly seat against the wall of the bore **110** and thereby provide a liquid seal therebetween.

Registering with the passageway **103**, the stem **120** has a port **128** which communicates with a central bore **129** in the stem. Preferably, the bore **129** terminates in a flaring end to receive the conical section of the stem of the cooperating one-way valve member **135**, as shown in FIG. **5**. It will be noted that the bore **128** extends radially from the central bore **129**, as shown in FIG. **7**. Registering with the outer end of the bore **128** is a helical groove **130**. Thus, rotation of the stem **120** can present a blank wall **131** to the passageway **103**, or a completely free entrance into the bore **128**, or any intermediate setting in between.

Cooperating with the stem **120** is a valve member **135** which comprises a central collar **136** and a pair of oppositely extending guide pins **137** and **138** considerably smaller than the bores in which they lie. Preferably, the collar **136** is beveled to fit firmly against the flared end of the passageway **129** and, when fitted with a sealing O-ring **140**, will prevent back flow into passageway **128** and thence into the interior of cap **31**. A light compression spring **139**, seated between the end of the bore **110** and the collar **136**, biases the collar **136** against the end of the stem **120** and when in that position, will form a water-tight seal against passage of water from the channel **105** into channel **103** and thence into the pumping section. By turning the stem **120**, the amount of liquid that can pass through the port **128** can be very carefully regulated, thereby determining the length of the pumping stroke. Obviously, if the port is of small cross-sectional area, as by the small part of the helix registering with the passageway **103**, the action of the entire pump will be slowed down as the piston assembly in the pumping section (members **46**, **47** and piston rod **51**) can move only slowly as it is assumed that water will be contained in the control section and that is incompressible.

The control valve **107** associated with the suction passageway **108** is similar in many respects to the first mentioned control valve and comprises a stem **150** which can be set to any angular position by a handle **151**. It is held firmly seated in a bore **111** formed in the casing **101** by means of a dog pointed set screw **153** which registers with a groove **152** in the stem. While the stem **150** could be interchangeable with **120**, in which case it would need only one O-ring **157** and cooperating groove **155**, as it is only necessary to seal the valve assembly from leakage to outside of the chamber, while the valve **104** has to be sealed both against leakage to the outside of the chamber but also to reach into the passageway **105**. The stem **150** is provided with a radial bore **158** communicating with a central axial bore **159** and with a helical groove **160** which registers with the suction passageway **108**. However, the cooperating one-way valve member must necessarily be quite different. Again there is a valve member **165** which comprises a collar **166** and opposed guide stems **167** and **168**. In this case, however, the collar **166** is adjacent the upper end of the valve member and the upper stem **167** is quite short, as it should penetrate the aperture into the flow passage **105** and is biased against that aperture by a weak compression spring **169**. In this case, the upper face of the collar is beveled and the upper end of the bore **111**, in which the valve assembly fits, is flared so that the collar **166** will form a liquid-tight seal when abutting against the flared end wall of the bore **111**, which is the valve seat.

Preferably, the collars **136** and **166** of the two control valves **104** and **107**, respectively, can be provided with O-rings **140** and **170**, respectively, which seat against the flared bore **129** of the first one-way check valve or the flared end of the bore **111** in the suction one-way check valve. In each control valve the rotation of the stem **120** or **150** by means of its handle **121** or **151** will determine the cross-sectional area available for the passage of the force transmitting fluid, preferably water, during the pumping and suction strokes of the apparatus, and therefore determines the length of time required for the completion of each stroke. It is thus seen that both the diastolic and sistolic portions of a pumping cycle can be independently controlled as required by the operator.

It should be mentioned here that a very satisfactory pump could omit the two control valves **104** and **107**, or it might be a single control valve without any one-way feature. In the first instance, there would be no control of the speed with which the force transmitting fluid from the power section to the pump section could be controlled independently of the setting of the pressure reducing valve. In that case, it is assumed the entire control section of the preferred form of the invention could be omitted, and the chamber **34** of the power section would communicate directly with the pump chamber to be described in the next section. In the second instance, a single adjustable flow control valve would be interposed between the power chamber **34** and the pump chamber and the valve stems **135** and **165** eliminated. In that event, the rate of flow from the power chamber **34** to the pump chamber, and vice versa, could be controlled by the setting of the valve, but the rate on both the pumping and suction strokes would necessarily be the same. By providing the two control valves and their associated one-way valve stems **135** and **165** working in opposite directions, an operator is enabled to provide independent control of the timing of the two strokes. However, if such a feature is not desired, the pump could be simplified by omitting one or both of the control valves (and both one-way valve stems) and the pump would operate satisfactorily as a pump without the independent control feature which I prefer.

