(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 4 403 775 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
24.07.2024 Bulletin 2024/30

(21) Application number: **24151843.0**

(22) Date of filing: **15.01.2024**

(51) International Patent Classification (IPC):
F04C 2/107 *(2006.01)*

(52) Cooperative Patent Classification (CPC):
F04C 2/1075; F04C 2240/70; F04C 2240/805

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
GE KH MA MD TN

(30) Priority: **20.01.2023 US 202363480703 P**

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(54) **MODULAR STATOR FOR PROGRESSIVE CAVITY DEVICES**

(57) A stator is provided for a progressive cavity device. The stator includes modular stator segments connected together. Each stator segment includes a front surface, a rear surface, and an internal helical cavity extending longitudinally from the front surface to the rear surface. Each stator segment also includes a set of bolt holes extending longitudinally from the front surface to the rear surface, and a set of connection holes opening at the front surface and extending at least partially longitudinally from the front surface to the rear surface. Bolts, inserted through the bolt holes into connection holes of an adjacent stator segment, connect the stator segments and align the internal helical cavities to form a continuous helical chamber.

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Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to stator segments for progressive cavity devices, and more particularly to stators that are assembled from modular components.

[0002] Progressive cavity devices can be used for pumping and drilling applications. These devices typically include a rotor disposed within a stator. Progressive cavity pumps are frequently used in applications to handle highly viscous fluids and fluids containing solids. Even small solids can cause rapid abrasive wear to the stator, which can necessitate frequent stator replacement and/or refurbishment.

[0003] There are a few common types of stators inside of which a metal rotor spins during operation. One type is a deformable, elastomer-lined stator. A second type is a rigid, non-deformable stator, typically constructed from metal. A third type, referred to as an even walled stator, uses a rigid, non-deformable stator with an even layer of elastomer lining along the inside of the rigid portion.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004]

Fig. 1 is a perspective view of a modular stator segment, according to an implementation;

Figs. 2 and 3 are front and rear views, respectively, of a modular stator segment;

Fig. 4 is a schematic cross-sectional view of a stator assembled from multiple modular stator segments;

Fig. 5 is a perspective view of a portion of an assembled stator, according to an implementation;

Fig. 6A is an assembly view of two modular stator segments according to an implementation;

Fig. 6B is a front view of a modular stator segment that does not include a gasket groove;

Fig. 7 is a schematic cross-sectional view of a stator assembled from multiple modular stator segments, with a rotor disposed therein;

Figs. 8A and 8B are front and rear views of connecting flanges for a stator assembled from multiple modular stator segments;

Fig. 8C is a schematic cross-sectional view of a stator assembled from multiple modular stator segments with connecting flanges;

Fig. 9A is a cut-away view of a modular stator segment with an elastomer coating, according to another implementation;

Fig. 9B is a schematic cross-sectional view of a stator assembled from multiple modular stator segments, according to another implementation;

Fig. 10 is a flow diagram illustrating a process for forming a stator assembly, according to an implementation described herein;

Figs. 11A and 11B are front and rear views of a center stator segment for a modular stator according to an implementation;

Fig. 12 is a schematic cross-sectional view of a stator assembled from a center stator segment and multiple modular stator segments with connecting flanges;

Figs. 13A and 13B are front and rear views of a modular stator segment for use with the center stator segment of Figs. 12A and 12B; and

Figs. 14A and 14B are front and rear views of a connecting flange for a stator assembled from a center stator segment with multiple modular stator segments.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[0005] The following detailed description refers to the accompanying drawings. The same reference numbers in different drawings may identify the same or similar elements.

[0006] Systems and methods described herein provide an improved manufacturing process and product for stators of progressive cavity devices. One current manufacturing process for metal stators forms the stator from a stack of thin metal disks that are fused together. This is a complex process, and stacked disks create an inner helical profile that is not smooth. Another current manufacturing process for metal stators uses solid metal tubes which are machined to form an internal helical profile. This machining process is expensive and can only produce stators of limited length. Furthermore, when solid metal or metal disk stators wear out, they typically have to be replaced completely.

