July 24, 1962 E. V. RIPPINGILLE 3,045,601

MECHANICAL HEART PUMP OR THE LIKE

Filed July 28, 1953 7 Sheets-Sheet 1

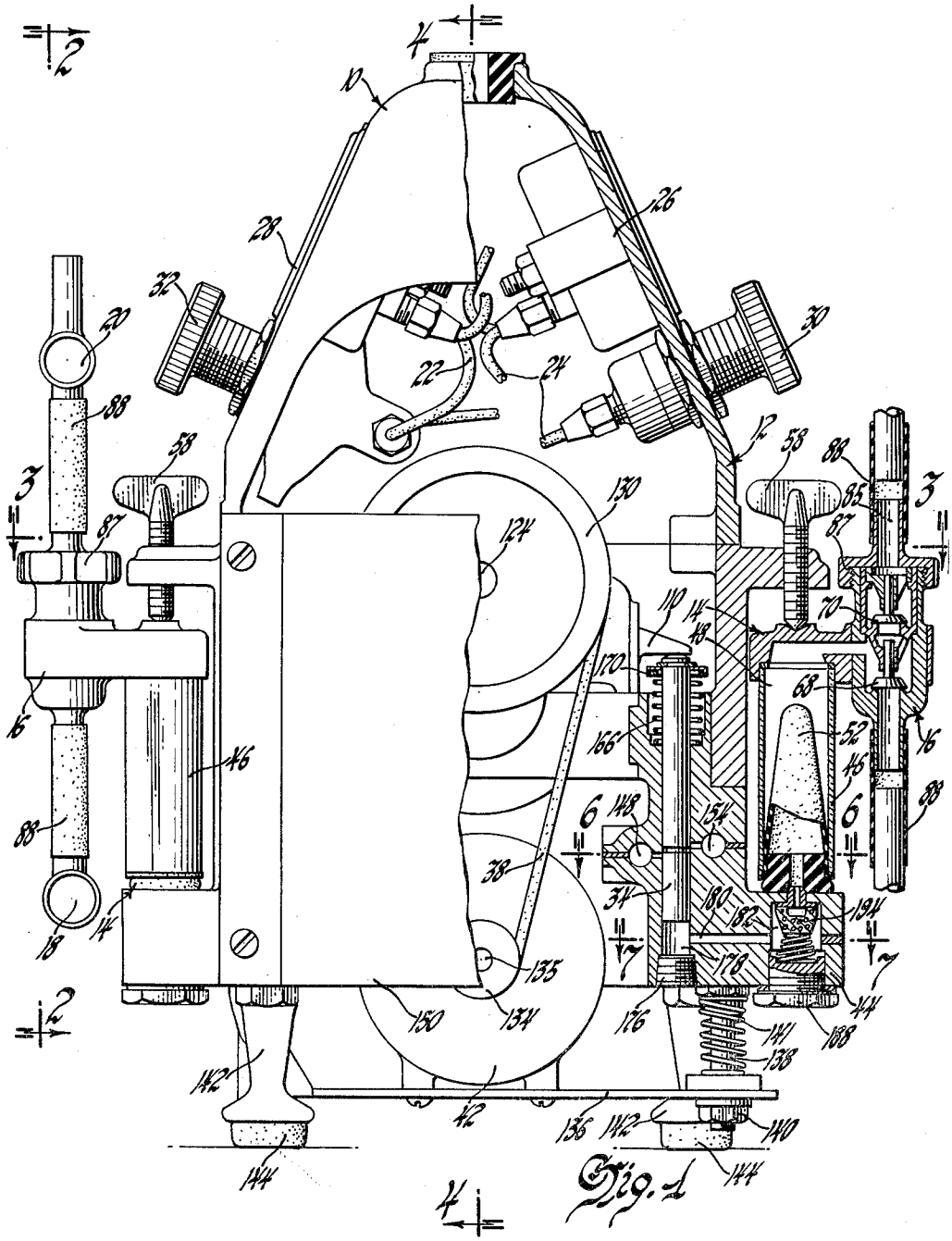


Fig. 1

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MECHANICAL HEART PUMP OR THE LIKE

