(12)Indian Patent Application

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(21) Application Number: 202141031977

(22) Filing Date: 15/07/2021 (43) Publication Date: 20/01/2023

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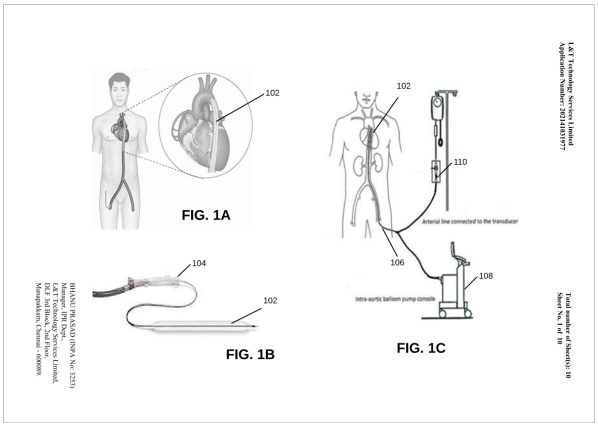
(51) International Classifications: F04B 45/053 B08B 3/14 F04B 43/113 A61H 9/00 F04B 17/04

(54) Title: SYSTEM AND METHOD FOR PUMP AUGMENTING FLUID CIRCULATION IN A BODY

(57) Abstract: System and pump for augmenting fluid circulation in a body is disclosed. The system includes a pump (402) for pumping the fluid. The pump (402) includes a housing (402A), and a flexible member (410) positioned inside housing (402A). Flexible member (410) divides housing (402A) into a first compartment and a second compartment. The second compartment includes a spout (606) for pumping working fluid. Pump (402) includes one or more solenoid actuators (416) configured to transition between a retracted state and an expanded state. The system includes a processing device (418) coupled to the pump (402) and a balloon (502) fluidically coupled to the pump (402) via the spout (606) to receive the pumped working fluid. In response to the pumped working fluid received from the pump (402), the balloon (502) is configured to transition between an inflated and a deflated state to assist an organ in augmenting fluid circulation in the body.



FORM 2

THE PATENTS ACT 1970
(39 OF 1970)
&
The Patent Rules, 2003
Complete Specification
(See Section 10 and Rule 13)

1. TITLE OF THE INVENTION

SYSTEM AND METHOD FOR PUMP AUGMENTING FLUID CIRCULATION IN A BODY

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3. PREAMBLE TO THE DESCRIPTION

COMPLETE

The following specification particularly describes the invention and the manner in which it is to be performed.

DESCRIPTION

Technical Field

[001] This disclosure relates generally to devices used in clinical practice and surgical assistance, and more particularly relates to a mechanical circulatory assistance system for a mammal heart.

Background

[002] Fluids play an important role in body functions of a mammal. The primary fluid flow functions may include, without limitation, circulation of blood in a body, breathing air through lungs, and food ingestion and exit. However, due to abnormalities developed by illness or other factors, some of such functions may get compromised and the mammal may need temporary or permanent augmentation of some form to maintain a requisite level of fluidic body functions through a mechanical circulatory assistance or support device.

[003] Existing blood circulation systems may need correct timing and trigger with respect to heart beat rate for effective augmentation. In certain scenarios, wrong timing of an augmentation trigger can turn out to be out of phase with augmentation need of a cyclic process and thereby, leading to counterproductive action and even fatality and irreparable damage. Therefore, such systems may need an instantaneous trigger to response time to remain in tandem with the heart rhythm. Existing sophisticated systems may perform real time Electrocardiogram (ECG), blood pressure monitoring and trigger augmentation event. However, primary delay from trigger to response happens because of inertia of mechanics of an augmentation device.

[004] Further, existing intra-aortic augmentation devices use pneumatic circuits and reservoirs with a pneumatic pump, to provide instantaneous energy on release of a solenoid valve to trigger Helium based balloon augmentation in an artery. Such a device may have a low response time, bulky and costly. Many a times, people with augmented state may need to be transported to alternate facilities and thus, the process becomes cumbersome due to the need to tag along a heavy device with the all subsystems, effecting mobility of such people. Furthermore, use of generic mechanical pumps can drastically reduce the system weight. However, such mechanical pumps may never be able to match the response time needed to respond in tandem with the heartbeat. Such pumps are better suited for periodic cycling and cannot synchronize to a body event in every cycle. Generic mechanical pumps may also expose

bodily fluids to contamination from moving parts, unless there are special means to isolate the body fluid from pump elements.

[005] Accordingly, there is a need for a more compact and portable system to enable augmentation in quick response time without the need of excessive paraphernalia like pneumatic reservoirs and pumps to enable compactness of the system for safe and mobile augmentation for a patient, and to make life easier for care providers who move the patient from one facility to another.

SUMMARY

[006] In accordance with an embodiment, a system for augmenting fluid circulation in a body is disclosed. The system includes a pump for pumping the fluid. In accordance with an embodiment, the pump includes a housing, and a flexible member positioned inside the housing. In accordance with an embodiment, the flexible member divides the housing into a first compartment and a second compartment. In accordance with an embodiment, the second compartment includes a spout for pumping a working fluid and one or more of solenoid actuators positioned in the first compartment. In accordance with an embodiment, the one or more of solenoid actuators are configured to transition between a retracted state and an expanded state. In accordance with an embodiment, in the expanded state, the one or more of solenoid actuators are configured to press the flexible member towards the second chamber to pump the working fluid via the spout. The system further includes a processing device coupled to the pump. In accordance with an embodiment, the processing device may be configured to receive a signal indicative of requirement of fluid circulation in the body and trigger, based on the signal, the transition of the one or more of solenoid actuators between the retracted state and the expanded state to cause the flexible member to pump working fluid. The system further includes a balloon fluidically coupled to the pump via the spout to receive the pumped working fluid. In response to the pumped working fluid received from the pump, the balloon may be configured to transition between an inflated and a deflated state to assist an organ in augmenting fluid circulation in the body.

[007] In accordance with another embodiment, a pump for pumping a fluid is disclosed. The pump includes a housing and a flexible member positioned inside the housing. In accordance with an embodiment, the flexible member divides the housing into a first compartment and a second compartment. In accordance with an embodiment, the second compartment comprises a spout for pumping working fluid. The pump further includes one or more of solenoid actuators positioned in the first compartment. In accordance with an embodiment, the one or

more of solenoid actuators are configured to transition between a retracted state and an expanded state. In accordance with an embodiment, in the expanded state, the one or more of solenoid actuators are configured to press the flexible member towards the second chamber to pump working fluid via the spout.

[008] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

[009] The accompanying drawings, which are incorporated in and constitute a part of this disclosure, illustrate exemplary embodiments and, together with the description, serve to explain the disclosed principles.

[010] FIGS. 1A-1C collectively illustrate in schematic diagrams, an intra-aortic balloon pump (IABP) configured with catheter and IABP equipment for augmenting fluid circulation in a human body, in accordance with an embodiment of the disclosure.

[011] FIG. 2 is a block diagram that illustrates a conventional pneumatic pump for augmenting fluid circulation in a human body, in accordance with an embodiment of the disclosure.

[012] FIG. 3 is a block diagram that illustrates an electromagnetic pump for augmenting fluid circulation in a human body as a replacement for the conventional pneumatic pump, in accordance with an embodiment of the disclosure.

[013] FIGS. 4A-4B collectively illustrate diagrams for an electromagnetic pump for augmenting fluid circulation in a human body, in accordance with an embodiment of the disclosure.

[014] FIG. 5 illustrates an electromagnetic pump configured inside a human heart for augmenting fluid circulation in a human body, in accordance with an embodiment of the disclosure.

[015] FIG. 6A-6C collectively illustrate schematic diagrams of a front view and a side section view of an electromagnetic pump for augmenting fluid circulation in a human body, in accordance with an embodiment of the disclosure.

[016] FIG.7A-7B collectively illustrate schematic diagrams of solenoids of an electromagnetic pump in a retracted state and an expanded state for augmenting fluid circulation in a body, in accordance with an embodiment of the disclosure.

[017] FIG. 8 illustrates a schematic diagram for a system using an electromagnetic pump configured in a human heart for augmenting fluid circulation in a human body, in accordance with an embodiment of the disclosure.

[018] FIGS. 9A-D illustrate various views of an electromagnetic pump for augmenting fluid circulation in a human body, in accordance with an embodiment of the disclosure.

[019] FIG. 10A-10C collectively illustrate diagrams of various components of an electromagnetic pump configured inside a human heart for augmenting fluid circulation in a human body, in accordance with an embodiment of the disclosure.