[0007] In contrast with metal stators, current manufacturing processes for elastomeric stators inject an elastomer into a tube around an inner core. Similarly, walled stators also have an elastomer injected into a tube around an inner core. Stators that utilize elastomers are typically injected from one or both ends. Many of the stators are very long, and successfully injecting the elastomer across these lengths can be a challenge. There are many steps in the injection process in order to ensure that the elastomer is bonded sufficiently to the tube or supporting disks. There are also many variables that can affect the outcome of the injection process. When the elastomer stators wear out over time, the elastomer must be cut out and re-injected to be put back into use.

[0008] Elastomeric stators generally cannot run without fluid or they will be destroyed, but they have better sealing and performance than metal stators due to an interference fit between the stator and the rotor. Metal stators can run dry, but have comparatively poorer sealing and performance due to a clearance fit between the rotor and stator.

[0009] Systems and methods described herein eliminate the use of cores, thin disks, tubes, fusing, and/or use of tie-rods required with the conventional manufacture of metal and/or elastomeric stators. Instead, portions (or segments) of a stator are bolted together to make the complete stator. In one implementation, the segments are designed so that each segment can be identical and can be aligned with an integrated locating feature. In another implementation, a unique center stator segment may be used, from which a set of modular stator segments can be added on either side of the center stator segment to form a complete stator. In some implementations, adjacent segments may be bolted together and sealed using a compressible gasket.

[0010] According to an implementation described herein, a stator is provided for a progressive cavity device. The stator includes modular stator segments connected together. Each stator segment includes a front surface, a rear surface, and an internal helical cavity extending longitudinally from the front surface to the rear surface. Each stator segment also includes a set of bolt holes extending longitudinally from the front surface to the rear surface, and a set of connection holes opening at the front surface and extending at least partially longitudinally from the front surface to the rear surface. Bolts, inserted through the bolt holes into connection holes of an adjacent stator segment, connect the stator segments and align the internal helical cavities to form a continuous helical chamber.

[0011] Because the entire stator is made up of a multiple of modular segments, the manufacture of the modular stator will allow for more elastomer material options due to the easier inject-ability. Thus, a significant amount of the typical manufacturing processes can be reduced or eliminated altogether. Also, according to implementations described herein, when one or more stator segments wear out, the stator segments can be removed by removing the bolts and replaced on site, eliminating waste, reducing down time for the customer, and eliminating the need for reinjection of the elastomer.

[0012] Fig. 1 depicts a perspective view of a modular stator segment 100. Fig. 2 depicts a front view of modular stator segment 100. Fig. 3 depicts a rear view of modular stator segment 100. Referring to Figs. 1-3, a modular stator segment 100 includes an internal cavity 102, a front surface 104, a rear surface 106 (Fig. 3), and an outer profile 108.

[0013] As described further herein, modular stator segment 100 may be connected to other identical modular stator segments 100 to form a desired stator length. Each modular stator segment 100 may be configured for a particular pump/rotor size. Manufacturing processes such as casting and computer numerical control (CNC) machining can ensure sufficient precision to provide a flush interface between adjacent stator segments and a smooth and continuous inner profile of the stator.

[0014] Modular stator segment 100 may be formed from any of a variety of materials, including metal materials, elastomers, urethane, etc. Because of the relatively short segment size of modular stator segment 100, different materials may be used than would otherwise be available for use in long stator segments. For example, modular stator segment 100 may be casted, injection molded, machined, and/or coated as individual pieces that can be aligned and connected to form internal cavities 102 into a continuous helical chamber (e.g., chamber 152, Fig. 4) for receiving a rotor. In some implementations, modular stator segment 100 may be made from metal, such as steel, bronze, or iron. In other implementations, modular stator segment 100 may be formed from special materials, such as titanium, ceramic, or hardened tool steel. In still other implementations, modular stator segment 100 may be formed from an elastomeric material, such as rubber. In another implementation, modular stator segment 100 may include a combination of metal and non-metal materials. For example, a metal piece that is coated with an elastomer on the surface of internal cavity 102 may be used to form modular stator segment 100.