Filed July 28, 1953 7 Sheets-Sheet 2

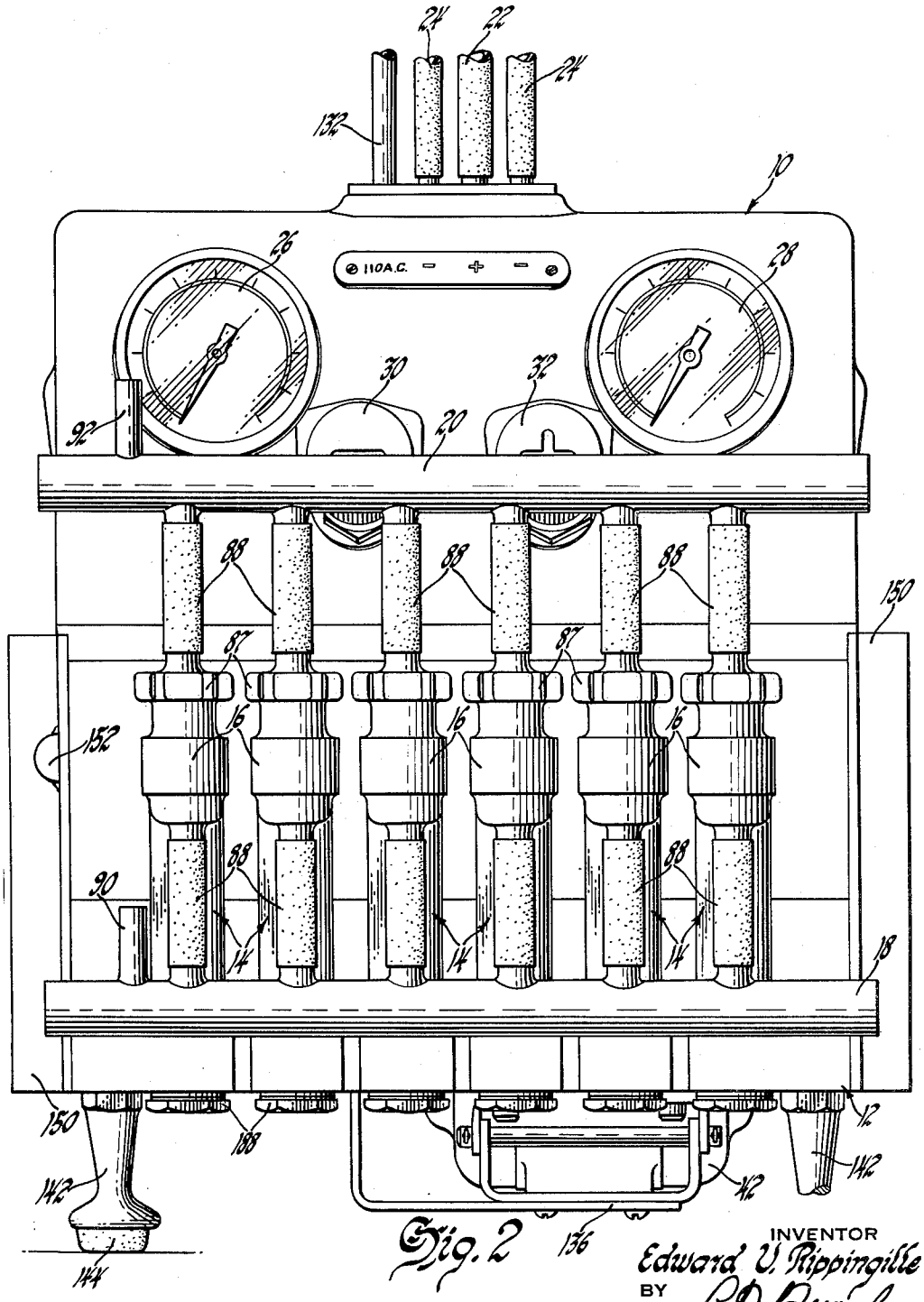


Fig. 2

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MECHANICAL HEART PUMP OR THE LIKE

Filed July 28, 1953 7 Sheets-Sheet 3

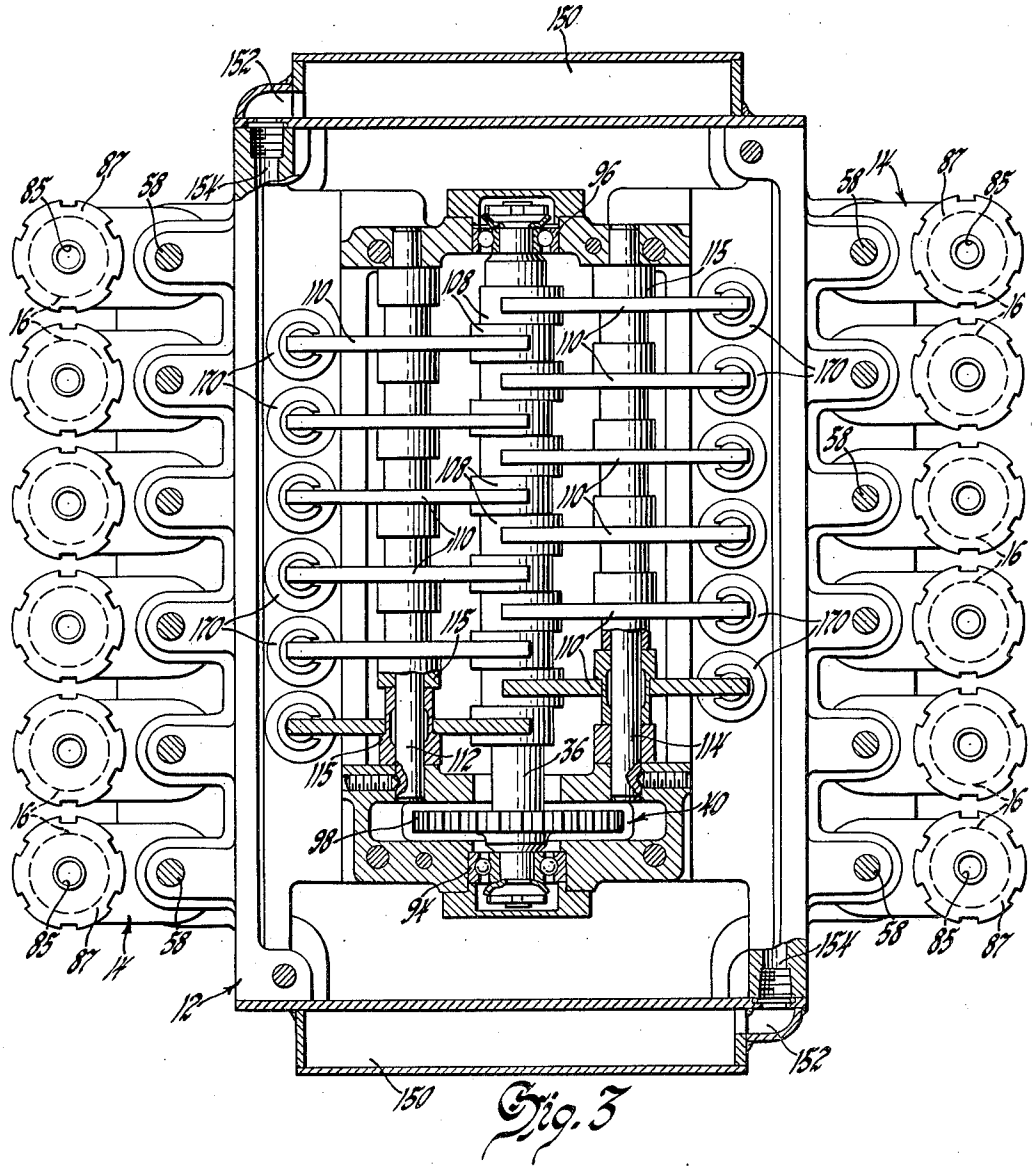


Fig. 3

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MECHANICAL HEART PUMP OR THE LIKE