DETAILED DESCRIPTION

[020] Exemplary embodiments are described with reference to the accompanying drawings. Wherever convenient, the same reference numbers are used throughout the drawings to refer to the same or like parts. While examples and features of disclosed principles are described herein, modifications, adaptations, and other implementations are possible without departing from the spirit and scope of the disclosed embodiments. It is intended that the following detailed description be considered as exemplary only, with the true scope and spirit being indicated by the following claims. Additional illustrative embodiments are listed below.

[021] The mammal (such as, humans and animals) may need temporary or permanent augmentation of some form or the other to maintain the requisite level of fluidic body functions through mechanical circulatory support devices. Examples of such augmentations may include use of ventilation to augment breathing function in Acute Respiratory Distress by maintaining positive pressure, augmentation of blood flow in aorta by inflating a balloon to ensure perfusion of oxygen rich blood in coronary arteries and then deflation to ensure blood ejection, in tandem with heartbeat, and continuous positive airway pressure therapy devices to maintain air pressure in throat to prevent obstructive sleep apnea and so on. The following described implementations may be found in the disclosed system which is compact and portable to enable augmentation with quick response time by using an electromagnetic pump without the need of excessive paraphernalia like pneumatic reservoirs and pumps. The disclosed system may have reduced weight and easier to transport, thereby making it a mobile device that allows long term therapy patients to carry it in a small bag with them.

[022] Exemplary aspects of the disclosure provide a system that is easy to handle transportation of patients on the therapy since that can be latched on to a stretcher or a patient himself, and need not be dragged along. The disclosed system may have a longer battery life allowing more freedom and lower risk of loss of support.

[023] Exemplary aspects of the disclosure provide a system that has a reduced product cost by a larger extent. Exemplary aspects of the disclosure provide a system that is mobile than just portable and thus allows more versatility in application and transportation, a better Mean Time Between Failures (MTBF) as number of components are less as compared to conventional systems, better MTBF as a plurality of solenoids allow operations to continue even if one solenoid fails. Hence, usage of the disclosed system lends precious lifeline when a defect crops out as the augmentation does not seize immediately.

[024] The disclosed system may involve less components in the loop making the design and assembly procedures of the system simple, lower failure risk due to parallel operation of a plurality of solenoids used in the electromagnetic pump, lower frictional losses and hence better battery life. The disclosed system may have better reliability as compared to existing conventional systems.

[025] FIGS. 1A-1C collectively illustrate in schematic diagrams, an intra-aortic balloon pump (IABP) configured with catheter and IABP equipment for augmenting fluid circulation in a human body, in accordance with an embodiment of the disclosure.

[026] With reference to FIG. 1A, an intra-aortic balloon pump (IABP) 102, typically available, may be configured on a human heart to pump blood when the heart is unable to pump enough blood for the human body. An enlarged view of the IABP configured on the heart is shown in FIG. 1A. Typically, the IABP may be inserted into the aorta which is the largest artery in the human body. The IABP may act as a therapeutic device that aids in pumping more blood from the heart.

[027] With reference to FIG. 1B, the IABP configured with the catheter 104 is shown. The catheter 104 may correspond to a long, and thin tube with a balloon on the end of the catheter 104. The IABP 102 may reduce workload on the heart, allowing the heart to pump more blood. The IABP 102 may be placed inside the aorta that corresponds to an artery that takes blood from the heart to the rest of the body. The balloon on the end of the catheter 104 inflates and deflates with the rhythm of the heart, thereby, helping the heart to pump blood to the body.

[028] With reference to FIG. 1C, the IABP equipment is shown. The IABP equipment includes an IABP console 108 attached to an arterial line 106 associated with the IABP 102. Further, the arterial line 106 associated with the IABP 102 may be connected to a transducer 110 that converts the ECG input signal from the heart into an electrical signal. Alternately, the signal may be a pressure signal received directly from a pressure sensor. The trigger may be provided by a Dicrotic notch.

[029] FIG. 2 is a block diagram that illustrates a conventional (prior art) pneumatic pump for augmenting fluid circulation in a human body, in accordance with an embodiment of the disclosure. There is shown an external tank 202, a fill manifold 204, a vacuum reservoir 206, a pneumatic interface module (PIM) manifold 208, a pneumatic pump balloon 210, a pressure manifold 212, a pressure reservoir 214, a compressor/motor 216, a vacuum manifold 218, a drive manifold 220, and a safety disk 222.

[030] With reference to FIG. 2, for the conventional pneumatic pump, use of pressurized working fluid in the pressure reservoir 214, where the pressurized working fluid may be continuously maintained in certain pressure by pneumatic pump, as a prime mover, enables to eliminate the inertia of a direct mechanical pump which shall have very poor response time, if it were to instantaneously pump Helium (He) gas. Hence, typically intra-aortic augmentation devices use a pneumatic circuit and reservoir with a pneumatic pump, to provide instantaneous energy on release of a solenoid valve to trigger the Helium based balloon augmentation in the artery of a human body.

[031] The Helium from the external tank 202 may enter the internal Helium reservoir (not shown separately from fill manifold) in the fill manifold 204 through one directional check valve with a certain pressure (such as, 220 psi pressure). Further, a quick disconnect valve may be used to stop Helium flow when the IABP console is removed from the cart by ensuring internal helium reservoir is full. In fill manifold 204, the helium pressure may be regulated to a certain pressure (such as, 6 psi pressure) and flow rate may be kept constant throughout the process. Helium may be purified in the fill manifold 204 and purification of Helium may require some amount of vacuum from the vacuum reservoir 206. Helium may enter to the PIM manifold 208 from the vacuum reservoir 206.

[032] Further, the pneumatic pump may be used to pump Helium into the balloon associated with the pneumatic pump for inflation and to suck Helium out of the balloon associated with the pneumatic pump for deflation. To deflate and inflate the balloon, the diaphragm associated with the pneumatic pump may move left and right respectively. For such movement, pressurized working fluid may be used with the help of the pressure manifold 212 and the pressure reservoir 214 to push diaphragm associated with the pneumatic pump right and the vacuum may be created to pull the diaphragm left. The drive manifold 220 may be configured to control valves V1 and V2. For inflation, V2 valve may be opened by the drive manifold 220 and V1 valve may be closed. For deflation, V2 valve may be closed by the drive manifold 220 and V1 valve may be opened. The compressor or motor 216 may be used to create the

pressurized working fluid and vacuum to drive the diaphragm associated with the pneumatic pump.

[033] Efficacy of augmentation devices using the pneumatic pumps as described in FIG. 2 may, however, have low response time. Such augmentation devices using the pneumatic pumps may become bulky and costly. In some scenarios, persons with augmented state may need to be transported to alternate facilities and thus, the process becomes cumbersome due to the need to tag along a heavy augmentation device using the pneumatic pumps along with related sub systems. Additionally, such augmentation devices using the pneumatic pumps may affect mobility of persons with augmented state.

[034] Further, mechanical pumps (not shown in FIG. 2) are also available which have high inertia. The mechanical pumps can provide reversals of pressure at very high frequencies provided the cycles are fixed periodic cycles. However, the cardiac cycle does not have a fixed time period and needs to be triggered based on a cardiac cycle event detection (like detection of dicrotic notch). Additionally, there have been significant developments in the field of electromagnetic actuator-based pumps, especially in micro and nano fields (where inertia is typically low). Such systems have been known to have a response time of as low as 5 milli seconds. However, such systems have not been scaled to a larger force requirement with low response times as inertia pulls down the system efficiency to respond.

[035] Additionally, typical reciprocating systems have multiple friction points and major inertial change as they change direction, and reach up to 8000 Hz in periodic speeds which are trigger independent. However, when the event has to be trigger based and near-instantaneous response times is even low, frequencies like 100 Hz are difficult to attain due to start-stop inertial forces. The aforementioned problems associated with conventional systems for augmenting fluid circulation in a body may be addressed by using a system and an electromagnetic pump explained in description of FIGS. 3 to 10.

[036] FIG. 3 is a block diagram that illustrates an electromagnetic pump that addresses problems associated with a conventional pneumatic pump for augmenting fluid circulation in a human body, in accordance with an embodiment of the disclosure. There is shown an external tank 302, a fill manifold 304, an electromagnetic pump 306, and a drive circuit 308.

[037] Helium Gas may be pushed in and out through the safety disc 222 as explained in description of FIG. 2 where the other end of the safety disc 222 may be actuated by an elaborate pneumatic system comprising the pressure manifold 212, the pressure reservoir 214, the compressor/motor 216, the vacuum manifold 218, the drive manifold 220, and the vacuum reservoir 206.