[0015] Internal cavity 102 of modular stator segment 100 may extend longitudinally (e.g., axially) from an opening 114 in front surface 104 to an opening 116 in rear surface 106. Internal cavity 102 may have an interior helical profile that defines a central path. Internal cavity 102 may include multiple helical lobes 112, with two lobes being shown in the embodiment herein. According to an implementation, internal helical cavity 102 in each modular stator segment 100 may have the same degree of helical rotation between opening 114 and opening 116 (e.g., 5 degrees, 20 degrees, 30 degrees, 45 degrees, or another rotational value up to 360 degrees, about a central axis). When multiple modular stator segments 100 are joined together, the aligned internal cavities 102 may form helical chamber 152 with a smooth inner profile. Helical chamber 152 is configured to accept a portion of a rotor (e.g., rotor 500, Fig. 7) having a helical contour that rotates within helical chamber 152.

[0016] Front surface 104 and rear surface 106 may define parallel planes. Each of front surface 104 and rear surface 106 may be machined surfaces to provide clean contact with mating surfaces of other modular stator segments 100. In addition to opening 114, front surface 104 may include a gasket groove 120, a set of bolt holes 122, and a set of connection holes 132.

[0017] Gasket groove 120 may be configured to hold a compressible seal or gasket (e.g., gasket 300, Fig. 6A), as described further herein. Gasket groove 120 may be a continuous groove that encircles or surrounds the perimeter of opening 114. Although shown in the figures as being located around opening 114, in other implementations, gasket groove 120 may be located around opening 116 on surface 106.

[0018] Bolt holes 122 may include a bore 123 having first diameter and a bore 124 having a second diameter, so as to form a shoulder 125 therebetween. The depth of the first bore 123 is sufficient for the head of an installed bolt (e.g., bolt 400, Figs. 5 and 6A) to be recessed within bolt hole 122 and not protrude beyond surface 104. Bore 123 may include an enlarged upper opening for receiving a head portion 402 of bolt 400 in a recessed manner (e.g., such that head portion 402 is recessed below the front surface 104 when fully installed). In one implementation, bore 123 may have enough depth to accommodate a lock washer (not shown) while permitting recessing of head portion 402. In some implementations, least a portion of bore 124 may be threaded to receive a bolt (e.g., bolt 400).

[0019] Connection holes 132 may open at front surface 104 and extend partially through the thickness of modular stator segments 100. Connection holes 132 may be configured to align with bolt holes 122 of an adjacent modular stator segment 100. Connection holes 132 may include interior threads to receive a threaded portion 404 of bolt 400 that protrudes through bore 124 and beyond rear surface 106 of an adjacent modular stator segment 100. Connection holes 132 may serve as an indexing mechanism for modular stator segments 100 and internal cavity 102, such that, when connection holes 132 of one modular stator segment 100 are aligned with bolt holes 122 of another modular stator segment 100, the corresponding internal cavities 102 form a continuous smooth helical chamber.

[0020] In embodiments described herein, a set of two bolt holes 122 and two connection holes 132 are used in each modular stator segment 100. In other embodiments, a different number and or arrangement of holes 122/132 may be used. In any configuration, the number of bolts holes 122 and connection holes 132 may be the same, such that the set of bolt holes 122 in one modular stator segment 100 is configured to align with the set of connection holes 132 in an adjacent modular stator segment 100.

[0021] Fig. 4 depicts a cross-sectional view of a stator 200 assembled from multiple modular stator segments 100, and Fig. 5 depicts a perspective view of a portion of stator 200. Bolt holes 122 and connection holes 132 are not depicted in Fig. 4 for simplicity. According to implementations described herein, modular stator segment 100 may be connected end-to-end with other modular stator segments 100 (e.g., front surface 104 of one segment 100 to rear surface 106 of another segment 100) to form a long stator 200 with a continuous internal helical chamber 152. For example, lobes 112 may be configured to align with lobes of another modular stator segment 100 when front surface 104 abuts rear surface 106 of the other modular stator segment 100.