Filed July 28, 1953 7 Sheets-Sheet 4

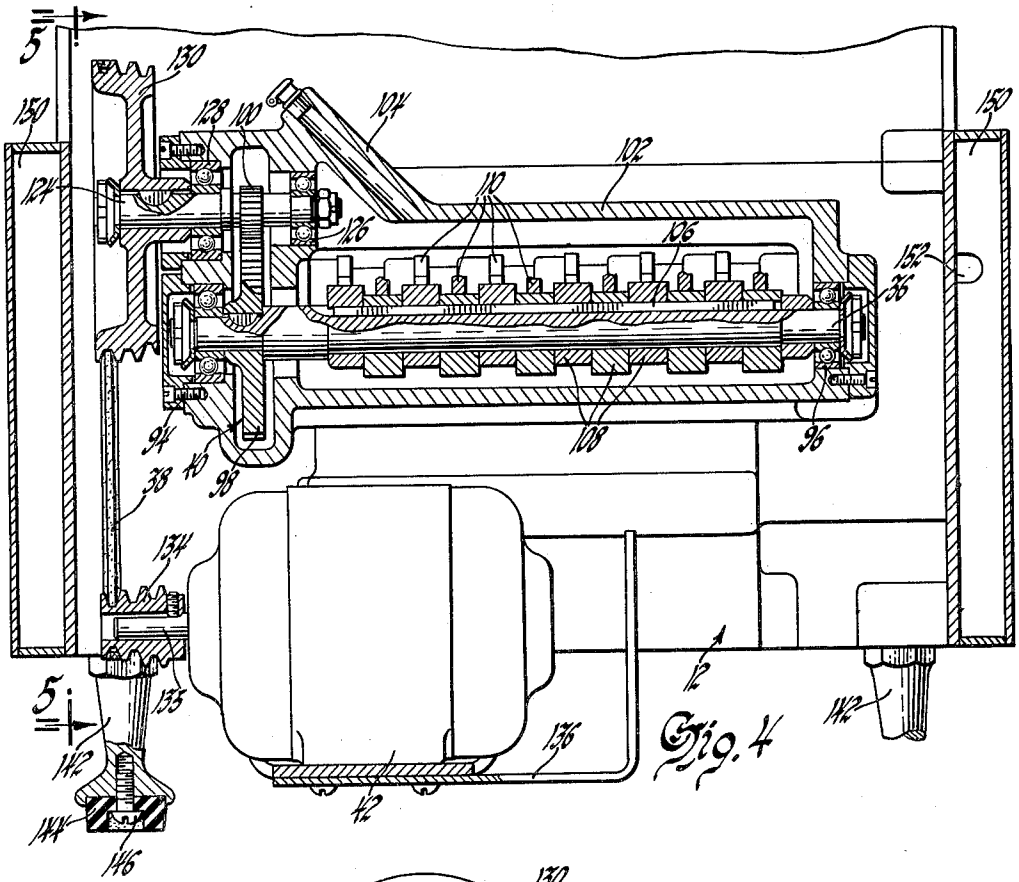


Fig. 4

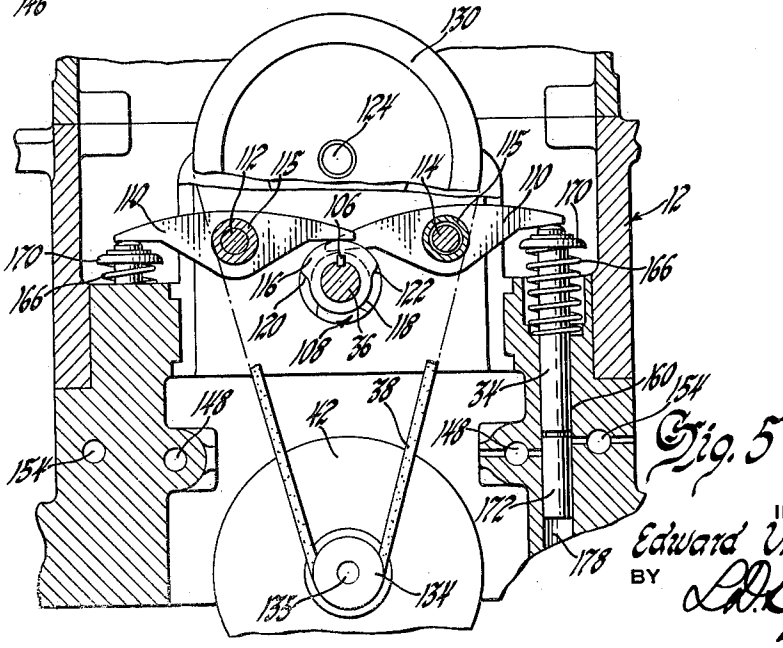


Fig. 5

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MECHANICAL HEART PUMP OR THE LIKE

Filed July 28, 1953 7 Sheets-Sheet 5

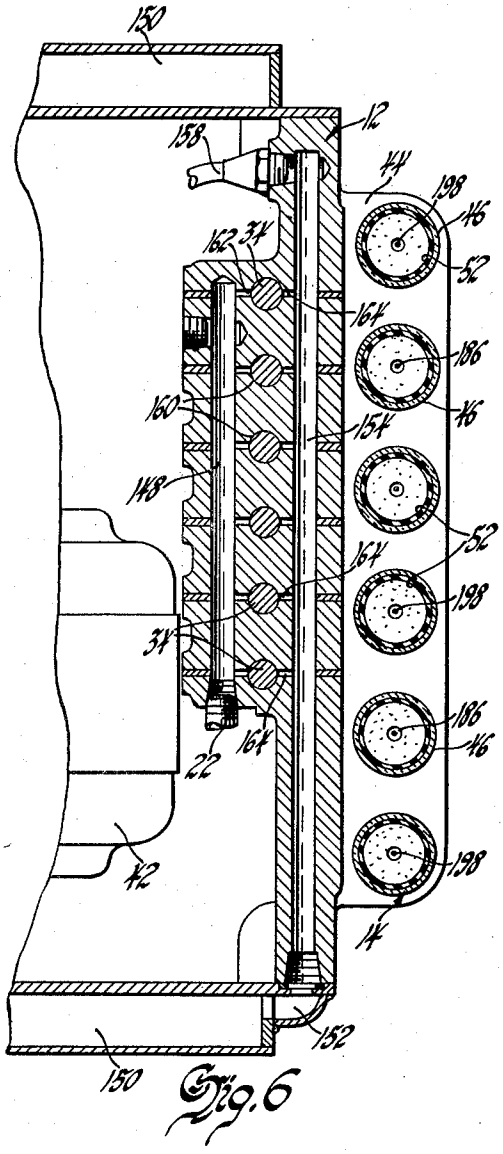


Fig. 6

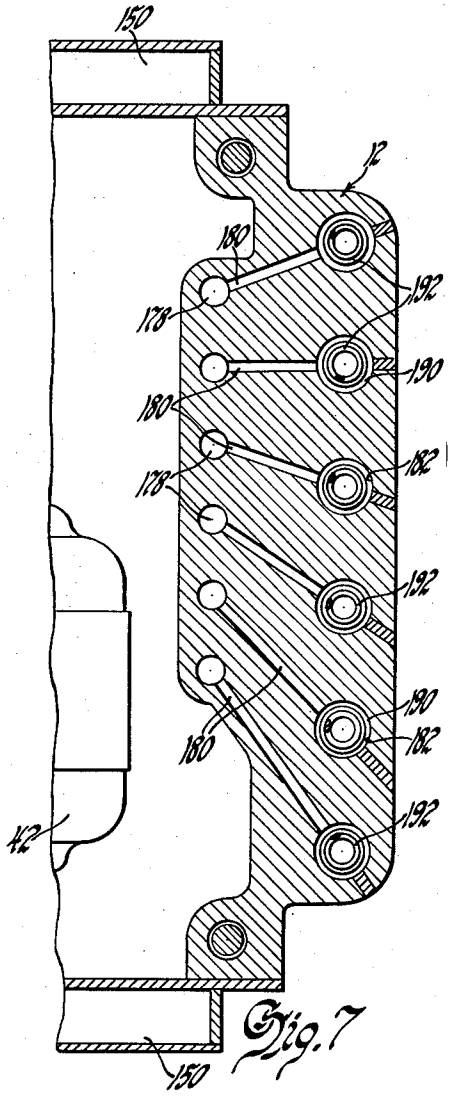


Fig. 7

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MECHANICAL HEART PUMP OR THE LIKE