[038] With reference to FIG. 3, the pneumatic system may be replaced with an electromagnetic actuation system (hereinafter referred as system) (not labelled in FIG. 3). Consequently, the need of pneumatic system may be eliminated completely. Therefore, the components, namely, the pressure manifold 212, the pressure reservoir 214, the compressor/motor 216, the vacuum manifold 218, the drive manifold 220, and the vacuum reservoir 206 of the pneumatic system are eliminated in the system. In accordance with an embodiment, the system may include the external tank 302, the fill manifold 304, the electromagnetic pump 306, and the drive circuit 308. The electromagnetic pump 306 may correspond to an Intra-Aortic Balloon Pump (IABP) device. In accordance with an embodiment, the external tank 302 and the fill manifold 304 may correspond to the external tank 202 and the fill manifold 204 respectively as described in FIG. 2.

[039] In accordance with an embodiment, the electromagnetic actuation system that includes the electromagnetic pump 306 may enable rapid fluidic mass transfer or pressure change in various systems that may have such application in maintaining body fluid functions.

[040] In accordance with an embodiment, the electromagnetic pump 306 may act as a cost-effective replacement for conventional pneumatic pump and pressure reservoir 214 used as an IABP device to drive helium-based balloon interface in the heart. The system may enable direct drive of Helium interface and enable cost productivity and reduction of IABP device size.

[041] In accordance with an embodiment, the electromagnetic pump 306 may be configured to achieve synchronization of augmentation with the pumping phase of heart with a very high response time and a low inertia so that the electromagnetic pump 306 can respond in a few milliseconds and can be individually triggered for each cycle as per actual phase of the heart. Such high response times are typically difficult to attain of conventional mechanical pumps.

[042] The electromagnetic pump 306 may be utilized in building a compact mobile unit that can be strapped-on or hung on a patient and allows easy mobility. For morbid patients, the patient handling may drastically improve with a system having the electromagnetic pump. The system may further work in a closed mode such that no solenoids are used to trigger the event. Instead, the electromagnetic pump may directly push the helium and withdraws it, as and when required. Hence the repository of helium required may be small for minor leakage refill only.

[043] In another embodiment, the electromagnetic pump 306 can work in open circuit with ambient air (working fluid), provided the drive line cross section is enlarged sufficiently to compensate for the increased viscosity of working fluid. This may however not be applicable in all augmentation sites (especially narrower veins) and so the option to run on helium shall be present with the device. The electromagnetic pump 306 may aid in providing trigger-based

augmentation of fluid flow in the body, with specific applications to cardiac cycle, at much lower form factor and cost.

[044] In accordance with another embodiment, the electromagnetic pump 306 may be extended to dosed fluid delivery and release in micro and nano platforms. In accordance with another embodiment, the electromagnetic pump 306 may be used to replace fluid flow applications, such as, hydraulics that uses fluid or gases.

[045] FIGS. 4A-4B collectively illustrate diagrams for working of an electromagnetic pump for augmenting fluid circulation in a human body, in accordance with an embodiment of the disclosure. FIGS. 4A-4B are explained in conjunction with FIG. 3.

[046] With reference to FIG. 4A, there is shown an electromagnetic pump 402, an outer frame 404, a catheter tube 406, a pressure sensor 408, a flexible member 410 (also referred as silicon sheet 410), a plate 412, a plunger 414, and a plurality of solenoid actuators 416. In accordance with an embodiment, the plurality of solenoid actuators 416 (hereinafter referred as solenoid actuators 416) may correspond to push-type solenoid actuators. There is further shown a housing 402A of the electromagnetic pump 402. FIG. 4A illustrates an initial position of the electromagnetic pump 402 when the solenoid actuators 416 are in off state (or retracted state). The pressure sensor 408 may be placed inside the balloon to get signal from patient body.

[047] With reference to FIG. 4B, there is shown a system 400. There is further shown the electromagnetic pump 402, the drive circuit 308, a processing device 418, an ECG input signal 420, a power supply 422, and a final position 424 when the solenoid actuators 416 are in on state (or expanded state).

[048] The function of the electromagnetic pump 402 is to make the balloon inflate and deflate by pumping Helium gas in and out respectively on time based on the ECG input signal 420. In accordance with another embodiment, the ECG signal 420 as an input may be fed into the processing device 418, thereby generating a pulse type signal to drive the solenoid actuators 416. The pulse type signal may be generated by the drive circuit 308 which may be connected to the solenoid actuators 416.

[049] The plate 412 may be connected to the plungers 414 of the solenoid actuators 416. When the solenoid actuators 416 are activated, the solenoid actuators 416 create an electro-magnetic push on the plungers 414 eventually pushing the plate 412 connected to them, thereby pushing Helium back and forth. The movement of the plate 412 may be very fast and accurate so that the response time of the solenoid actuators 416 may be very less. The accuracy cannot be compromised as it deals with the human heart.

[050] It may be noted that the cross section of the pump may be much higher than the stroke of the solenoids, so that through minimal stroke and inertial effects of solenoid, maximized volumetric displacement can be obtained.

[051] A plurality of solenoids, such as the solenoid actuators 416, may be required to create more electromagnetic force with low current and voltage, and to reduce the eddy current loses when the load is distributed. Further, the diameter of the plate 412 may be kept higher as compared to current disk diameter to generate high pressure with low plate displacement. The silicon sheet 410 may be used as flexi gland to hold the plate 412 and may act like a sealing layer for a working fluid chamber. By way of an example, an expected fatigue life for a silicon rubber that may be used as the silicon sheet 410 is in the range of 5M-10M cycles.

[052] FIG. 5 illustrates a patient side of an Intra-aortic balloon pump device inserted in a human heart for augmenting blood circulation in a human body by identifying the right moment for inflation with help of pressure sensor 500 and ECG signals, in accordance with an embodiment of the disclosure. There is shown a balloon 502 of an electromagnetic pump, an aorta 506, a drive line 508, and a flexible member 608. FIG. 5 is explained in conjunction with FIG. 3 to FIG. 4B.

[053] Referring to FIG. 5 that shows the patient side of the electromagnetic pump device where the balloon 502 may be placed in the aorta 506. The balloon 502 may be supplied a working fluid via the drive line 504 to augment the blood flow to the human body.

[054] FIG. 6A-6C collectively illustrate schematic diagrams of a front view and a side section view of an electromagnetic pump for augmenting fluid circulation in a human body, in accordance with an embodiment of the disclosure.

[055] With reference to FIG. 6A, there is shown a front view of an electromagnetic pump 600. With reference to FIG. 6B, there is shown a side view of the electromagnetic pump 600. There is further shown a front cover 602, a back cover 604, a spout 606, the flexible member 608, the solenoid actuators 416, and the plate 412. The flexible member 608 may be sandwiched between the front cover 602 and the back cover 604. The front cover 602 may have a suitably sized spout 606 to allow the flow of a working fluid. The plate 412 (corresponding to a metallic plate) may be attached to the central region of the flexible member 608. On the back cover 604, one or more of the solenoid actuators 416 may be mounted that can push or pull the plate 412 joined to the flexible member 608. The arrangement of the solenoid actuators 416 may be such that an actual movement of each of the solenoid actuators 416 is very low. In accordance with an embodiment, the movement of each of the solenoid actuators 416 may be in the range of 0.5mm to 2mm. The solenoid actuators 416 may work in tandem to push the

flexible member 608 to create a reduction in available volume between the flexible member 608 and the front cover 602. Consequently, the working fluid may rush out. Hence, an electromagnetic pump with a low inertia and a high response time may be achieved with negligible friction.

[056] Referring to FIG. 6C that shows the flexible member 608 associated with the electromagnetic pump may be made of an elastomer, such as, without limitation, silicone rubber or other such similar material. The flexible member 608 may be similar to the silicon sheet 410 as shown in FIG. 4A. The flexible member 608 may have a flexibility to deform in either direction when a force is applied to the flexible member 608 in the middle as shown in FIG. 6C.

[057] FIG. 7A-7B collectively illustrate schematic diagrams of an electromagnetic pump in a relaxed state (retracted state) and a working state (expanded state) for augmenting fluid circulation in a body, in accordance with an embodiment of the disclosure.

[058] Referring to FIG. 7A, an electromagnetic pump 600 in a relaxed state is shown. There is further shown a working fluid 702. For the sake of brevity, the parts of the electromagnetic pump are not labelled and are same as illustrated in FIG. 6B. In the relaxed state of the electromagnetic pump 600, the working fluid 702 may lie between the flexible member 608 and the front cover 602 at a low pressure.

[059] FIG. 7B illustrates that when the solenoid actuators 416 act, the flexible member 608 may deform causing a reduction in the volume available between the flexible member 608 and the front cover 602, thereby causing the working fluid 702 to rush out or get displaced into the balloon 502 at higher pressure.