[0022] Each of modular stator segments 100 may have a thickness, T (Fig. 4), in the axial direction. The overall length of bolts 400 may generally exceed the thickness, T, of modular stator segment 100 to extend through bolt holes 122 and into connection holes 132 of an adjacent modular stator segments 100. Thickness, T, may correspond to a length that permits continuous alignment of internal cavity 102 between modular stator segments 100 when indexing holes of adjacent modular stator segments 100 are aligned. For example, in one implementation, when bolt holes 122 and connection holes 132 of two modular stator segments 100 are aligned, their respective internal cavities 102 may form continuous helical chamber 152. In one embodiment, the amount of helical rotation of each internal helical cavity 102 includes an axial rotation or angle of at least 20 degrees and up to 45 degrees. Thus, for a cavity 102 with two lobes 112, axial thickness, T, may be sufficient to include a helical path of between 20 and 45 degrees. As a non-limiting example, thickness, T, may generally be one-eighth of a complete stator stage. In other words, for a given stator size, eight modular stator segments 100 may be used to form a stator stage.

[0023] As shown in Figs. 4 and 6A, gasket 300, positioned in gasket groove 120, may be located between two modular stator segments 100 when assembled in stator 200. Gasket 300 provides a resilient compressible material at the interface between one modular stator segment 100 (e.g., front surface 104) and another modular stator segment 100 (e.g., rear surface 106). Gasket 300 may include a continuous substantially elliptical body that fits within gasket groove 120 and extends beyond the plane of front surface 104 (e.g., when not compressed). Gasket 300 may be constructed of any suitably durable and elastomeric material, such as silicone, butyl rubber polyamide, polyester, olefin, styrenics, urethane, or a composite of a thermoplastic and cured rubber. More specific examples include room temperature vulcanization silicone, uncured ethylene-propylene-diene-monomer (EPDM) blended with polypropylene, styrene-butadienestyrene block polymer, styrene-ethylene-butylene-styrene block polymer, cured ethylene-propylene-diene copolymer/polypropylene blend, cured isobutylene isoprene rubber/polypropylene blend, and cured nitrile butadiene rubber/polyvinylchloride blend. When gasket 300 is seated in gasket groove 120 and front surface 104 is mated to rear surface 106 of another modular stator segment 100, gasket 300 may be compressed against rear surface 106 to form a fluid-tight seal. Gasket 300 thus forms a fluid-tight seal between connected modular stator segments 100, preventing fluid leakage through stator 200.

[0024] Referring to Fig. 6B, in another implementation, modular stator segment 100 may not include gasket groove 120. Front surface 104 and rear surface 106 may be machined to a precision flat surface. That is, front surface 104 may be machined for a smooth interface with rear surface 106 of an adjacent modular stator segment 100. When bolts 400 of adjacent modular stator segments 100 are tightened to mate a rear surface 106 with a front surface 104, a substantially fluid-tight seal may be formed. In another implementation, a fluid-tight seal may be achieved when a washer, copper layer, liner, or sealant (e.g., a curable liquid or spay) is inserted between a front surface 104 and rear surface 106 when adjacent segments 100 are joined together.

[0025] Outer profile 108 may be substantially circular to provide a continuously smooth exterior surface of stator 200, regardless of the rotational orientation of each connected modular stator segment 100. Generally, the diameter of outer profile 108 may be sufficient to provide structural integrity around bolt holes 122, connection holes 132, and internal cavity 102 to support bolted connections and forces imparted by a rotor (e.g., rotor 500). According to one implementation, the diameter of outer profile 108 may be consistent with an outer diameter for conventional stator tubes to provide for convenient retrofit/interchangeability.