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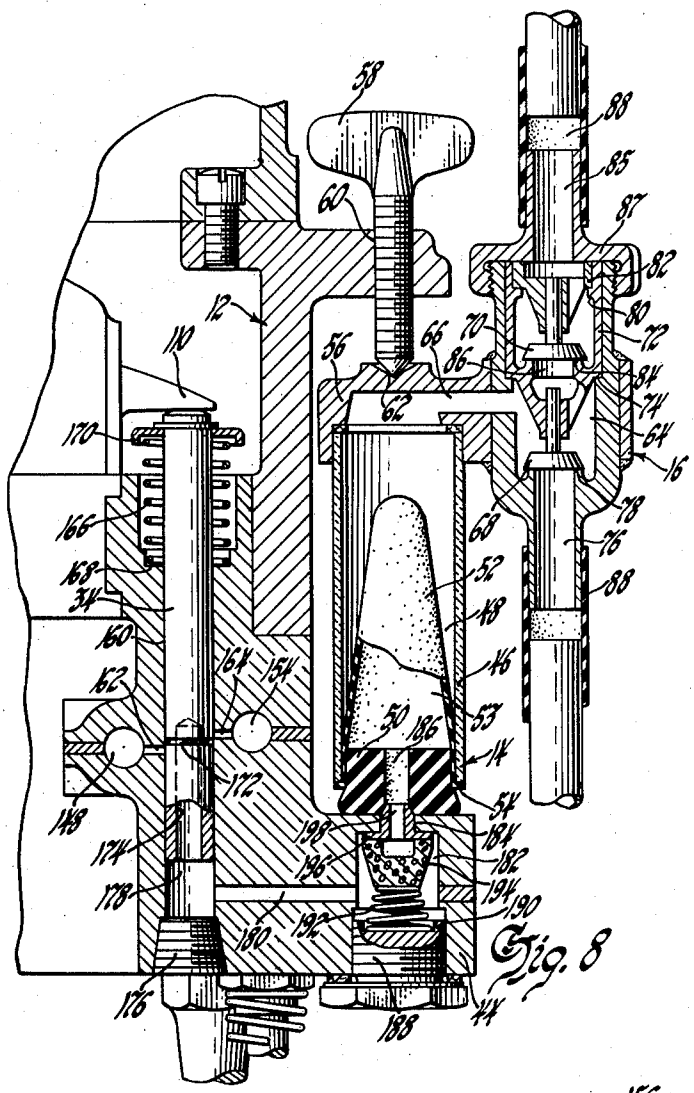


Fig. 8

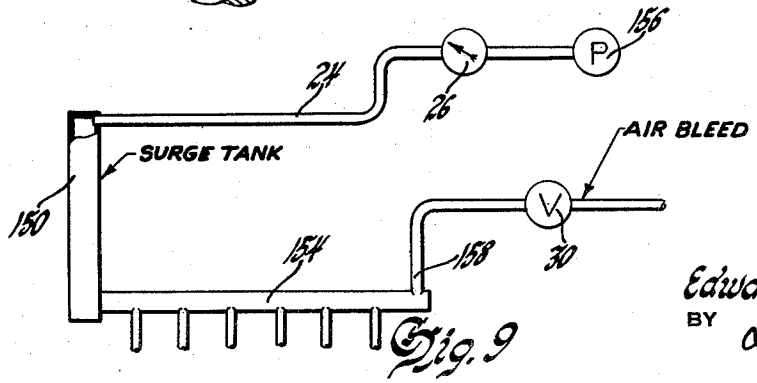


Fig. 9

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MECHANICAL HEART PUMP OR THE LIKE

Filed July 28, 1953 7 Sheets-Sheet 7

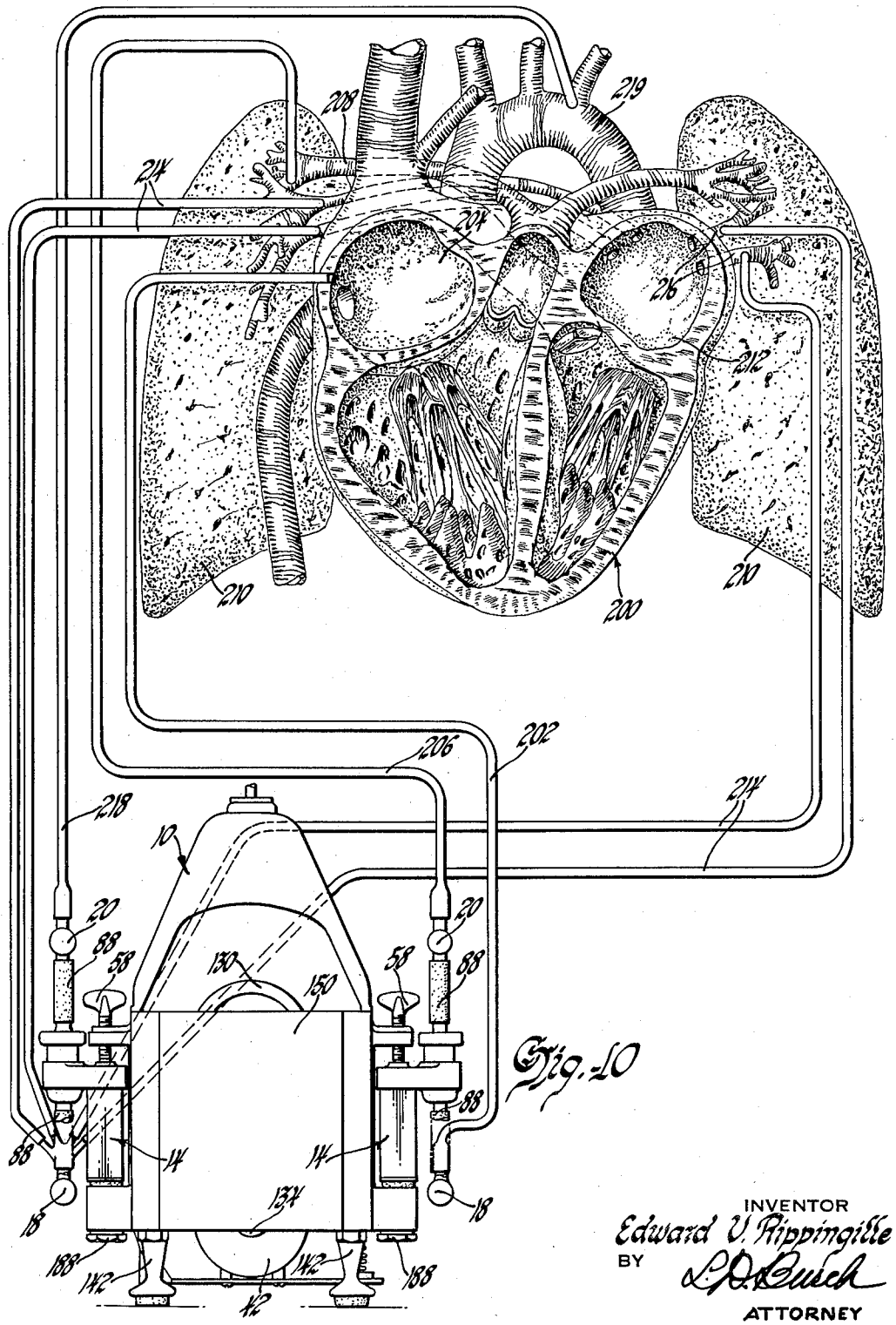


Fig. 10

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United States Patent Office 3,045,601 Patented July 24, 1962