[060] FIG. 8 illustrate a schematic diagram of a system using an electromagnetic pump for augmenting fluid circulation in a human body, in accordance with an embodiment of the disclosure. With reference to FIG. 8, a complete setup of the system at a patient side and the electromagnetic pump side (also referred as a device side) is illustrated. The electromagnetic pump 600 may run through the processing device 418 (also referred as control circuit 418) which is powered by either a battery or the power supply 422. The ECG input signal 420 and pressure 802 from patient side may be received using pressure sensor by the processing device 418 and processed to identify the trigger point and accordingly actuate the electromagnetic pump 600. A one-way valve 804 may allow the flow from the electromagnetic pump to the drive line 504 to inflate and deflate the balloon 502 placed inside the patient. A stabilizing valve 806 may be configured to allow refill of the working fluid 702 stored in the external tank 302 to the processing device 418 on need basis. In accordance with an embodiment, the

stabilizing valve 806 may be Solenoid-powered and electronically controlled. The stabilizing valve 806 provided on a fluid line between working fluid tank (also referred as external tank 302) and the electromagnetic pump. In accordance with an embodiment, the stabilizing valve 806 may be configured to open and close in response to a drop in line pressure to stabilize the working pressure of the fluid line.

[061] FIGS. 9A-D illustrate various views of the electromagnetic pump 600 for augmenting fluid circulation in a human body, in accordance with an embodiment of the disclosure. FIG. 9A illustrates a perspective view of the electromagnetic pump 600, in accordance with an embodiment of the disclosure. FIG. 9B illustrates a front view of the electromagnetic pump 600, in accordance with an embodiment of the disclosure. FIG. 9C illustrates a side view of the electromagnetic pump 600, in accordance with an embodiment of the disclosure. FIG. 9D illustrates another side view of the electromagnetic pump 600, in accordance with an embodiment of the disclosure.

[062] FIG. 10A-10C collectively illustrate Computer Aided Design (CAD) of various components of an electromagnetic pump for augmenting fluid circulation in a human body, in accordance with an embodiment of the disclosure.

[063] With reference to FIG. 10A, there is shown a cross-sectional view of the electromagnetic pump. FIG. 10B illustrates a partial view of the electromagnetic pump showing a port for solenoid connection. FIG. 10C shows a fastening of a plunger to a plate of the electromagnetic pump.

[064] The disclosed implementation of the electromagnetic pump may enable body fluid augmentation in tandem on a trigger with a low response time, and with least possibility of contamination, so that mobility and independence of a patient can be improved. The intra-aortic balloon pump may have a low inertia and a quick response time based on electromagnetic actuation. The electromagnetic actuation happens against a flexible member of the intra-aortic balloon pump and hence eliminates several friction points of generic pumps and improves response time. The intra-aortic balloon pump may have better battery life since pumping and maintenance of pneumatic circuits and corresponding paraphernalia is eliminated by direct drive of the working fluid circuit. Using a large cross section work volume with low displacement of flexible member further helps to reduce inertial losses and improves response time. Using of a plurality of high response low power solenoid actuators in tandem and connected in parallel may aid in minimizing the effect of flux losses, heat generation and inertial effects. Eliminating the need for an elaborate pneumatic driving circuit and miniaturizing the device can make the intra-aortic balloon pump mobile strap-on OR carry-on

Bag based design. This gives more freedom to patients in long term therapy and does not restrict them to the bed. Thus, quality of life is improved. A small air pump with filtration may be used. The working fluid may be air, or Helium (He) gas, or any other suitable gas. For example, air may be employed as the working fluid in case the augmentation balloon site allows for larger drive lines to be used. The use of a plurality of solenoid actuators allows the operation of augmentation to continue even if one solenoid fails and therefore is less prone to down time.

[065] In accordance with an embodiment, the disclosed system 400 and the pump 402 may be configured to aid in augmenting fluid circulation, assist in a surgery or clinical examination of the heart of a human subject. A person of ordinary skill in the art will understand that the scope of the disclosure is not limited to implementation of the disclosed system 400 and the pump 402 to aid in augmenting fluid circulation, to assist in a surgery or clinical examination of a human heart. In accordance with an embodiment, the disclosed probing instrument 100 may be used to assist in a surgery or clinical examination of the internal region or internal organ of interest of an animal subject. Further, the disclosed system 400 and the pump 402 may also be useful in augmenting fluid circulation, assist in a surgery or clinical examination of the heart of mammals, as discussed above.

[066] It will be appreciated that, for clarity purposes, the above description has described embodiments of the disclosure with reference to different functional units and processing device. However, it will be apparent that any suitable distribution of functionality between different functional units, processors or domains may be used without detracting from the disclosure. For example, functionality illustrated to be performed by separate processors or controllers may be performed by the same processor or controller. Hence, references to specific functional units are only to be seen as references to suitable means for providing the described functionality, rather than indicative of a strict logical or physical structure or organization.

[067] Although the present disclosure has been described in connection with some embodiments, it is not intended to be limited to the specific form set forth herein. Rather, the scope of the present disclosure is limited only by the claims. Additionally, although a feature may appear to be described in connection with particular embodiments, one skilled in the art would recognize that various features of the described embodiments may be combined in accordance with the disclosure.

[068] Furthermore, although individually listed, a plurality of means, elements or process steps may be implemented by, for example, a single unit or processor. Additionally, although individual features may be included in different claims, these may possibly be advantageously combined, and the inclusion in different claims does not imply that a combination of features

is not feasible and/or advantageous. Also, the inclusion of a feature in one category of claims does not imply a limitation to this category, but rather the feature may be equally applicable to other claim categories, as appropriate.

CLAIMS

We claim:

1. A system (400) for augmenting fluid circulation in a body, the system comprising:

a pump (402) for pumping the fluid, the pump (402) comprising:

a housing (402A);

a flexible member (410) positioned inside the housing (402A), wherein the flexible member (410) divides the housing (402A) into a first compartment and a second compartment, wherein the second compartment comprises a spout (606) for pumping a working fluid; and

one or more of solenoid actuators (416) positioned in the first compartment, wherein the one or more of solenoid actuators (416) are configured to transition between a retracted state and an expanded state, wherein in the expanded state, the one or more of solenoid actuators (416) are configured to press the flexible member (410) towards the second chamber to pump the working fluid via the spout (606);

a processing device (418) coupled to the pump (402), the processing device (418) configured to:

receive a signal indicative of requirement of fluid circulation in the body; and

trigger, based on the signal, the transition of the one or more of solenoid actuators (416) between the retracted state and the expanded state to cause the flexible member (410) to pump working fluid; and

a balloon (502) fluidically coupled to the pump (402) via the spout (606) to receive the pumped working fluid, wherein, in response to the pumped working fluid received from the pump (402), the balloon (502) is configured to transition between an inflated and a deflated state to assist an organ in augmenting fluid circulation in the body.

2. The system (400) as claimed in the claim 1, wherein the signal is received from one of an Electrocardiogram and a pressure sensor, and wherein the trigger is provided by a Dicrotic notch.

3. The system (400) as claimed in the claim 1, comprising:

a gas tank comprising a pressurized Helium gas, wherein the gas tank is coupled to the pump (402) via the spout (606),

wherein during transition from the expanded state to the retracted state of the one or more of solenoid actuators, the gas tank is configured to supply the pressurized helium gas.

4. The system (400) as claimed in the claim 3, comprising: a stabilizing valve (806) provided on a fluid line between the gas tank (114) and the pump (402), wherein the stabilizing valve (806) is configured to open and close in response to a drop in line pressure to stabilize the working pressure of the fluid line.

5. The system (400) as claimed in the claim 4, wherein the stabilizing valve (806) is Solenoid-powered.

6. The system (400) as claimed in the claim 1, comprising:

a one-way valve (804) provided on a fluid line coupling the spout (606) with the balloon (502), wherein the one-way valve (804) is configured to allow flow of working fluid from the pump (402) to the balloon (502) during the transition of the one or more of solenoid actuators (416) from the retracted state to the expanded state, and wherein the one-way valve (804) is configured to block the flow of working fluid from the pump (402) to the balloon (502) during the transition of the one or more of solenoid actuators (416) from the expanded state to the retracted state.

7. The system (400) as claimed in claim 6, wherein the one-way valve (804) is Solenoid-powered.

8. The system (400) as claimed in claim 1, comprising:

a plate (412) positioned in the first chamber and attached to the flexible member (410), wherein the plate (412) is attached to the one or more solenoid actuators (416).

9. A pump (402) for pumping a fluid, the pump comprising:

a housing (402A);

a flexible member (410) positioned inside the housing (402A), wherein the flexible member (410) divides the housing (402A) into a first compartment and a

second compartment, wherein the second compartment comprises a spout (606) for pumping working fluid; and

one or more of solenoid actuators (416) positioned in the first compartment, wherein the one or more of solenoid actuators (416) are configured to transition between a retracted state and an expanded state, wherein in the expanded state, the one or more of solenoid actuators (416) are configured to press the flexible member (410) towards the second chamber to pump working fluid via the spout (606).

