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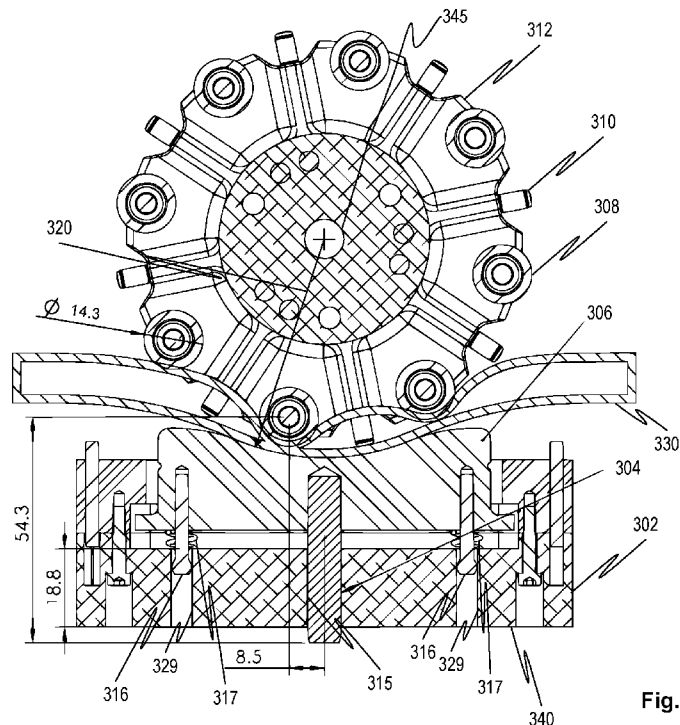


Fig. 3

(57) Abstract: A peristaltic pump actuator includes a rotor element supporting rollers, the rotor element being configured to rotate about a rotor axis and the rollers each being configured to rotate about a roller axis that is parallel to the rotor axis. The rotor element and each of the rollers is constrained such that the rotor element and rollers are able to rotate only about their respective axes. A shoe having a displacement axis perpendicular to the rotor axis is forced against the rollers by an urging element without rotation in any axis. A tube may be placed between the shoe and the rollers.

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PERISTALTIC PUMP

Cross-Reference to Related Applications

[0001] This application claims priority to and the benefit of U.S. Provisional Patent Application No. 62/819,016 filed March 15, 2019, which is hereby incorporated by reference in its entirety.

Background

[0002] Peristaltic pumps can pump fluid through tubing without exposing the fluid to contact with the tubing exterior or any of the pump components. This feature is relevant in medical and laboratory devices where maintaining the sterility of a fluid is often vital. An example of a fluid that is often pumped with a peristaltic pump is blood and other biological fluids. Such fluids are damaged by excessive pressure and lack of occlusion of the pump. For example, placing blood under high pressure in an extracorporeal tubing system may result in the blood cells being forced at high pressure through a narrow passage that is poorly occluded.

[0003] A peristaltic pump is a volumetric positive displacement pump that moves fluid through a tube by progressively compressing the fluid tube in one direction. A peristaltic pump typically comprises a housing having a semi-circular internal raceway formed on a shoe for receiving a fluid tube and a rotating member mounted in the center of the semi-circle formed by the raceway. The rotating member generally has roller elements that compress the fluid tube against the raceway.

[0004] For blood pumps, there is a spring that forces either the rollers toward the shoe or which forces the shoe toward the rollers. The force is often set to achieve full occlusion. For blood and other biological fluids this may be advantageous because it prevents the cells being damaged.

[0005] It will not be here attempted to set forth and indicate all of the various objects and advantages incident to the invention, but other objects and advantages will be referred to in or else will become apparent from that which follows.

Summary

[0006] Objects and advantages of embodiments of the disclosed subject matter will become apparent from the following description when considered in conjunction with the accompanying drawings.

[0007] In embodiments, a peristaltic pump shoe has at least one rotational degree of freedom constrained. In embodiments, the shoe has at least two rotational degrees of freedom constrained. In embodiments, the shoe has three rotational and two displacement degrees of freedom constrained.