3,045,601

MECHANICAL HEART PUMP OR THE LIKE

Edward V. Rippingille, Farmington, Mich., assignor to General Motors Corporation, Detroit, Mich., a corporation of Delaware

Filed July 28, 1953, Ser. No. 370,731
2 Claims. (Cl. 103—44)

This invention relates to a fluid pumping device and more particularly to a device for moving a cellular fluid such as blood at a prescribed rate, pressure and capacity without damage or injury thereto.

Medical science has long been confronted with the knowledge that numerous defects within the heart and pulmonary system of man could be readily repaired if it were possible to temporarily interrupt the flow of blood to the defective areas of the heart to enable opening such regions for visual inspection and positive remedial surgery. However, cessation of the circulation of blood through the body for excessive periods of time causes a condition of anoxia, from insufficient aeration of the blood, resulting in neurological changes in the functioning of vital organs of the body and producing an irreversible state of shock with respect to the patient. The kidneys and intestines have been found capable of withstanding almost three hours of anoxia without serious damage but the spinal cord is endangered beyond five minutes and the brain beyond a minute and a half. Experienced surgeons operating under the most ideal conditions and with the utmost of assistance are not presently able to correct all cardiac defects within such a limited space of time.

The heart is formed in essentially two parts each having two separate chambers. Blood is received within the right auricle or atrium of the heart from various parts of the body. The fluid passes through a tricuspid valve known as the mitral valve into the right ventricle. Muscular contraction and expansion of the right ventricle moves the blood in a more or less constant flow through the pulmonary valve where it is distributed through the right and left pulmonary arteries to the lungs. Upon the removal of carbon dioxide from the blood and oxygenation thereof, within the lungs, the blood returns through the pulmonary veins to the left auricle or atrium of the heart. The fluid flows into the left ventricle through the mitral valve and from there is moved by the contraction of the left ventricle walls through the aortic valve, another tricuspid, to the aortic arch for redistribution through the body. The flow of blood from the left side of the heart is more pulsive than from the right side of the heart to provide greater pressure for circulation throughout the body.

Since cessation of the flow of blood to the heart for any length of time is not feasible and no device has been heretofore developed which will enable successfully bypassing the flow of blood around the heart all operations with respect to the heart have been largely limited to massaging or palpitating the heart externally. In a few instances enlargement of the mitral, aortic or pulmonary valves has been attempted by incision directly into the heart. These operations require insertion of the surgeon's finger, with a surgical instrument attached, blindly into the heart without interruption of the blood flow and are completely dependent upon the surgeon's sense of touch and his vast experience. The correction of defects within the septal wall separating the right and left ventricle of the heart and of other defects requiring positive remedial surgery have until now been virtually impossible.

Mechanical devices which have been devised in the past to duplicate the action of the heart have never, heretofore, been used successfully upon human beings to entirely take over the function of the heart and enable complete isolation thereof. The problems encountered have been numerous. Blood entering the heart may not be redistributed throughout the body until the carbon dioxide has been removed and the blood rejuvenated by oxygenation. Sterile condition must be maintained to prevent contamination of the blood. The blood must be positively moved without disrupting the cellular structure thereof. There must be no foaming or coagulation, the formation of fibrin must be prevented, and dehydration and hemolysis must be minimized. Beyond these and other aspects any instrument used must be capable of being readily disassembled to enable a thorough cleaning and sterilization of all elements with which the blood comes in contact before being used again.

Blood comprises a multitude of individual cellular bodies hereafter referred to as blood cells which are in suspension forming a fluid mass. The blood cells are quite delicate and may be easily damaged by being squashed or deformed. A cell which has been deformed is unable to function properly and is carried through the blood stream uselessly. Broken blood cells have detrimental effects upon the body. Cells may be broken and blood clots formed in a number of ways as by a sharp article projected into the blood stream, contact with a rough surface, excessive fluid pressure, and so forth. Any blood clot which is formed in the system may not only obstruct the fluid flow but may break-off and be carried to the brain resulting in fatality. One of the major reasons that no pumping system has been heretofore devised which could be used upon a human patient has been the inability of such devices to handle blood without breaking some of the cells and without subjecting the patient to the resultant dangers. Every element with which the cellular fluid comes in contact must have a clean, smooth, non-wettable surface, every piece of tubing or cannula must provide a free flowing passage, and all pressures must be properly gauged to eliminate unit pressures in excess of that which will either deform, rupture, or break any of the blood cells.

It is now proposed to provide a mechanical device in the form of a variable displacement fluid pumping system which will completely take over the entire function of the human heart and which will move the blood to respective vascular passages without injury or damage to the cellular fluid. It is an object of this invention to provide an artificial mechanical heart which may be substituted for the living member for extended periods of time. This device may be substituted for either the right side of the heart or the left side thereof, or for both sides simultaneously using either an oxygenating device or the lungs. It is proposed to provide a pump which will simulate the flow conditions of blood emitted from the right side of the heart as well as the pulsating flow from the left side thereof.

It is another object of this invention to provide a plurality of individual pumping units readily associated together to provide for variable fluid capacity. It is proposed that each unit will provide a displacement of fluid but that such pumping action shall not adversely effect the cellular composition of the fluid. It is an object of this invention to provide for such pumping action through the media of positive and negative air pressures alternately admitted to a flexible sac disposed within a fluid flow chamber. Obstruction of the fluid flow will not therefore cause cellular damage to the fluid since the displacing force is itself compressible.

It is a further object of this invention to provide for the unidiretcional flow of fluid through each pumping unit by means of stop-check valves. It is proposed that such valves have a large seating area and be sufficiently light in weight to minimize the unit pressure exerted against

fluid disposed between the valves and their seats during closure to prevent damage to the cellular structure of the fluid. The proposed check valves are adapted in closing to seat upon a layer of blood cells disposed upon the valve seat without injuring the cells and to hold the cells thereon and obstruct the flow of other cells past the valve.

It is a still further object of this invention to provide a pumping unit comprising elements which may be readily disassembled, cleaned, sterilized and reassembled under sterile conditions with the least effort and the minimum of mechanical skill.