Dated this 18th day of March 2022

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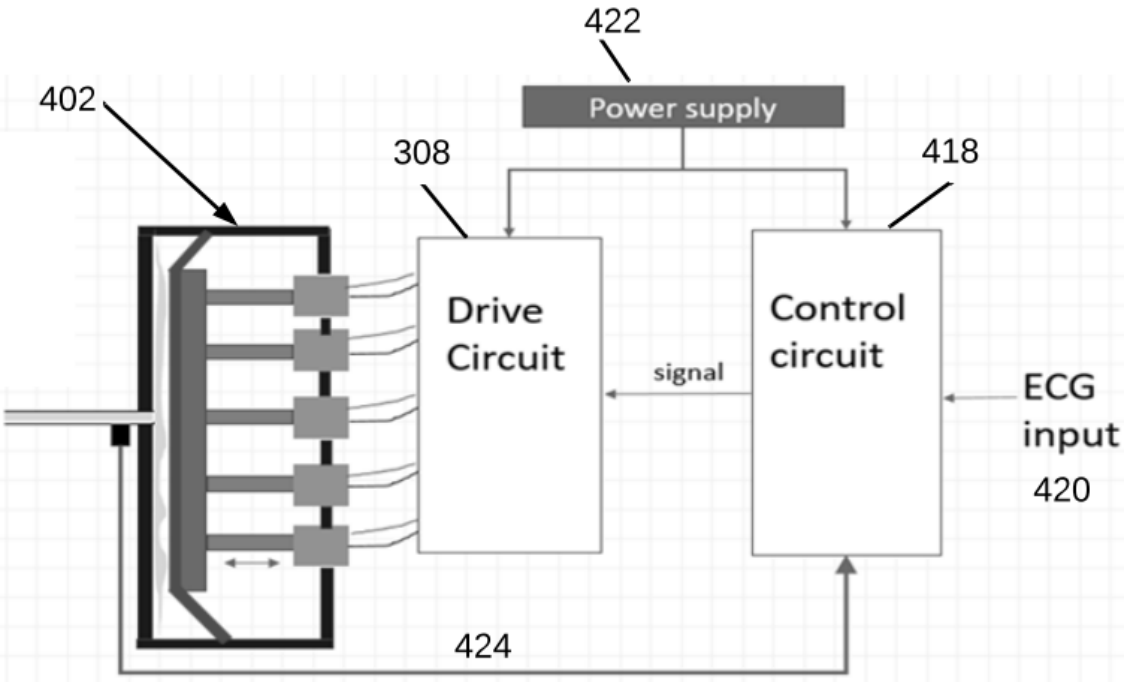
SYSTEM AND METHOD FOR PUMP AUGMENTING FLUID CIRCULATION IN A BODY

ABSTRACT

System and pump for augmenting fluid circulation in a body is disclosed. The system includes a pump (402) for pumping the fluid. The pump (402) includes a housing (402A), and a flexible member (410) positioned inside housing (402A). Flexible member (410) divides housing (402A) into a first compartment and a second compartment. The second compartment includes a spout (606) for pumping working fluid. Pump (402) includes one or more solenoid actuators (416) configured to transition between a retracted state and an expanded state. The system includes a processing device (418) coupled to the pump (402) and a balloon (502) fluidically coupled to the pump (402) via the spout (606) to receive the pumped working fluid. In response to the pumped working fluid received from the pump (402), the balloon (502) is configured to transition between an inflated and a deflated state to assist an organ in augmenting fluid circulation in the body.