C. PUMP SECTION

The pump section **180** comprises a tubular casing **181** that has a relatively tight fit with the bore **112** in the casing **101** (FIGS. **3** and **4**). The casing **181** can be locked in position by a set screw, not shown, threaded into a suitable aperture in the casing **101** and registering with an annular groove **182** in the casing **181**. This permits rotation of the pump member **180** if desired, but not longitudinal movement. The casing **181** is formed with an annular groove **183** which registers with passageway **106** when the pump is in proper position. A plurality of radial orifices **184** lead from the annular groove **183** into the interior portion of the cylindrical casing **181**. A pair of O-rings **185** and **186** lie in grooves **187**, **188** in the casing **181**, thereby forming liquid-tight seals on either side of the annular passageway **183**.

In order to insure against leakage of the fluid in the control chambers either to atmosphere or into the tube-carrying blood or other liquid, I prefer to seal the interior of the casing **181** by a flexible tubular membrane **190**. Preferably, this membrane will be a silastic tube which is passed lengthwise through the casing **181**, as shown in FIG. **4**. The two ends of the cylindrical membrane **190** are preferably sealed, as by means of folding over a conical collar **191**, placing a truncated conical thimble **192** over the folded tube and collar, and the whole rigidly sealed by a cap **193** which is threaded onto suitable threads formed on the casing **181**. A gasket **195** compressed between the conical collar **191** and the end of the casing **181** seals the tubular membrane **190** against leakage. Preferably, as shown in FIG. **4**, the ends of the casing **191** are restricted for a slight distance, thereby providing an elongated, cylindrical chamber **194** throughout the length of the casing, and lying between the wall of the casing **181** and tubular membrane **190**. Thus, throughout most of its length within the casing **181**, the outer silastic tubing **190** will not lie against the wall of the casing but will be embraced by the fluid of the control section which will completely encompass the tube throughout most of its length within the casing at all times. This construction permits the rapid and equalized transmission of pressure to the entire length of the pump chamber on the pump stroke but also the rapid and equalized vacuum thereto on the suction stoke.

It is believed obvious that the operation of the power section, through the medium of the liquid entrapped in the control section, will cause the pulsation of fluid in the chamber **194** that lies within the casing **181** and outside of the tubular sleeve **190**. During the pumping stroke, the tube **190** will be squeezed inwardly and during the suction stroke it will expand outwardly beyond the position shown in FIG. **4**. The amount of squeezing will be determined by the length of stroke in the power section, and the speed with which that squeezing takes place is determined by the setting of the control valve shown in FIG. **5** and the speed of restoration by the setting of control valve **107** shown in FIG. **6**.

The blood, or other fluid, to be pumped passes through a suitable silastic tube **200**. Preferably, the tube **200** will be of a length slightly greater than the length of casing **181** and will be provided at each end with conical nipples **201** over which the blood supply tubes of suitable size, selected by the surgeon, an be forced. The surgeon has the option at the time of surgery of selecting a suitable orifice size for the pump by simply cutting off the nipple at the location where its diameter is desired. The tube **200** is provided with a pair of one-way valves **202** which can be of any suitable construction. However, I prefer to use tricuspid valves, such as shown in FIG. **8**. Bicuspid valves are known in the art and have been found more suitable for use in pumping blood than the older ball-type valves. Bicuspid valves comprise a single pair of lips which normally lie together but which open as liquid is pumped through them. However, I have found that a tricuspid valve, such as shown in FIG. **8**, is better for pumping blood, as it opens more widely and does less damage to the blood cells. As shown in FIG. **8**, such a valve comprises three pairs of lips **203** at the axis of the tube, the lips normally being compressed lightly together but opening to substantially the full circumference of the tube as liquid is forced through them. Normally, such a valve would be made on a short stem **204**, separate from the blood tube **200**, and later cemented into place. Any force which would push the pumped liquid backwardly through the tube is prevented, as such force only seals the lips more tightly together. It is believed obvious that the two valves **202** are located outside of the pumping chamber but within the pumping section **180**, preferably without the casing **181** but within the lock nuts **193**.