[0008] In embodiments, a peristaltic pump shoe is constrained by a linear bearing to sliding along the Z-axis. In embodiments, the linear bearing has a Teflon liner. In embodiments, the linear bearing has two Teflon liners trapping a reservoir of lubricant between them.

[0009] In embodiments, the shoe engages an arc of the pump actuator that is less than 180 degrees. In embodiments, the shoe engages an arc of the pump actuator that is less than 150 degrees. In embodiments, the shoe engages an arc of the pump actuator that is less than 120 degrees.

Brief Description of the Drawings

[0010] Embodiments will hereinafter be described in detail below with reference to the accompanying drawings, wherein like reference numerals represent like elements. The accompanying drawings have not necessarily been drawn to scale. Where applicable, some features may not be illustrated to assist in the description of underlying features.

[0011] Figs. 1A through 1C show a peristaltic pump from three orthogonal views, according to embodiments of the disclosed subject matter.

[0012] Fig. 1D shows the pump of Figs. 1A through 1C with an actuator engaging a pumping tube segment, according to embodiments of the disclosed subject matter.

[0013] Fig. 1E shows a mechanism for constraining a pump shoe of the pump of Figs. 1A through 1C, according to embodiments of the disclosed subject matter.

[0014] Figs. 2A and 2B show linear bearings, according to embodiments of the disclosed subject matter.

[0015] Fig. 3 shows a detailed embodiment of a peristaltic pump according to embodiments of the disclosed subject matter.

[0016] Figs. 4A and 4B compare pressure fluctuations for a pump according to an embodiment with a prior art pump.

Detailed Description

[0017] The invention will appear more clearly from the following detailed description when taken in connection with the accompanying drawings, showing by way of example a preferred embodiment of the inventive idea wherein like numerals refer to like parts throughout.

[0018] Figs. 1A through 1C show a peristaltic pump from three orthogonal views, according to embodiments of the disclosed subject matter. Fig. 1A shows a top view looking at a pumping actuator 118 with the pumping tube segment 122 partially hidden. Fig. 1B shows a side view looking at a flat face of a pumping actuator 118. Fig. 1C shows the pump from an end view looking along the pumping tube segment 122. Fig. 1D shows the pump of Figs. 1A through 1C with an actuator 118 engaging a pumping tube segment by way of rollers 120, according to embodiments of the disclosed subject matter. Fig. 1D shows the same view as Fig. 1B except that Fig. 1D shows the pumping tube clamped by the actuator between the pumping shoe and the actuator.

[0019] An actuator 118 has eight rollers 120 (only one indicated by the reference numeral in each figure to avoid clutter). Note that the actuator 118 can have any number of rollers and the example of eight rollers is not limiting of the disclosed subject matter. A pumping tube segment 122 is clamped between a pumping shoe 124 and the rollers 120. The pumping shoe 124 is constrained to move along a Z-axis by a linear bearing 110 that constrains the movement of a shaft 114 which is rigidly affixed to the pumping shoe 124. The linear bearing 110 constrains the rotational motion about the roll 106 and pitch 104 axes. A spring 116 urges the pumping shoe toward the pumping actuator. On one end, the spring 116 is held by bushing 112, which has a basin in which the end of the spring 116 sits. The basin prevents lateral movement of the spring 116. The spring is centrally-located about the shaft

114. In embodiments, the yaw motion can be constrained by means of a housing 130 (See Fig. 1E) within which the pumping shoe 124 slides.

[0020] Note that the mechanism of Fig. 1E is capable of constraining against roll 106, pitch, 104 and yaw 102 motion and may be used as an alternative to the linear bearing 110 of Figs. 1A through 1C. Thus, the linear bearing 110 and shaft 114 could be replaced by the housing 130 in embodiments. The linear bearing may be a metal cylindrical sleeve 202 with a Teflon liner 208 supporting a shaft 210 as shown in Fig. 2A. In an embodiment, shown in Fig. 2B, there are two Teflon liners 206 and 208 which enclose, in cooperation with the metal cylindrical sleeve 202 and the shaft 210 a reservoir of lubricant 204.