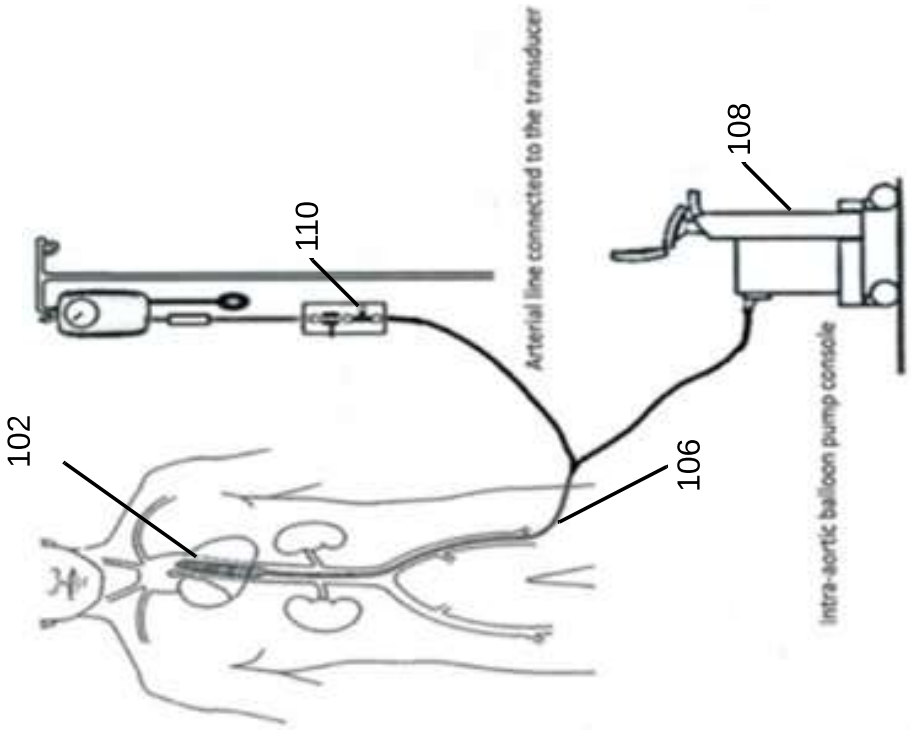


FIG. 1C

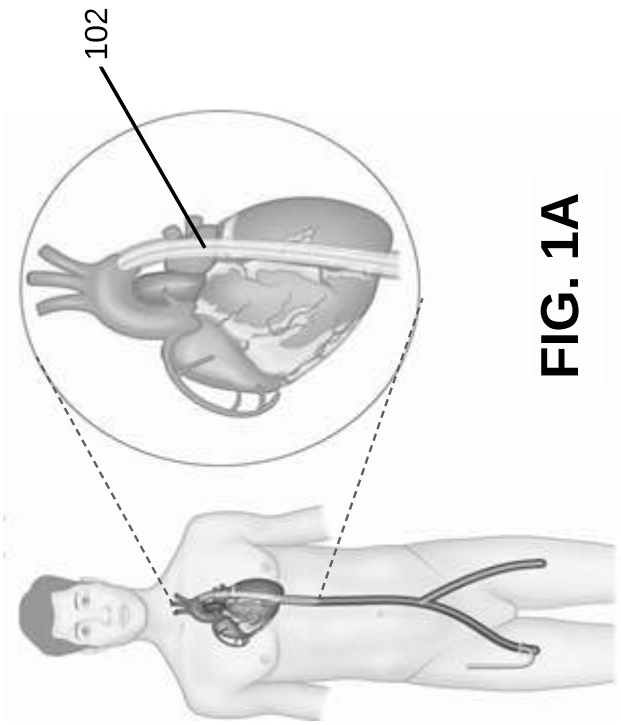


FIG. 1A

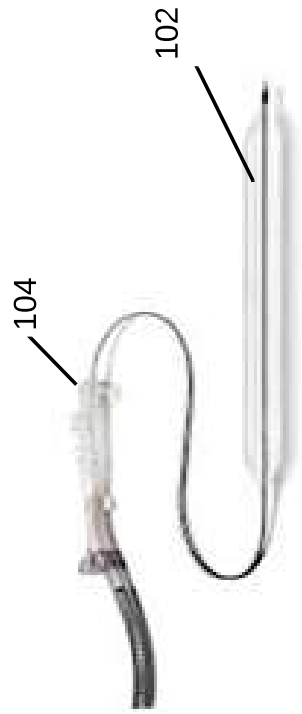


FIG. 1B

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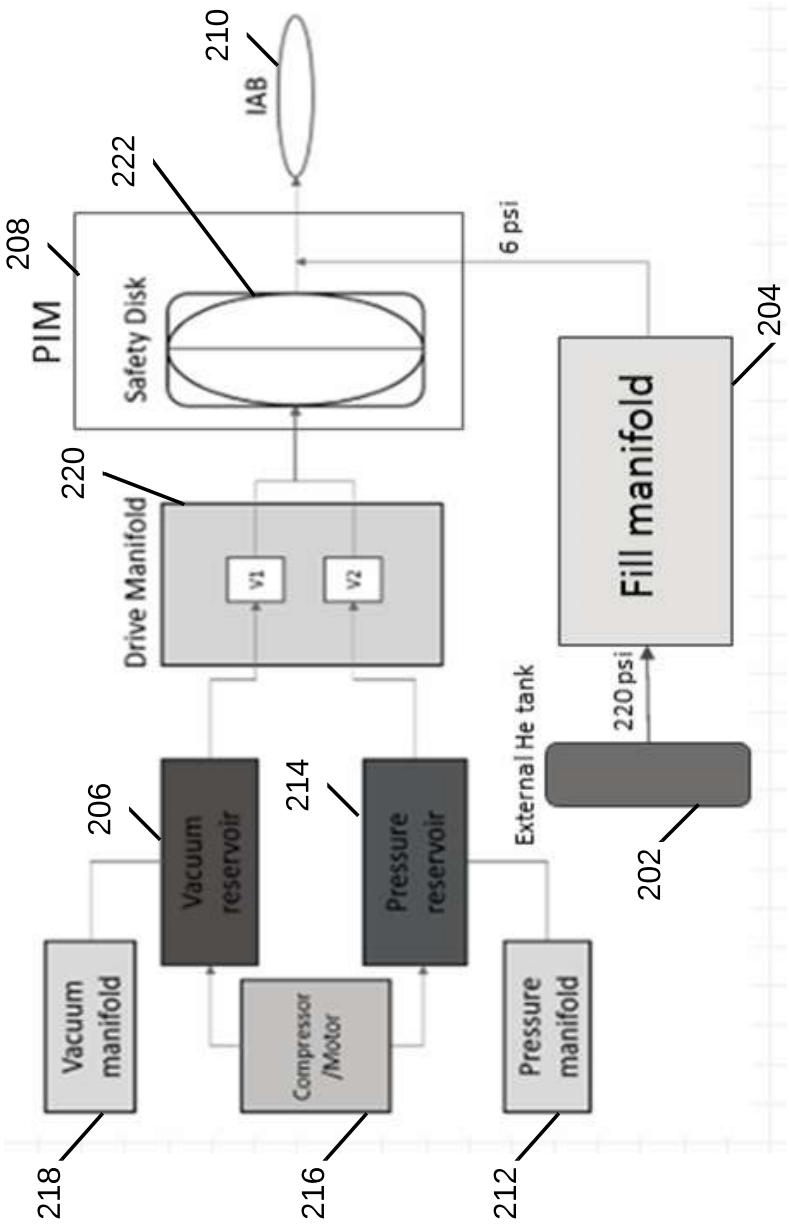

FIG. 2 (PRIOR ART)

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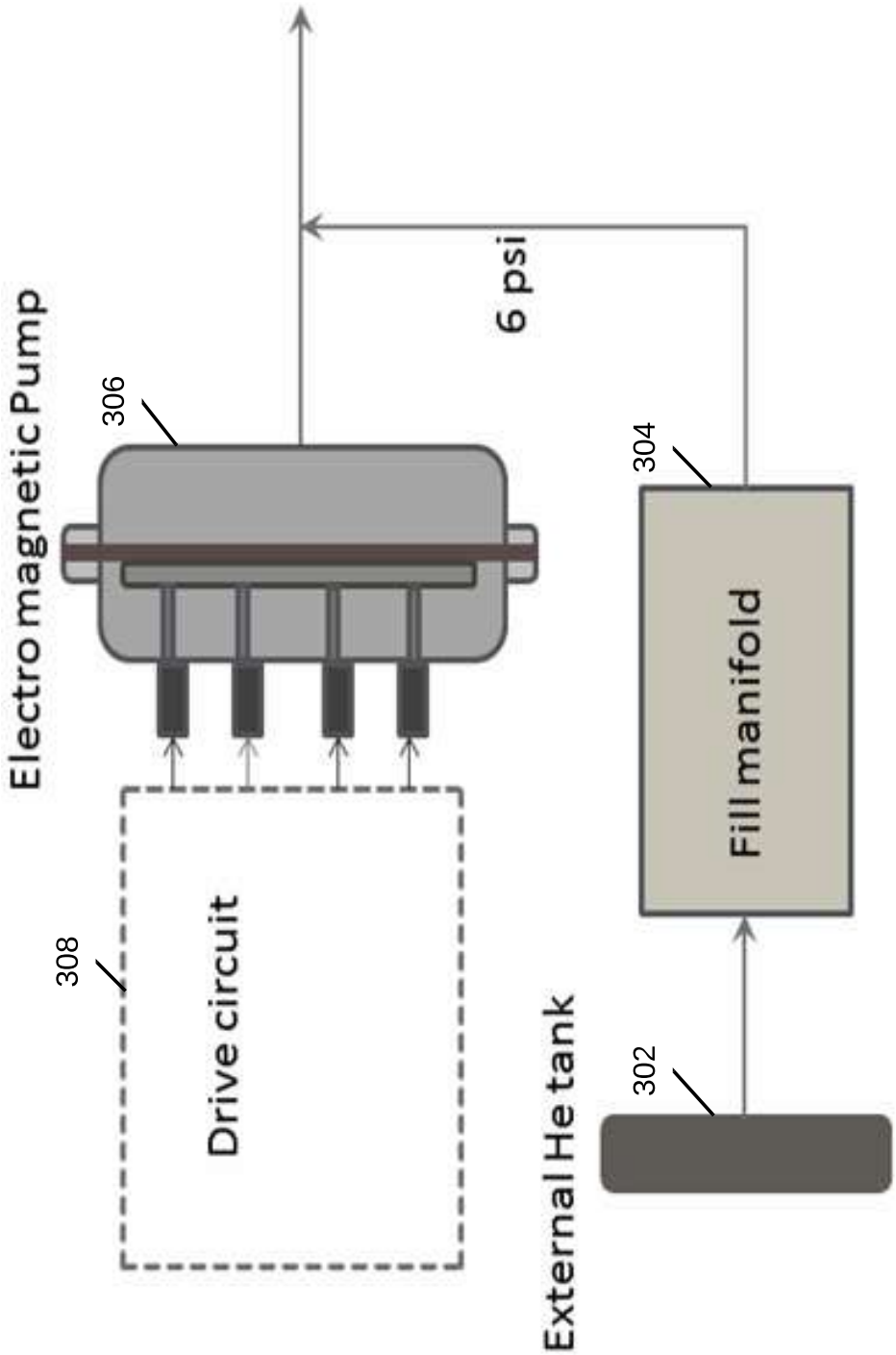

FIG. 3

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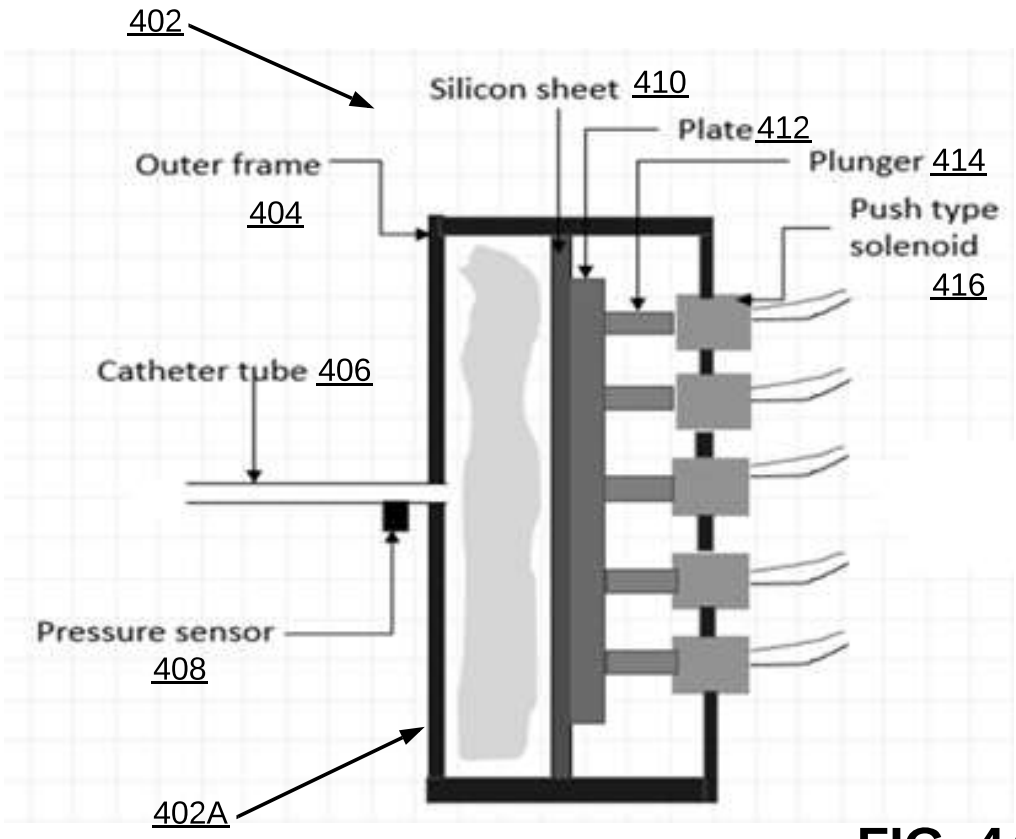