Preferably, the blood tube would be prepared by taking a length of silastic tubing **200** longer than spacing of the two nipples **201**; cementing the one-way valves **202** in the proper location; and then cementing the two nipples within the tube — leaving a length of tube **200** — extending beyond the nipples. The entire assembly can then be sterilized and the ends of the tube sealed. Thus, a hospital can store a desired supply of sterile pump sections, any one of which can be used at a moment's notice. When a surgeon desires to use a pump, he will cut off the end of the tube and can fold it back to form a cuff **205** around the base of the nipple. Preferably, one end of the sealed and sterile blood tube **200** will be provided with a lanyard **206** as it is easier to pull such a tube through a rather tightly fitting aperture, such as that provided by the tubular membrane **190**, than to push it through. After the blood tube is inserted in the pump chamber **180** and the ends cut off, the tubes that connect the pump to the patient, or to treating devices, can be pushed over the nipples **201**, and the device is ready for use.

In most conditions it can be assumed that the length of tube between the input nipple **201** and its associated one-way valve **202** is longer than at the output end, to provide a small blood storage reservoir between the nipple and the one-way valve.

D. SUMMARY

While it is believed that the operation of the pump of the present invention is obvious, it is not amiss to briefly summarize it. The force which can be applied to the pumping section **180** will be determined by the pressure of the liquid entering the pump power section **20**. This can be controlled by a suitable pressure-reducing valve **22** in the inlet conduit **21**. In most instances water pressure should be reduced in order to use the pump in open-heart surgery, or other times when it is necessary to pump blood for a patient. The total amount of blood to be pumped in each stroke is determined by the setting of the collar **53** on piston rod **51** and the setting of the cup **91** with respect to the spool valve **63**. That is, a greater or lesser amount of blood can be pumped in each cycle as controlled by these settings, as they control the limit of response for the action of the spool valve **63**. Hence, for a small child, the strokes will be relatively short, while for a mature and athletic adult they could be quite long to provide for a pumping of a considerable amount of blood with each cycle of operation. It should be noted that in no case should the stroke be sufficient to totally collapse (occlude) the pump tube, as this would submit the blood to direct compression against opposite walls of the tube and thereby rupture the blood cells so they cannot carry oxygen (hemolysis) and cause the platelets to destruct (causing coagulation). The speed of the diastolic and sistolic portions of a pumping cycle are controlled by the respective settings of the one-way check valves **104** and **107** which are settable independently, so that it is possible to have a rapid diastolic stroke and a slow sistolic one, or vice versa. It can be noted that the force transmitting liquid contained within the control chambers is small but can never come in contact with the tube through which the blood is circulating. It is, therefore, impossible for any unsterile condition of the pump to affect the sterility of blood within the tube **200**. Thus, the pump does not have to be completely sterilized (although it is assumed that it will always be cleaned) and the only portion of the apparatus that does have to be sterilized, is the tube **200** and the tubes which connect it to the body of the patient. Since it is anticipated that the blood tube will be furnished sealed and sterile, it may be placed in the pump and stored, ready for use in an emergency.

Since power to operate the pump is supplied by water under pressure, the doctor can rely upon the water supply within the hospital, and power failure would not be the problem that it is when relying on an electric system.

It is believed that several advantages are inherent in a pump of this type, for adjustments can readily be made, even while the pump is in operation. Thus, an operating assistant can change the settings of the pump so that it will operate in synchronism with the heart of the patient, and the supply of blood with each beat can be modified as required. It is also possible, by means of a pump of this kind, to use it as a partial bypass after surgery to permit the heart to operate at reduced capacity while healing takes place without interfering with the normal blood supply of the patient. It is believed that these and other advantages of the pump of the present invention will be obvious to those skilled in the art. It should also be noted that it is possible to provide the control chamber with a plurality of pump chambers, so that it could operate not only to pump blood but also some other liquid — for example, also pump dialysate and blood to an artificial kidney. Accordingly, it is intended that all modifications which lie within the scope of the underlying inventive concepts are to be included within the scope of the claims and the invention is not limited to the particular forms herein shown and described.

I claim:

1. A surgical pump comprising:

1. a cylinder,
2. a tubular flexible diaphragm within said cylinder, said tubular diaphragm being adapted to embrace a blood supply tube provided with a pair of one-way valves therein to permit flow therethrough in one direction only,
3. means for sealing the ends of said diaphragm to the ends of said cylinder and thereby providing a space between the cylinder and said tubular diaphragm,
4. a chamber adapted to contain a pressure transmitting liquid,
5. a passageway connecting said chamber and the space between said cylinder and said tubular diaphragm; and
6. means for sequentially applying a positive and then a negative pressure to the liquid in said chamber.