[0026] As shown in Fig. 7, rotor 500 generally has one or more lobes or helices that match the configuration of lobes 112 in modular stator segments 100. Generally, rotor 500 has one fewer lobe than the number of lobes 112 in modular stator segment 100 to facilitate a pumping rotation through chamber 152. The lobes of rotor 500 and lobes 112 engage to form sealing surfaces and cavities there between. For a drilling motor, fluid is pumped into one end of chamber 152 at a higher pressure than that at an opposite end, which creates forces that cause rotor 500 to rotate within stator 200. Gaskets 300 installed between each modular stator segment 100 prevent fluid leakage between the modular stator segments 100. In other implementations, gaskets 300 (and corresponding gasket grooves 120) may be omitted.

[0027] Figs. 8A and 8B are front and rear views of a connecting flange 800. Fig. 8C is a cross-sectional view of two connecting flanges 800 attached to a modular stator 200. According to an implementation, bolt holes 122 and/or connection holes 132 of modular stator segment 100 may be used to secure connecting flanges 800 to either end of stator 200.

[0028] According to one implementation, connecting flange 800 may include a standard flange (e.g., an American National Standards Institute (ANSI) compliant flange) modified to attach to either side of a modular stator segment 100. Connecting flange 800 may include an internal cavity 802 (e.g., a non-helical cavity) that may extend between a front surface 804 and a rear surface 806 of connecting flange 800.

[0029] Front surface 804 and rear surface 806 may substantially define parallel planes. Portions of front surface 804 may be machined to provide flush contact with a mating front surface 104 or rear surface 106 of modular stator segment 100. Front surface 804 may include a gasket groove 820, a set of bolt holes 822, and a set of connection holes 832. In contrast with the arrangement of gasket groove 120 on modular stator segment 100, gasket groove 820 may encircle or surround bolt holes 822 and connection holes 832. Gasket groove 820 may be configured to receive a compressible gasket or seal therein, such as a gasket similar to gasket 300 described above.

[0030] Bolt holes 822 may be configured similar to bolt holes 122 of modular stator segment 100 to receive a bolt 400 in a recessed manner (e.g., such that head portion 402 is recessed below the front surface 804 when fully installed). In some implementations, least a portion of bolt hole 822 may be threaded to receive a bolt (e.g., bolt 400).

[0031] Connection holes 832 may open at front surface 804 and extend partially through the thickness of connecting flange 800. Connection holes 832 may be configured to align with bolt holes 122 of an adjacent modular stator segment 100. Connection holes 832 may include interior threads to receive a threaded portion 404 of bolt 400 that protrudes through bore 124 and beyond rear surface 106 of an adjacent modular stator segment 100. Connection holes 832 may serve as an indexing mechanism for mating connecting flange 800 to a modular stator segment 100, such that, when connection holes 832 are aligned with bolt holes 122, internal cavity 802 aligns with the corresponding internal cavity 102 of the adjacent modular stator segment 100. Internal cavity 802 may be configured to allow for clearance with a rotor (e.g., rotor 500) and may loft to a standard pipe size for the ANSI flange.

[0032] As shown in Fig. 8C, connecting flanges 800 may be configured to installed at either end of stator 200 with front surface 804 contacting/facing an adjacent modular stator segment 100. The diameter of gasket groove 820 may be slightly smaller than a diameter of modular stator segment 100 to permit an installed gasket (e.g., gasket 840) to form a seal between front surface 804 and either of front surface 104 or rear surface 106, when connecting flange 800 and modular stator segment 100 are bolted together. Connecting flanges 800 may be used to connect stator 200 to other components of a progressive cavity device. For example, each connecting flange 800 may include standardized bolt holes 850 (e.g., ANSI standard hole patterns) that may be used to join stator 200 to other components. According to another implementation, a threaded connector may be selected (e.g., in place of connecting flange 800) for a particular application/configuration of progressive cavity device and bolted to modular stator segment 100.