FIGURE 1 is an end view of a device embodying the principals of this invention with parts broken away and shown in section to more clearly show pertinent features thereof.

FIGURE 2 is a side view of the device shown in FIGURE 1 taken in the plane of line 2—2 and viewed in the direction of the arrows thereon.

FIGURE 3 is a cross-sectional view of the device shown in FIGURE 1 taken in the plane of line 3—3 and viewed in the direction of the arrows thereon.

FIGURE 4 is a cross-sectional view of a part of the device shown in FIGURE 1 taken centrally therethrough in the plane of line 4—4 and viewed in the direction of the arrows thereon.

FIGURE 5 is a fragmentary end view of part of the proposed device taken in the plane of line 5—5 of FIGURE 4 and broken away to more clearly show certain pertinent features thereof.

FIGURE 6 is a cross-sectional view of a part of the device shown in FIGURE 1 taken substantially in the plane of line 6—6 and viewed in the direction of the arrows thereon.

FIGURE 7 is a cross-sectional view of a part of the device shown in FIGURE 1 taken in the plane of line 7—7 and viewed in the direction of the arrows thereon.

FIGURE 8 is a fragmentary view of part of the proposed device enlarged and shown in section.

FIGURE 9 is a schematic illustration of certain air lines employed wtih the proposed device.

FIGURE 10 is a schematic illustration of the connections made between the proposed mechanical device and a living heart.

The device shown in the drawings is a mechanical heart pump capable of duplicating the pumping action of the human heart and of moving living blood cells without injury or damage thereto. Essentially the heart pump **10** comprises a casing **12** having a plurality of individual fluid pumps **14** removably secured to opposite sides of the casing and adapted to be associated together to provide greater fluid capacity and variable fluid flow. The pumping units **14** secured to one side of the casing are adapted to act together to simulate the flow action desired with regard to the right side of the anatomical heart and those secured to the other side of the casing are adapted to act together to simulate the action of the left side of the heart. Each fluid pump **14** has a separate passage member **16** associated therewith to provide for the flow of fluid to and from that particular pump. The fluid pumps which are adapted to act together have their respective passage members **16** connected between common fluid inlet and outlet flow passages **18** and **20** respectively. To provide for the actuation of the fluid pumps **14** a source of positive and negative air pressure is supplied to the heart pump **10** by air lines **22** and **24**. Air pressure gauges **26** and **28** and regulating valves **30** and **32** are mounted on each side of the casing and are connected to unidirectional flow of fluid through each pumping unit mitted to the fluid pumps **14**. The time and extent of emission is controlled by sleeve valves **34** associated individually with each pump **14**. The sleeve valves **34** in turn are controlled by a camshaft **36** centrally disposed and horizontally mounted within the casing **12**. The camshaft **36** is driven through a drive belt **38** and gear reduction arrangement **40** by an electric motor **42**.

Referring to FIGURES 1 and 8; along each side of the heart pump casing **12** is formed a base ledge **44** upon which the fluid pumps **14** are adapted to be seated. Each fluid pump **14** comprises a transparent cylindrical member **46** having a fluid chamber **48** formed therein. A stopper **50** is inserted within one end of the cylinder **46** to close off the fluid chamber **48**. A flexible sac, finger stoll or cot **52** provides a flexible walled member having an air pocket **53** formed therein and is engaged upon the stopper **50** and projects upwardly within the fluid chamber **48**. A bead **54** formed around the open end of the finger cot **52** is engaged by the lower edge of the cylinder **46** to prevent the cot from coming loose within the chamber **48**. A closure cap **56** is held in pressure engagement with the other end of the cylinder **46** by a thumb screw **58** threaded through an outwardly extending portion **60** of the casing **12** parallel and in spaced relation to the base ledge **44**. The thumb screw **58** is received within a conical detent **62** formed centrally in the top of the closure cap **56** and is adapted to urge the cap in secure engagement with the cylinder **46**, the cylinder more tightly around the stopper **50**, and the stopper more firmly against the base ledge **44**.

Secured to each closure cap **56** is a passage member **16**. The passage member **16** has a fluid flow passage **64** formed therethrough and is connected to the fluid chamber **48** by another passage **66** formed through the closure cap **56** and passage member **16**. The passage member includes two check valves **68** and **70** mounted within the flow passage **64** and arranged to provide a unidirectional flow of fluid therethrough. A valve guide **72** disposed within the passage member **16** seats upon an annular shoulder **74** formed about the fluid passage **64** above the passage **66** leading to the fluid chamber **48**. The valve guide **72** centers the poppet type inlet check valve **68** over the inlet opening **76** formed in the base of the passage member **16**. The face of the inlet valve **68** is flat and engages an equally flat annular valve seat **78** formed about the inlet opening. The inlet valve guide **72** is also formed to provide an annular ledge **80** within the fluid passage **64** upon which is seated the outlet valve guide **82**. The outlet valve guide **82** centers the outlet check valve **70** over an annular valve seat **84** formed about an opening **86** provided through the inlet valve guide **72**. The faces of the outlet valves **70** and valve seats **72** are flat and parallel as with the inlet check valve arrangement. The valve seats **78** and **84** provided for the check valves **68** and **70**, which need not necessarily be poppet type check valves, have a large receiving area or seat against which the valves are received. By providing for a large seating area the unit pressure exerted by the valves **68** and **70** against their seats **78** and **84** is considerably minimized. This is a particularly essential feature where a cellular fluid is being moved through such valves in that excessive unit pressures would damage and destroy the cellular structure of such a fluid.

In making use of the proposed pumping means for transferring cellular fluids it is necessary that the valve means used in controlling fluid flow do not damage the cellular structure of the fluid. In the presently proposed embodiment of this invention, for use as a mechanical heart pump and to control the flow of blood being diverted around a living heart, the blood cells must not be injured or hemolysis will result. Hemolysis is the release of hemoglobin, the oxygen carrying constituent, from the blood cell which disrupts the metabolism of the body tissues as well as having other effects which increase the likelihood of fatality. One of the more essential features of the proposed pumping means therefor is the use of valve means wherein unit pressures between valve seats and valves will not exceed the unit pressure which will break down or damage the blood cells. The unit pressures obtained by the valve means are related to the valve seating area and the fluid pressures acting to close

the valve means. The necessary seating area to allow the valve means to close without damaging the cellular structure of the fluid flowing through the system may readily be calculated by those skilled in the art.

A knurled cap 87, threaded upon the upper end of the passage member, urges the outlet valve guide 72 in secure engagement with the shoulder 74 and the inlet valve guide firmly against the ledge 80. An outlet fluid passage 85 is formed through the cap 87 and is in communication with the passage 64 formed through the passage member 16. The passage members are connected at each end by sections of flexible tubing 88 to the passage means 18 and 20 respectively common to all pumps as previously mentioned. In FIGURE 2 is shown the arrangement of the passage members 16 and pumps 14 which are mounted on one side of the heart pump 10. The common flow passages 18 and 20 are closed at both ends and are provided with connectors 90 and 92 respectively for association by surgical latex tubing to arterial and venous heart vessels.