2. The apparatus of claim **1** comprising also a flow regulating valve in said passageway.

3. The apparatus of claim **1** wherein there is a second passageway between said chamber and the space between said cylinder and said tubular diaphragm, and comprising also an adjustable flow regulating valve in each of said passageways, a one-way valve in one of said passageways permitting flow only from said chamber, and a one-way valve in the other of said passageways permitting flow only into said chamber.

4. The apparatus of claim **1** wherein the means for applying a positive and then a negative pressure to the liquid in said chamber comprises:

1. a cylinder,
2. a flexible diaphragm within said cylinder, said diaphragm forming one wall of said chamber,
3. an inlet into said cylinder on the other side of said diaphragm,
4. an outlet from said cylinder on said other side of said diaphragm,
5. a valve means operated by movement of said diaphragm for opening said inlet while closing said outlet and then opening said outlet and closing said inlet.

5. The apparatus of claim **4** comprising also an adjustable means for adjusting the amount of liquid admitted to said cylinder with each stroke thereof.

6. A surgical pump comprising:

A. a power section including

1. a cylinder adapted to receive a liquid under pressure,
2. a flexible diaphragm within said cylinder,
3. an inlet into said cylinder on one side of said diaphragm,
4. an outlet from said cylinder on the same side of said diaphragm,
5. means for biasing said diaphragm toward said one side thereof,
6. means for supplying liquid under pressure to said inlet, and
7. valve means operated by movement of said diaphragm for opening said inlet and closing said outlet and then closing said inlet and closing said outlet;

B.

1. an intermediate control chamber adapted to hold a liquid, one wall of said chamber being said diaphragm,
2. an outlet from said chamber,

3. a one-way flow-control valve in said outlet,
4. an inlet to said chamber,
5. a one-way flow control valve in said inlet, and
6. means for introducing a liquid into said chamber; and

C. a pumping section comprising:
1. a cylinder,
2. a cylindrical flexible diaphragm within said cylinder,
3. means for sealing the ends of said cylindrical diaphragm to the ends of said cylinder and thereby providing an open-ended cylinder adapted to receive a flexible tube carrying blood, said tube being provided with one-way check valves, and
4. passageways into said chamber communicating with said one-way outlet and said one-way inlet valves in the control chamber.

7. The apparatus of claim **6** wherein the outlet valve from said control chamber has an adjustable port whereby the volume of liquid passing through said valve in any interval of time can be controlled.

8. The apparatus of claim **6** wherein the inlet valve into said control chamber comprises an adjustable port whereby the volume of liquid passing through said port in any given interval of time can be controlled.

9. The apparatus of claim **6** wherein the one-way outlet valve and the one-way inlet valve have adjustable ports wherein the volume of liquid passing through said ports in any given interval of time can be adjusted independently.

10. The apparatus of claim **6** comprising also means for selectively changing the operation of said first-mentioned valve means to vary the volume of liquid under pressure admitted into said cylinder.

11. The apparatus of claim **6** wherein the flexible diaphragm within said cylinder of said power section is clamped between a pair of washers, and wherein said valve means operated by movement of said diaphragm comprises a rod carried by said washers, a spool valve controlling said inlet and said outlet slidably mounted on said rod, and means fixed to said rod for operating said spool valve at the extremes of movement of said rod.

12. The apparatus of claim **11** comprising also means for causing said valve means to snap from one position to another.

13. A blood pump comprising:
1. a cylinder,
2. a tubular flexible diaphragm within said cylinder,
3. means for sealing the ends of said diaphragm to the ends of said cylinder and thereby providing a space between the cylinder and said tubular diaphragm,
4. a tube for conducting a flow of blood embraced within said tubular diaphragm,
5. a pair of one-way valves for permitting flow in one direction only in said tube and located outside of the diaphragm,
6. a chamber adapted to hold a pressure transmitting liquid,
7. a passageway from said chamber to the space between said cylinder and said tubular diaphragm,
8. means for introducing a liquid into said chamber, and
9. means for sequentially applying pressure to the liquid in said chamber and then applying a vacuum thereto.

14. The apparatus of claim **13** wherein the one-way valves in said blood tube comprise three pairs of lips meeting adjacent the axis of said tube.

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