[0033] Referring to Figs. 9A and 9B, a modular stator segment 900 may include an elastomer coating 160 along internal cavity 902. Elastomer coating 160 may be applied and cured, for example, on individual modular stator segments 900 prior to connection of modular stator segments 900 into stator 200. According to one implementation, the dimensions of modular stator segment 900 may be identical to those of modular stator segment 100, with the exception of internal cavity 802, such that modular stator segment 900 and modular stator segment 100 may be interchangeable within a stator 200. Modular stator segment 900 may have a smaller internal cavity 902 compared to internal cavity 102. For example, dimensions of internal cavity 902 may provide an interference fit for rotor 500, while dimensions of internal cavity 102 may provide a clearance fit for rotor 500. As shown in Fig. 9B, multiple modular stator segments 900 may be connected (in a similar manner described above) to form a continuous helical chamber 152. In other implementations, modular stator segments 900 and modular stator segments 100 may be included within the same stator 200.

[0034] Fig. 10 is a flow diagram of a process 1000 for forming a stator 200 for a hydraulic motor or pump, according to an implementation described herein. Process 1000 may include providing multiple module stator segments (block 1010). For example, a technician may select a set of modular stator segments 100/900 for a required pump or motor size. As described above, each of the modular stator segments may have an internal helical cavity 102/802, a gasket groove 120, as set of bolt holes 122, and a set of connection holes 132.

[0035] Process 1000 may also include applying a seal between the stator segments (block 1020). For example, applying a seal may include inserting a gasket into a gasket groove 120 of each modular stator segment 100. For example, a technician may insert a gasket 300 into a gasket groove 120 for each of modular stator segment 100/900 (or confirm a gasket was previously inserted). In other implementations, applying a seal may include inserting a washer, a copper layer, a liner, between to a front surface 104 or rear surface 106 of modular stator segment 100. In still another implementation, applying a seal may include applying a sealant (e.g., a curable liquid or spay) to a front surface 104 or rear surface 106 of modular stator segment 100. In still other implementation, no seal may be applied between the stator segments (e.g., block 1020 may be omitted).

[0036] Process 1000 may also include aligning bolt holes of a first stator segment with connection holes of a next stator segment (block 1030), inserting bolts through the bolt holes and into the connection holes (block 1040), and tightening the bolts to mate the surfaces of the stator segments (block 1050). For example, a technician may align connection holes 132 of a first modular stator segment 100/900 with bolt holes 122 of a next modular stator segment 100/900. Bolts 400 (and washers, if necessary) may be inserted through the bolt holes 122 and into connection holes 122. Bolts 400 may be tightened to mate rear surface 106 of the second modular stator segment 100/900 to front surface 104 of the first modular stator segment 100/900 (e.g., as shown in Fig. 6A). Head portion 402 may be recessed withing bolt hole 122 and gasket 300 may be compressed between the mated surfaces 106/104.

[0037] If the required length of the stator assembly is not met (block 1060 - no), process 1000 may return to block 1030 to connect the next modular stator segment 100/800. If the required length of the stator assembly is met (block 1060 - yes), flanges may be attached to the ends of the stator (block 1070). For example, based on a particular implementation or use for stator 200, flanges (e.g., connecting flanges 800) for connecting the stator to other components may be bolted to the assembled stator 200 using connection holes 132 and/or bolt holes 122.

[0038] Figs. 11A depicts a front view of a center stator segment 1100, and Fig. 11B depicts a rear view of center stator segment 1100. Figs. 12A depicts a front view of a modular stator segment 1200, and Fig. 12B depicts a rear view of modular stator segment 1200. Fig. 13 depicts a cross-sectional view of a stator 1300 assembled using center stator segment 1100 and multiple modular stator segments 1200. Figs. 14A and 14B depict front and rear views of a connecting flange 1800, according to an implementation. Referring collectively to Figs. 11A through 14B, center stator segment 1100 includes an internal cavity 1102, a front surface 1104, a rear surface 1106, and an outer profile 1108. Internal cavity 1102 may generally correspond to internal cavity 102 described above.