FIG. 4A

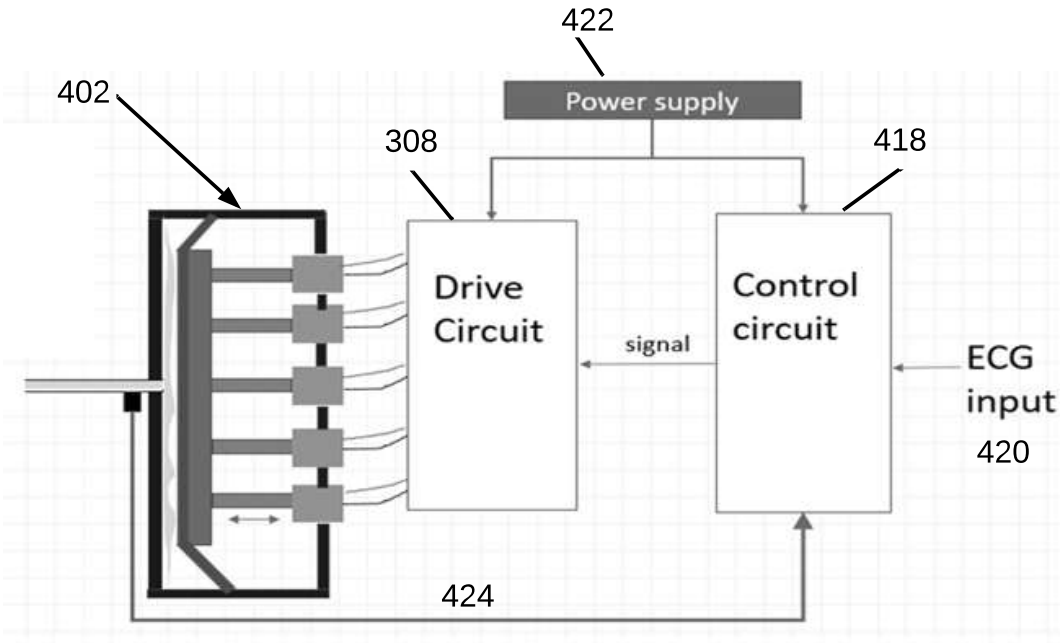

FIG. 4B

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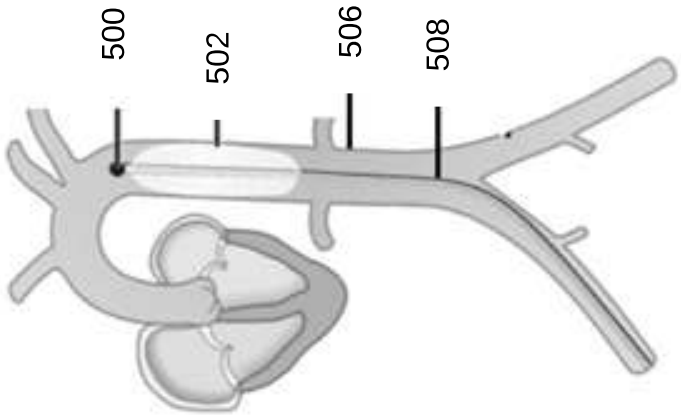

FIG. 5

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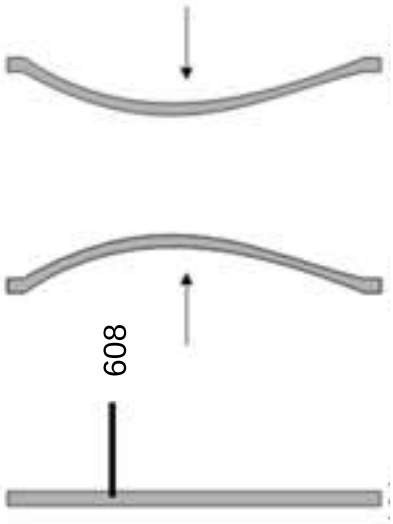

FIG. 6C

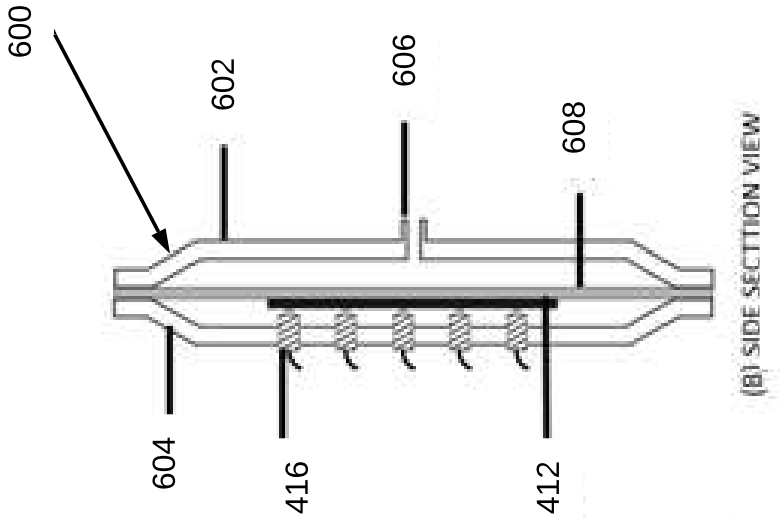

FIG. 6B

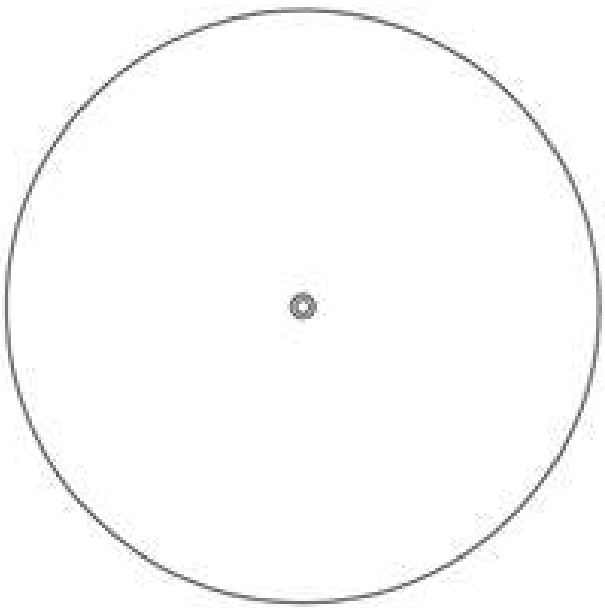

FIG. 6A

BHANU PRASAD (INPA No: 3253)
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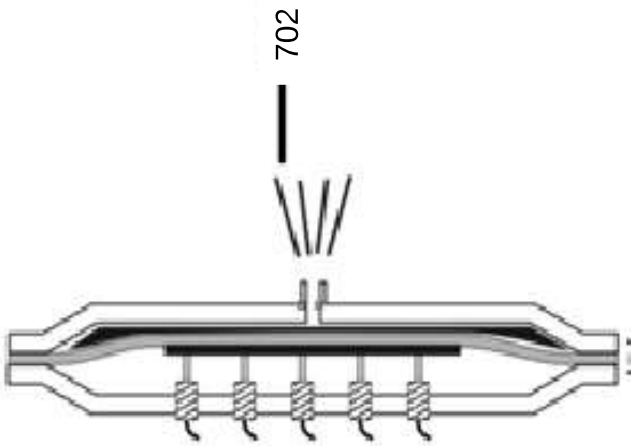