[0021] Fig. 3 shows a cross section (in a plane perpendicular to a rotor axle 345 of actuator 312) of a detailed embodiment of a peristaltic pump according to embodiments of the disclosed subject matter. An actuator 312 carries eight rollers 308 which rotate in a single direction and are otherwise constrained. The rollers 308 pinch a pumping tube segment 330 against a pump shoe 306. The pump shoe 306 has a curvature defined by radius 320 along a central region of the pump shoe 306. The pump shoe is urged by springs 317. The pump shoe is constrained from yaw rotation by pins 316. A linear bearing shaft 304, supported by a base 302, constrains the pump shoe against roll and pitch rotation by supporting Z-axis motion by sliding within a bore 315 in a base 340. Additional rollers 310 have axes of rotation along radii of the axis of the actuator 312 and serve to confine the pumping tube segment 330 against lateral movement with respect to the shoe 306. There may be a single roller 310 on each side of the pumping tube segment 330. These rollers 310 may extend on one or both sides of the pumping tube segment 330, thereby providing lateral support for the pumping tube segment 330. Guide pins 316 hold and position springs 317 to provide a force to urge the shoe 306 against the pumping tube segment 330 which is resisted by the rollers 308. The guide pins 316 slide within bores 329.

[0022] Figs. 4A and 4B compare pressure fluctuations for a pump according to an embodiment with a prior art pump. The curve 350 of Fig. 4A represents a prior art pump. The curve is labeled with individual roller strikes to show that the lower frequency oscillation corresponds to the phase of the actuator. In the pump according to an embodiment, this low

frequency oscillation is not present as shown by the curve 360 of Fig. 4B. The low frequency oscillation can be considered 1 revolution per minute (RPM) oscillation, as it repeats for every one revolution of the rotor (or actuator) that holds rollers. A consequence of this lack of a low frequency oscillation is that a minimum force required to obtain occlusion is reduced relative to the prior art pump.

[0023] In embodiments, the pump shoe is constrained against rolling rotation, only. Rotation in this mode can prevent full occlusion for a given force of compression of the pumping tube. Lack of full occlusion can cause damage to biological fluids such as blood. In the latter case, blood is forced backward through a small space causing hemolysis.

[0024] According to embodiments, the disclosed subject matter includes a peristaltic pump with an actuator with rollers that are held by the actuator such that they are free to rotate but otherwise fixed to the roller. A shoe is positioned to force a tube between the rollers and the shoe. The shoe is forced against the rollers and constrained against pivoting in at least one degree of freedom. The embodiments include variations in which the shoe is constrained against pivoting in all degrees of freedom. The embodiments include variations in which the shoe is constrained against all modes of displacement except toward and away from the actuator. The embodiments include variations in which the shoe is constrained against all modes of displacement except toward and away from the actuator. The embodiments include variations in which the shoe rides on a linear bearing. The embodiments include variations in which the shoe is constrained against yaw rotation by a sliding housing.

[0025] According to embodiments, the disclosed subject matter includes a method of operating a peristaltic pump that includes squeezing a tube between at least one actuator roller and a pump shoe by urging the pump shoe toward the at least one roller. The method includes constraining movement of the at least one roller in one rotating direction and constraining the pump shoe to a single displacement and no rotational directions.

[0026] The embodiments include variations in which the urging is effective to minimize a total force on the tube required for occlusion. The embodiments include variations in which the shoe is constrained against yaw rotation by a sliding housing. The embodiments include variations in which the shoe is constrained against yaw rotation by a sliding housing.