[0039] Each of front surface 1104 and rear surface 1106 may include a gasket groove 1120 and a set of connection holes 1132. Gasket groove 1120 may be similar to gasket groove 120 described above and may generally be any symmetrical or asymmetrical shape that encircles or surrounds an opening to internal cavity 1102 on front surface 1104 or rear surface 1106. Connection holes 1132 may be similar to connection holes 132 described above. In contrast with modular stator segments 100 and 1200, center stator segment 1100 may include connection holes 1132 on each of front surface 1104 and rear surface 1106 and may not include bolt holes. Thus, center stator segment 1100 may be configured to adjoin surface 1104 to a rear surface 106 of a modular stator segment 1200 and to adjoin surface 1106 to a rear surface 106 of a different modular stator segment 1200.

[0040] In the configuration of Figs. 11A and 11B, center stator segment 1100 may include four (4) connection holes 1132 and two (2) index holes 1142 (also referred to as alignment holes). Index holes 1142 may be used to align center stator segment 1100 with modular stator segments 1200. Index holes 1142 may be configured to receive bolts 400 and follow the same bolt hole pattern as connection holes 1132. However, index holes 1142 have a smaller diameter counter bore than connection holes 1132 for precise alignment. Two index holes 1142 can provide adequate alignment with minimal precision (e.g., as compared to having 3 or more index holes).

[0041] Connection holes 1132 are provided to increase the clamping force between two segments (i.e., center stator segment 1100 and a modular stator segment 1200) and evenly distribute clamping force around the component. Thus, index holes 1142 are used for clamping force and for alignment, with bolts 400 being installed first into index holes 1142 during assembly, while connection holes 1132 are generally not relied upon for alignment.

[0042] Similar to segments 100 described above, modular stator segment 1200 may include bolt holes 122 and connection holes 132 to allow for connection and alignment of multiple segments 100 (i.e., extending from either side of center stator segment 1100). As shown in the embodiment of Figs. 11A-13, index holes 1142 may also be included to align connecting modular stator segments 1220 in a manner as described above in connection with Figs. 11A and 11B. The pattern of bolt holes 122, connection holes 132, and index holes 1142 in Figs. 12A and 12B is exemplary. Other amounts and arrangements of bolt holes 122, connection holes 132, and index holes 1142 may be used.

[0043] Center stator segment 1100 may be connected to modular stator segments 1200 at both surfaces 1104 and 1106 to form a stator 1300 of desired length. Center stator segment 1100 and modular stator segments 1200 may be connected to align internal cavities 1102 and 102 into a continuous helical chamber (e.g., chamber 152, Fig. 13). Similar to stator segments 100 described above, in one implementation, center stator segment 1100 and each modular stator segment 1200 may be configured for a particular pump/rotor size.

[0044] Center stator segment 1100 and modular stator segments 1200 may be joined together using bolts 400. In contrast with the embodiments described in connection with Figs. 1-9, however, use of center stator segment 1100 allows the stator 1300 to be built out from a "center" piece (e.g., center stator segment 1100) instead of being built up from one side. Assembly and disassembly of stator 1300 may be performed from either end regardless of how the stator is installed. The number of modular stator segments 1200 on either side of center stator segment 1100 may be the same or different.

[0045] Connecting flanges 1800, similar to connecting flanges 800 described above, may be secured to each end of stator 1300. In one implementation, connecting flanges 1800 may be identical parts.

[0046] Each connecting flange 1800 may include an internal cavity 1802. In contrast with connecting flange 800, in which internal cavity 802 transitions from a circular opening to a lobed opening, internal cavity 1802 may have a circular opening that extends between surfaces 804 and 806.

[0047] Embodiments shown in Figs. 11A through 14B may be assembled using a process similar to process 1000 described above. In one implementation, alignment of each stator segment may be accomplished using bolts 400 inserted into index holes 1142 before inserting bolts 400 into connection holes 132/1132. As shown in Fig. 13, an optional extension section 1400 may be included to extend the overall length of stator 1300 for retrofit applications (i.e., so the total axial length dimension may match a previous installation for a "drop-in" replacement).