FIG. 7B

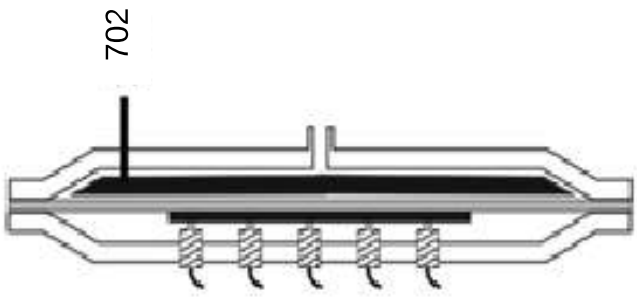

FIG. 7A

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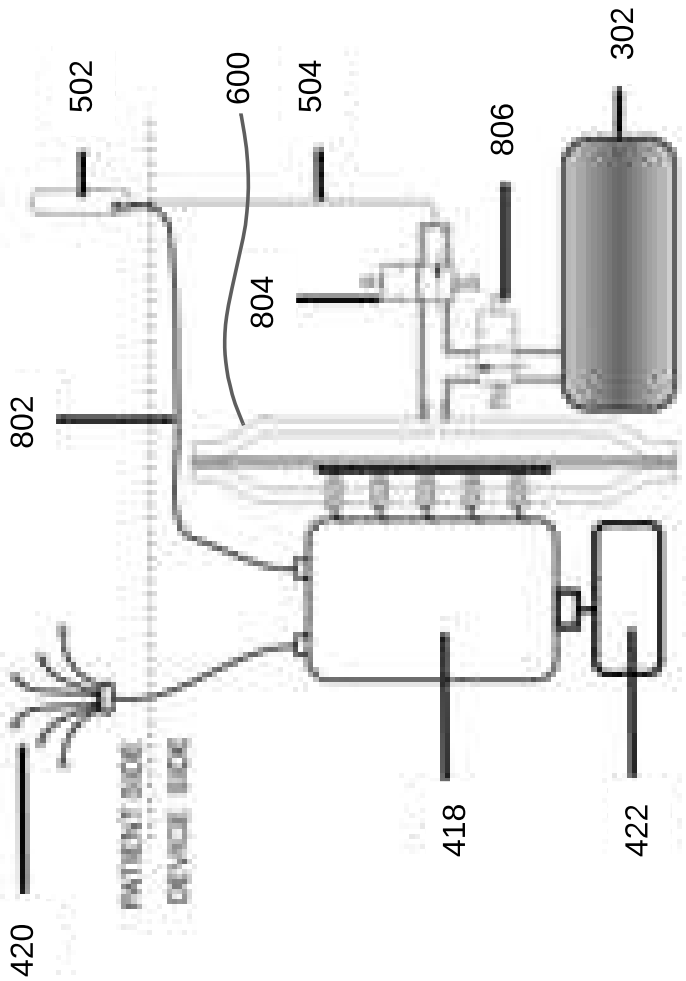

FIG. 8

BHANU PRASAD (INPA No: 3253)
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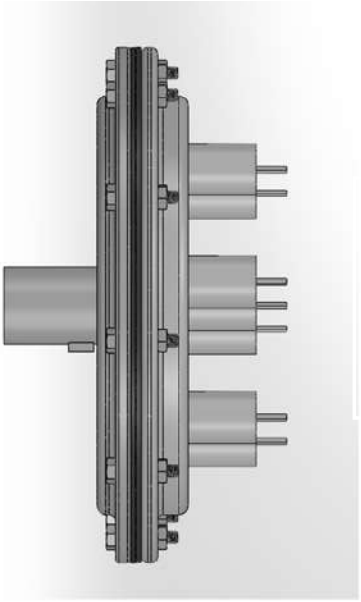

FIG. 9D

FIG. 9B

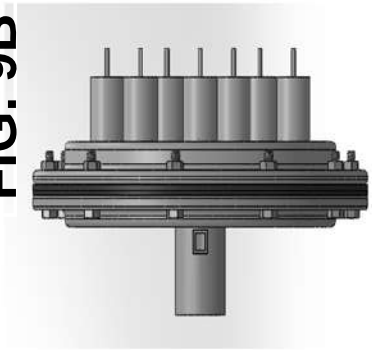

FIG. 9C

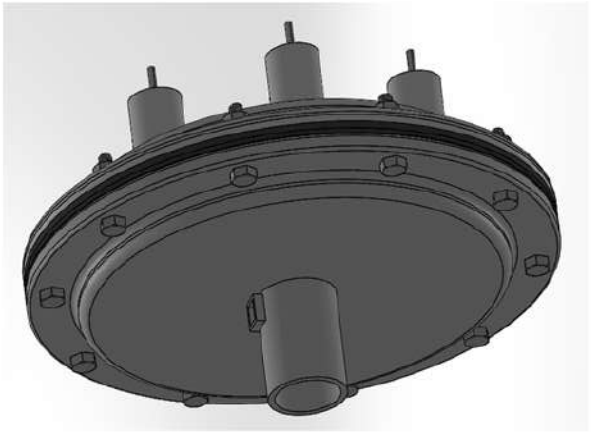

FIG. 9A

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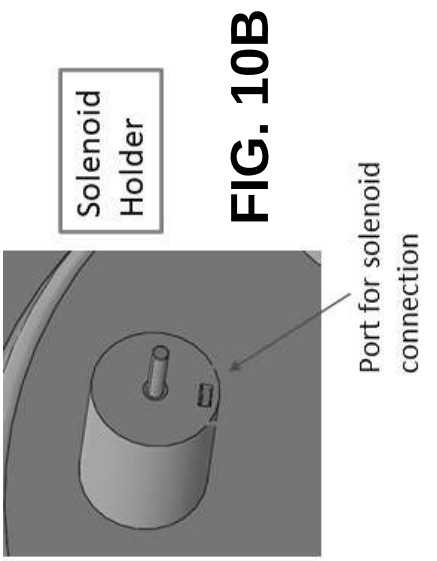

FIG. 10B

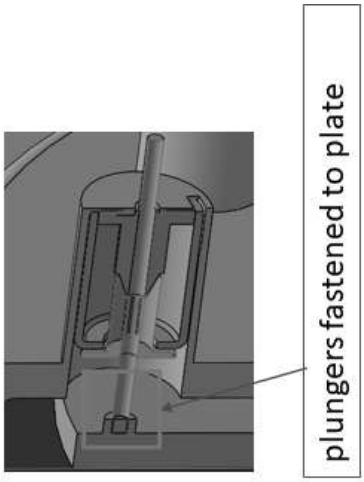

FIG. 10C

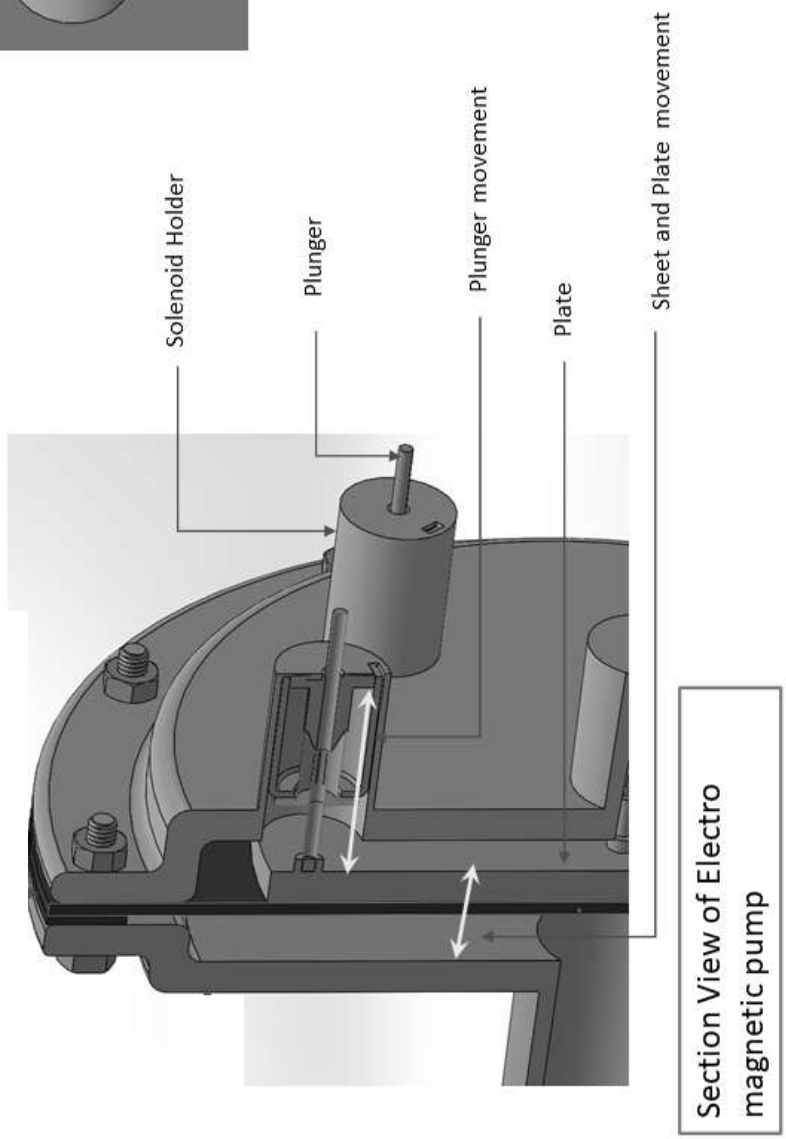

FIG. 10A

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