All elements of the fluid pumps 14 are adapted to be readily disassociated for cleaning and sterilization. All elements of the pumps with which blood comes in contact are silicone coated to provide non-wettable surfaces preventing the adhesion of blood thereto and the formation of fibrin; a characteristic of blood causing coagulation. In the present embodiment all elements with which blood comes in contact are stainless steel, glass, and rubber although the materials need not be limited thereto. Autoclaving of all elements of the pumps has been found to provide suitable sterilization.

Centrally mounted within the heart pump casing 12 is the camshaft 36 which is adapted to provide for the timing of each individual pump. Referring to FIGURES 3, 4, and 5 the camshaft 36 is shown to be rotatably mounted within bearings 94 and 96 at either end thereof. A gear 98 is keyed to one end of the shaft 36 and is driven by a smaller gear 100 engaged therewith. The camshaft 36 and associated gears 98 and 100 are housed within a lubrication cage 102 secured within the heart pump casing 12 and provided with a lubrication fitting 104 so that lubrication of the shaft and its gears will not affect other parts of the heart pump.

Secured to the camshaft 36 by a key and keyway or other means 106 are a plurality of cams 108 each adapted to be associated with one of the pumping units 14. Each cam 108 is engaged by one of a plurality of rocker arms 110 pivotally mounted upon one of two shafts 112 and 114 mounted along opposite sides of the casing 12 and parallel to the camshaft 36. The rocker arms 110 are maintained in spaced relation to each other, and each directly over one of the cams 108, by separators or spacers 115 mounted on the rocker arm shafts 112 and 114 and receiving the rocker arms. The cams 108 may be made in any convenient manner. In the present instance each cam is formed to provide two semi-circular cylindrical surfaces 116 and 118 of different radii on opposite sides of each cam. The cam surfaces each extend approximately 180 degrees around the cams 108 and are joined together by reversely bent connecting surfaces 120 and 122 adapted to provide a minimum period of lift and drop. The ends of the rocker arms 110 engaging the cams 108 are thus alternately raised and lowered during each revolution of the camshaft 36. Alternate cams are engaged by rocker arms 110 mounted on opposite sides of the casing 12 thereby providing for a more compact arrangement of the fluid pumps 14 and for simultaneous actuation of all pumps during each revolution of the camshaft 36 in accordance with the position of the cammed surfaces. In the present embodiment of this invention the unit pumps 14 secured to the right side of the casing 12 are adapted to provide a more or less constant fluid flow and the cams 108 associated with those pumps have their cammed surfaces 116 and 118 progressively positioned about the camshaft 36. The pumping units 14 secured to the left side of the casing 12 are similarly progressively positioned but are adapted to provide a pulsating fluid flow.

The camshaft is driven through the small gear 100 secured to the stub shaft 124 mounted above the camshaft 36. The stub shaft 124 is rotatably journaled within bearings 126 and 128 secured to the lubrication cage 102 and has a multiple pulley 130 secured to one end thereof. An electric motor 42 is mounted near the base of the heart pump casing 12 and is connected to an electrical source by an electrical lead 132. The electrical connection 132 enters the heart pump 10 with the air lines 22 and 24 near the top of the device. The motor 42 is sealed and explosion proof as are most electrical motors used with surgical instruments. A small multiple pulley 134 secured to the motor shaft 135 drives the larger pulley 130 through the belt 38. Relocation of the belt 38 upon the pulleys 130 and 134 enables minor control of the speed of rotation imparted to the camshaft 36. Further control may be provided by use of a variable speed motor. Rotation of the camshaft 36 herein has been limited to between 65 and 85 r.p.m. The motor 42 is mounted upon a base plate 136 disposed below the casing 12 and pivotally secured to the casing near one end as shown in FIGURE 2. A bolt 138 secured to the casing extends through the plate with a nut 140 threaded thereon to enable altering the vertical position of the motor 42 and varying the tension of the belt 38. A spring 141 disposed about the bolt 138 holds the base plate 136 in spaced relation to the casing 12 and provides a degree of vibrational absorption.

The heart pump is mounted upon four legs 142 to hold the device in level position above whatever surface it is placed on and has rubber cushions 144 secured to each leg as by bolts 146 to provide a secure footing. The legs 142 also elevate the casing 12 so that the motor 42 may be mounted therein and hang below the casing in the manner described. The air lines 22 and 24 entering the top of the heart pump casing 12 are adapted to provide a source of both positive and negative air pressure which comprises the pumping fluid and is introduced to each fluid pump 14 individually. The positive pressure air line 22 is connected to separate manifolds 148 formed through the casing 12 and along each side thereof. An air pressure gauge 28 and a regulating valve 32, providing means for varying the air pressure, are mounted to the casing 12 on each side thereof and are connected to the air line 22 between the pressure source and the manifold 148. The negative pressure air lines 24 are connected to surge tanks 150 secured to each end of the casing 12. Each surge tank 150 communicates by passage means 152 to a manifold 154 formed through the casing parallel to the positive pressure manifold 148 but separate and in a different plane therefrom. A vacuum gauge 26 and a regulating valve 30 are mounted on each side of the casing 12. The negative or vacuum pressure line connections are shown schematically in FIGURE 10. Each of the vacuum gauges 26 are connected in one of the air lines 24 between the vacuum pump 156 and the surge tanks 150. The vacuum regulating valves 30 are connected in the bleed lines 158 from the after end of the vacuum manifolds 154.

Formed vertically through the casing 12, between the air pressure manifolds 148 and 154, are a number of valve guide passages 160 individually connected by manifold passages 162 and 164 to both manifolds. The sleeve valve 34 is slidably mounted within each guide passage 160. Each sleeve valve 34 is biased against a rocker arm 110 disposed thereabove. Biasing means are provided by a spring 166 seated upon a shoulder 168 formed about the upper end of the guide passage 160 and bearing against a collar 170 secured to the upper end of the sleeve valve. An annular detent 172 is formed about the sleeve valve 34 and communicates with a passage 174 formed axially through one end of the valve. Action of the rocker arm 110 moves the sleeve valve 34 up and down within

the guide passage 160 and positions the detent 172 adjacent one or the other of the manifold passages 162 or 164. When one of the manifolds 148 or 154 is in communication with the detent 172 the other manifold is closed. Hence negative and positive air pressure are alternately admitted to the guide passages 160. Each guide passage is closed at its lower end by a plug 176 threaded therein. The sleeve valve 34 does not travel completely to the end of the guide passage 160 leaving a small air collecting chamber 178 at the lower end thereof.