[0027] According to embodiments, the disclosed subject matter includes a peristaltic pump actuator. An actuator has rollers that are held by the actuator such that they are free to rotate but otherwise fixed to the roller. An urging mechanism is configured to urge the shoe toward the rollers. The shoe is forced against the rollers and constrained against pivoting in at least one degree of freedom. the shoe is constrained against yaw rotation by enclosing the shoe in a housing that permits only sliding motion in the Z-axis direction.

[0028] The embodiments include variations in which the urging mechanism includes a spring. The embodiments include variations in which the shoe is constrained against rotational motion, except along the Z-axis, by a linear bearing. The embodiments include variations in which the linear bearing includes a pair of Teflon liners and a lubricant. The embodiments include variations in which the linear bearing includes a pair of Teflon liners and a lubricant-soaked sponge. The embodiments include variations in which the shoe spans less than 150 degrees of arc. The embodiments include variations in which the shoe spans less than 120 degrees of arc. The embodiments include variations in which the pump generates pressure pulses with no 1 RPM components.

[0029] It will be observed that the arc of the actuator subtended by the shoe may be less than 180 degrees. In embodiments such as that of Fig. 4, the arc subtended may be less than 45 degrees. In other embodiments, the arc is less than 150, less than 120, less than 90, less than 60. In embodiments, because of the short arc, the initial state of the pumping tube may be straight.

[0030] It is, thus, apparent that there is provided, in accordance with the present disclosure, a peristaltic pump. Many alternatives, modifications, and variations are enabled by the present disclosure. Features of the disclosed embodiments can be combined, rearranged, omitted, etc., within the scope of the invention to produce additional embodiments. Furthermore, certain features may sometimes be used to advantage without a corresponding use of other features. Accordingly, Applicants intend to embrace all such alternatives, modifications, equivalents, and variations that are within the spirit and scope of the present invention.

Claims

1. A peristaltic pump actuator, comprising:
a rotor element supporting rollers, the rotor element being configured to rotate about a rotor axis and the rollers each being configured to rotate about a roller axis that is parallel to the rotor axis;
the rotor element and each of the rollers being constrained such that the rotor element and rollers are able to rotate only about their respective axes; and
a shoe having a displacement axis perpendicular to the rotor axis,
the shoe being forced against the rollers by an urging element without rotation in any axis.
2. The actuator of claim 1, wherein the shoe is constrained against pivoting in all degrees of freedom.
3. The actuator of claim 2, wherein the shoe is constrained against all modes of displacement except toward and away from the rotor element.
4. The actuator of claim 2, wherein the shoe is constrained against all modes of displacement except toward and away from the rotor axis of the rotor element.
5. The actuator of claim 1, wherein the shoe is constrained against all modes of displacement except toward and away from the rotor element, and the pump is a peristaltic pump.
6. The actuator of claim 5, wherein said shoe rides on a linear bearing.
7. The pump of claim 5, wherein said shoe is constrained against yaw rotation by a sliding housing.

8. The actuator of claim 1, further comprising:
guard elements positioned along the rotor element between the rollers.
9. The actuator of claim 8, wherein
the guard elements are second rollers, each of the second rollers having an axis
extending radially away from the rotor axis and perpendicular to the rotor axis.
10. The actuator of claim 9, wherein
each of the second rollers has a width measured along its axis, and
the second rollers extend at least on one side of a pumping tube segment that is
positioned between the rotor element and the shoe.
11. The actuator of claim 10, wherein
the second rollers extend on both sides of the pumping tube segment.
12. A method of operating a peristaltic pump, comprising:
squeezing a tube between at least one actuator roller and a pump shoe by urging the
pump shoe toward the at least one actuator roller; and
constraining movement of the at least one actuator roller in one rotating direction and
constraining the pump shoe to a single displacement and no rotational directions.
13. The method of claim 12, wherein the urging is effective to minimize a total force on
the tube required for occlusion.
14. The method of claim 13, wherein said pump shoe is constrained against yaw rotation
by a sliding housing.
15. The method of claim 12, wherein said pump shoe is constrained against yaw rotation
by a sliding housing.

16. A peristaltic pump, comprising:
an actuator with rollers that are held by the actuator such that they are free to rotate but otherwise fixed to the roller; and
an urging mechanism configured to urge a shoe toward the rollers,
the shoe being forced against the rollers and constrained against pivoting in at least one degree of freedom.

17. The pump of claim 16, wherein said shoe is constrained against yaw rotation by enclosing the shoe in a housing that permits only sliding motion in the Z-axis direction.

18. The pump of claim 16 or 17, wherein the urging mechanism includes a spring.

19. The pump of claim 16 or 17, wherein the shoe is constrained against rotational motion, except along the Z-axis, by a linear bearing.

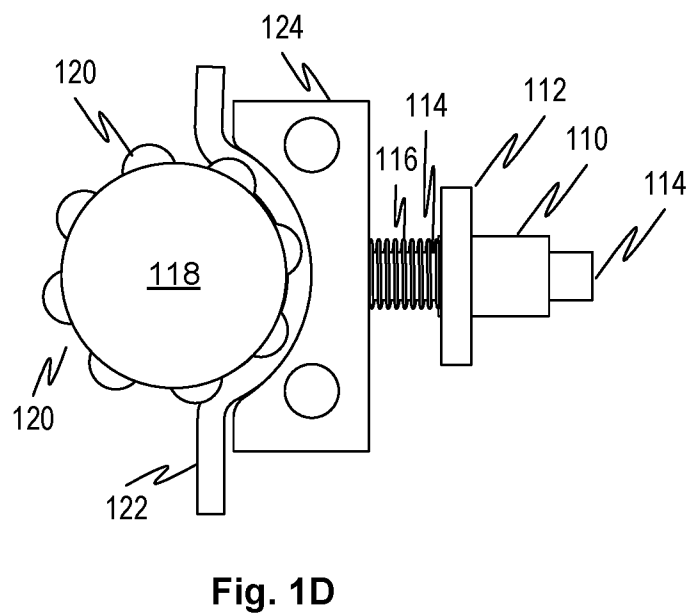
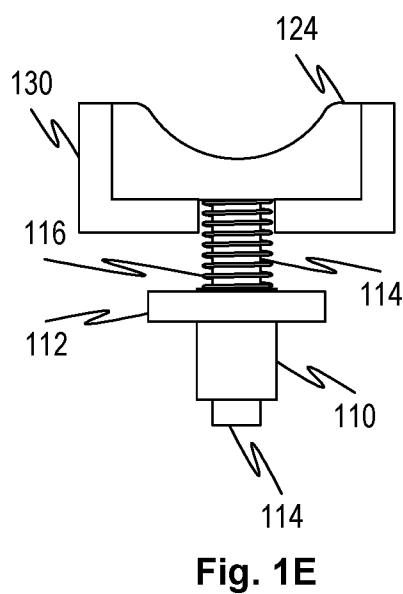
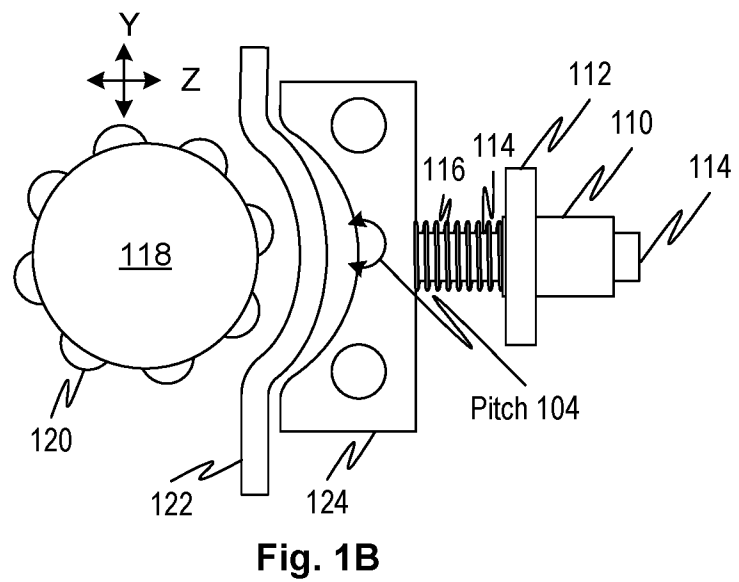
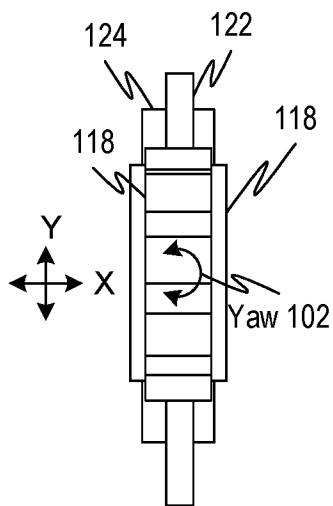
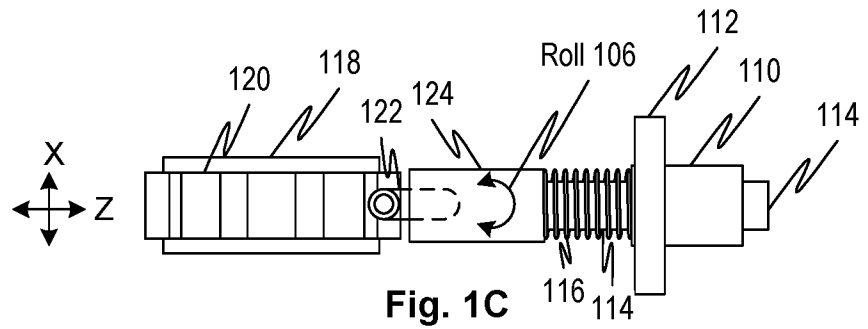
20. The pump of claim 19, wherein the linear bearing includes a pair of Teflon liners and a lubricant.