The air collecting chambers 178 below the sleeve valves 34 are connected by passages 180 formed through the casing 12 to air filter chambers 182 formed within the base ledge 44 below each fluid pump 14. Apertures 184 and 186 are provided through the base ledge 44 and the stopper 50 of each pump, between the filter chambers 182 and the air pockets 53 of the finger cots 52, to enable the admission of air pressures to and from the finger cots. The filter chambers 182 are closed at their lower ends by plugs 188 threaded within the base ledge 44. Each plug provides a seat 190 for a spring 192 which holds a porous filter 194 over the aperture 184 leading to the finger cot 52. The filter seats upon a seal 196 and urges an apertured button 198, formed centrally on the seal, to project through the base ledge aperture 184. The button 198 projects beyond the surface of the base ledge 44 and provides for centering of the stopper 50 thereover and alignment of the apertures 184 and 186.

In FIGURE 10 is shown schematically the connections made between the mechanical heart pump 10 and the living heart 200 during an operation in which all blood normally flowing through the heart is by-passed through the heart pump. These connections are prescribed by the surgeon and are shown here only as to general location. All connections between the mechanical device and the living heart are made through suitable mechanical connections and tubing. The common fluid inlet passage 18 on one side of the heart pump is connected by a tube 202 to the right auricle or atrium 204 of the heart 200. The blood passing through the fluid pumps 14 is returned through the common outlet passage 20 of the heart pump in a constant flow through a tube 206 connected into the right pulmonary artery 208. The blood flows to the lungs 210 giving off carbon dioxide and receiving oxygen and is intercepted on leaving the lungs and before entering the left auricle or atrium 212 of the heart by tubes 214 connected with the pulmonary veins 216. Blood is carried by these tubes to the common fluid inlet passage 18 on the other side of the mechanical heart pump and is returned from the common fluid outlet passage 20 through a tube 218 connected within the aortic arch 219. In an operation in which the heart pump is to take over only the functions of one side of the heart only those connections relating to that particular side of the heart are necessary. The other side of the pump may be left to operate without the flow of fluid therethrough without affecting the activated side of the device.

In preparing the mechanical heart pump for use in an operation the surgeon will prescribe whether both sides of the pump or only one are to be connected to the heart. This is dependent upon the type of cardiac operation necessary to be performed. The surgeon will also prescribe the blood pressure to be maintained and the quantity of blood to be circulated for the particular patient. The patient's physical condition determines these factors. The volume is variable by the number of pumps 14 used and by control of the frequency with which each pump is adapted to move its charge through the heart pump system. Varying the air pressure applied to the pump alters the fluid pressures applied through the flow system.

The drive belt 38 is checked on the pulleys 130 and 134 for the prescribed camshaft speed. The pumps 14 necessary to provide the required fluid capacity are secured to the casing 12 and their passage members 16 are connected to the common fluid flow passages 18 and 20. The motor is started and air pressure is introduced to the heart pump, the pressures being set on the gauges 26 and 28 by regulation of the control valves 30 and 32. Purging of air is accomplished by circulating a normal saline solution through the pump system. The saline solution is then followed by a quantity of donor blood of the same group and type as the patient to fill the system and remove the saline solution. The surgeon then makes the connections between the mechanical device and the patient's heart. The cams 108 secured to the camshaft 36 actuate the rocker arms 110 which in turn cause the sleeve valves 34 to move axially within the guide passages 160. Movement of the sleeve valve detent 172 between the air manifold passages 162 and 164 alternately admits positive or negative air pressure to each of the air pockets 53 within the finger cots 52. As the finger cot 52 is contracted blood is drawn into the fluid chamber 48 past the inlet check valve 68. When the finger cot 52 is expanded blood is expelled by lifting the outlet check valve 70. The blood moving through each pump 14 flows through the common outlet flow passage 20 to the connection 206 or 218.

Negative pressure supplied to the air pocket 53 in each finger cot 52 is required to exhaust the positive pressure existing therein. When a group of fluid pumps 14 are adapted to act simultaneously to provide a pulsating fluid flow the negative pressure volume applied through the negative pressure manifold 154 may be considerably depleted in overcoming the cumulative air volume under pressure released thereto. The surge tanks 150 therefore furnish a reserve source of vacuum to provide proper negative pressure at all times. Since the air pressures released to the vacuum manifold 154 also alter the air required to produce the necessary vacuum the negative pressure regulating valve 30 is disposed, as previously mentioned, in the air bleed line 158 below the manifold connection to the vacuum pump 156.

I claim:

1. Fluid pumping means comprising a casing having a plurality of individual pumping units removably secured thereto, a camshaft mounted within said casing, means for rotating said camshaft, positive and negative air pressure manifolds formed within said casing, a source of positive and negative air pressure connected to said positive and said negative manifolds respectively, a plurality of cams secured to said camshaft, a plurality of rocker arms pivotally mounted within said casing and each engaging one of said cams, valve guide passages formed within said casing between said manifolds, manifold outlet passages formed through said casing between each of said manifolds and each of said guide passages separately, sleeve valves disposed in each of said guide passages and in engagement with one of said rocker arms, interconnected passages formed through said casing between each of said guide passages and each of said fluid pumps, air filter chambers formed within said interconnected passages and having air filtering means disposed therein, a fluid chamber formed within each of said pumps, an air sac disposed within each of said fluid chambers and in communication through said interconnected passages with each of said pressure manifolds, passage means associated with each of said fluid pumps, fluid inlet and outlet check valves mounted within each of said fluid passages, valve seats formed within said fluid passage members and adapted to receive said check valves thereagainst, said valves being subjected to forces urging them into engagement with said valve seats, said valves and said valve seats having broad engaging surfaces cooperating with said forces for minimizing the unit area pressure therebetween.

2. A mechanical device for simulating the action of a living heart and comprising a casing having a plurality of individual blood pumps removably secured along opposite sides thereof, common fluid inlet and outlet passages associated with each of said pumps along each side

of said casing, said fluid pumps on one side of said casing being adapted to act together to provide a constant fluid flow simulating the action of the right side of the heart, said pumps secured to the other side of said casing being adapted to act together to simulate the pulsating fluid flow left side of said heart, a camshaft mounted centrally within said casing between said blood pumps secured to opposite sides thereof, means for driving said camshaft, and means in engagement and cooperating with said camshaft for actuating said blood pumps along said one side thereof successively and along the other side thereof simultaneously in two groups during each revolution of said camshaft.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,045,601 July 24, 1962

Edward V. Rippingille

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 2, line 69, for "unidiretcional" read -- unidirectional --; column 3, line 69, for "unidirectional flow of fluid through each pumping unit" read -- the air lines 22 and 24 to control the air pressures --; line 70, for "mitted" read -- admitted --.

Signed and sealed this 20th day of November 1962.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

DAVID L. LADD
Commissioner of Patents