21. The pump of claim 19, wherein the linear bearing includes a pair of Teflon liners and a lubricant-soaked sponge.

22. The pump of claim 16, wherein the shoe spans less than 150 degrees of arc.

23. The pump of claim 16, wherein the shoe spans less than 120 degrees of arc.

24. The pump of claim 16, wherein the pump generates pressure pulses without 1 RPM components.



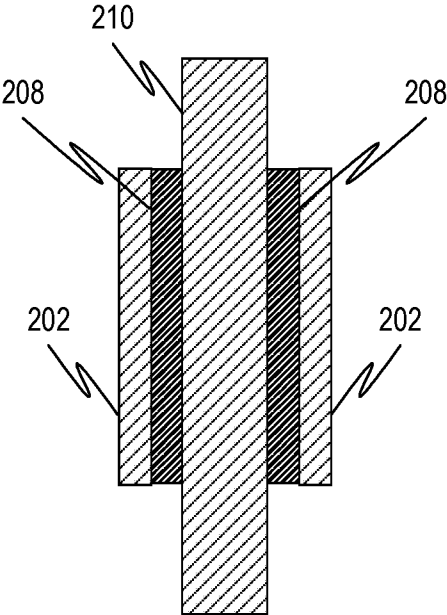


Fig. 2A

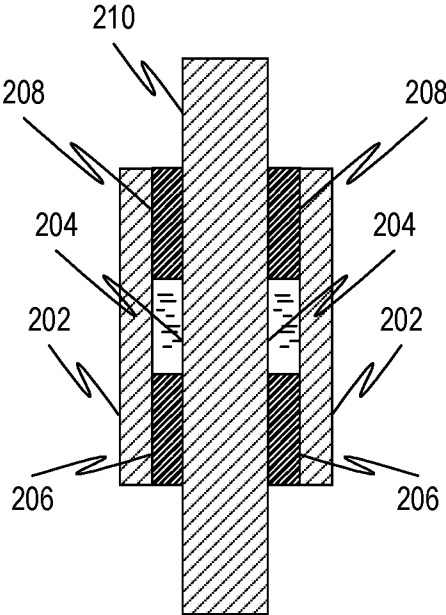


Fig. 2B

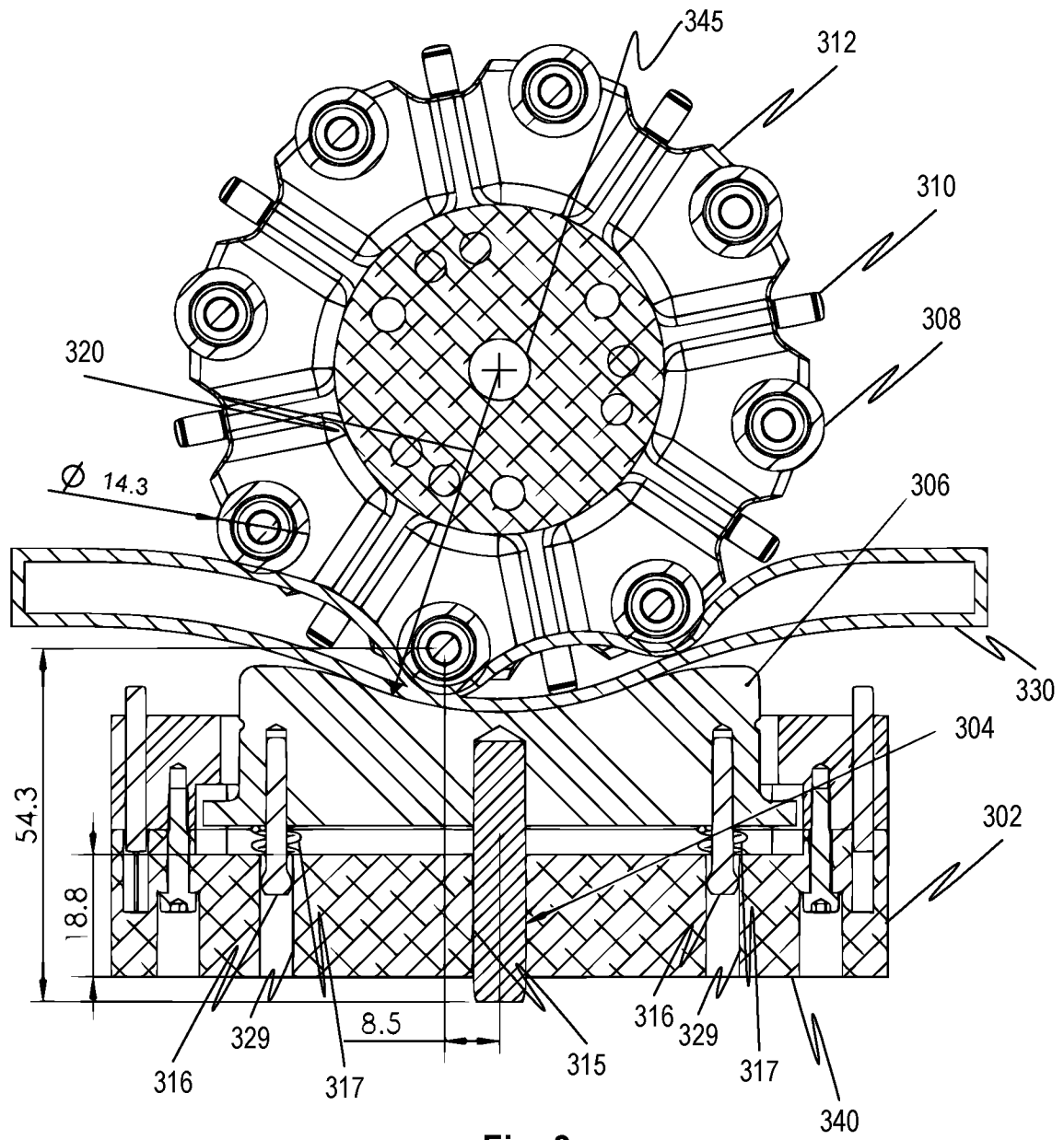
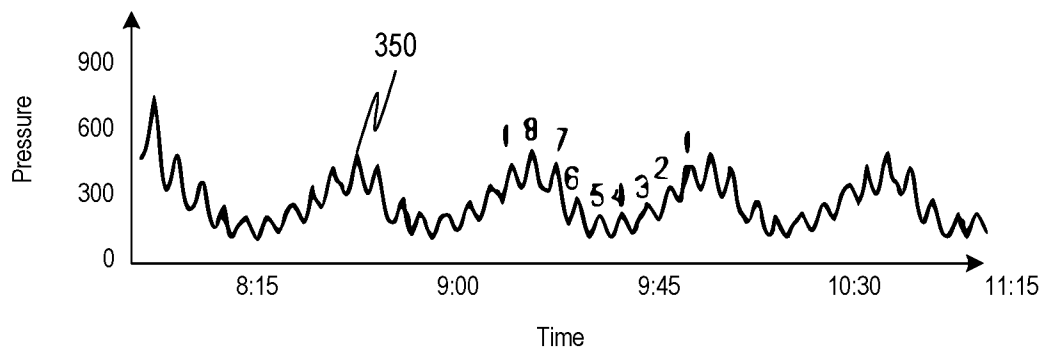
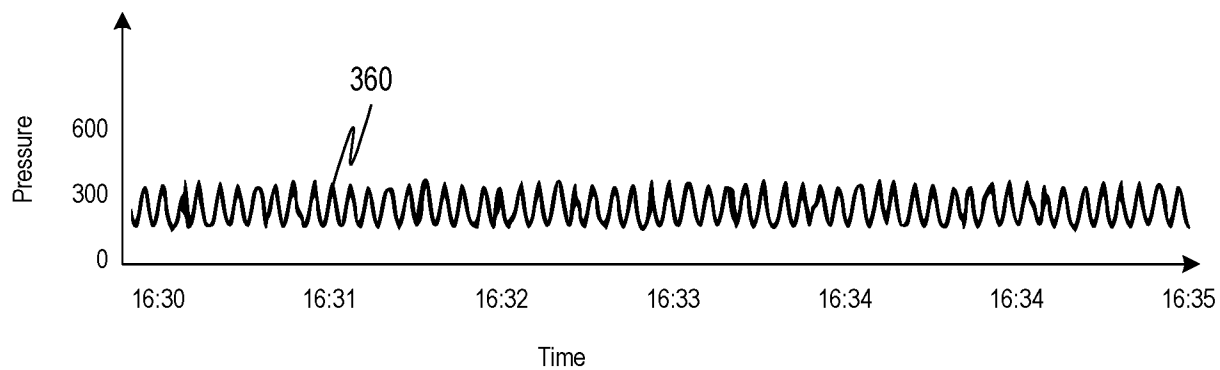


Fig. 3

**Fig. 4A****Fig. 4B**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2020/022778

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F04B 43/12; A61M 5/142; F04B 43/00 (2020.01)

CPC - F04B 43/1284; A61M 5/14232; F04B 43/1253; F04B 43/1261; F04B 43/1276 (2020.02)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

USPC - 417/476; 417/477.1; 417/477.2; 417/477.3; 417/477.5; 417/477.9; 417/477.11 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ---	US 2007/0212240 A1 (VOYEUX et al) 13 September 2007 (13.09.2007) entire document	1-7, 12-19, 22-24 ---
Y		8-11, 20, 21
Y	US 2015/0159643 A1 (TERUMO CARDIOVASCULAR SYSTEMS CORPORATION) 11 June 2015 (11.06.2015) entire document	8-11
Y	US 4,857,048 A (SIMONS et al) 15 August 1989 (15.08.1989) entire document	20, 21
Y	GB 1,067,529 A (REFSON) 03 May 1967 (03.05.1967) entire document	20, 21

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:

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Date of the actual completion of the international search

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