[0048] In an implementation described herein, a stator is provided for a progressive cavity device, such as a hydraulic motor or pump. The stator may include modular stator segments connected together. Each stator segment may include a front surface, a rear surface, an internal helical cavity extending longitudinally from the front surface to the rear surface, and a gasket groove on one of the front or rear surfaces. Each stator segment may also include a set of bolt holes extending longitudinally from the front surface to the rear surface and a set of connection holes opening at the front surface and extending at least partially longitudinally from the front surface to the rear surface. Bolts may be inserted through the bolt holes into connection holes of an adjacent stator segment to connect the stator segments and align the internal helical cavities to form a continuous helical chamber.

[0049] According to another implementation, a method for assembling a stator is provided. The method includes providing a plurality of modular stator segments as described herein. A gasket may be inserted into the gasket groove on a first modular stator segment or a second modular stator segment. Bolt holes of the first modular stator segment may be aligned with connection holes of the second modular stator segment. Bolts may be inserted through the bolt holes of the first modular stator segment and into the connection holes of the second modular stator segment. The bolts may be tightened to compress the compressible gasket and form a fluid-tight seal between the first modular stator segment and the second modular stator segment, wherein the first modular stator segment and the second modular stator segment are connected such that the internal helical cavities form a continuous helical chamber.

[0050] The systems and methods described here simplify assembly of stator for a progressive cavity device. Other benefits may include a smoother helical profile that will increase the life expectancy and performance of the progressive cavity device, a smaller overall footprint because the outer tube is removed, an easier stator product to repair/modify, an upgradable product by being able to add more segments to increase the size and capabilities of the pump if needed, and a less complex manufacturing process. Additionally, systems and methods described herein allow the mixing and matching of various stator materials. For example, two stator end segments may be provided with an elastomeric inner profile, while the remaining middle stator segments may be completely metal or another rigid material. This arrangement may provide better seal on the ends and allow a pump to run dry because most of the product is metal. Thus, even if the elastomeric end segments fail after running dry, the damaged end pieces can be easily replace without having to replace the whole stator.

[0051] The foregoing description of implementations provides illustration and description, but is not intended to be exhaustive or to limit the invention to the precise form disclosed. Modifications and variations are possible in light of the above teachings or may be acquired from practice of the invention. For example, while a series of blocks have been described with regard to Fig. 10, the order of the blocks and message/operation flows may be modified in other embodiments. Further, non-dependent blocks may be performed in parallel.

[0052] Although the invention has been described in detail above, it is expressly understood that it will be apparent to persons skilled in the relevant art that the invention may be modified without departing from the spirit of the invention. Various changes of form, design, or arrangement may be made to the invention without departing from the scope of the invention. Different combinations illustrated above may be combined in a single embodiment. Therefore, the above-mentioned description is to be considered exemplary, rather than limiting, and the true scope of the invention is that defined in the following claims.

[0053] The terms "a," "an," and "the" are intended to be interpreted to include one or more items. Further, the phrase "based on" is intended to be interpreted as "based, at least in part, on," unless explicitly stated otherwise. The term "and/or" is intended to be interpreted to include any and all combinations of one or more of the associated items. The word "exemplary" is used herein to mean "serving as an example." Any embodiment or implementation described as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments or implementations.

[0054] Use of ordinal terms such as "first," "second," "third," etc., in the claims to modify a claim element does not by itself connote any priority, precedence, or order of one claim element over another, the temporal order in which acts of a method are performed, the temporal order in which instructions executed by a device are performed, etc., but are used merely as labels to distinguish one claim element having a certain name from another element having a same name (but for use of the ordinal term) to distinguish the claim elements.

[0055] No element, act, or instruction used in the description of the present application should be construed as critical or essential to the invention unless explicitly described as such. Also, as used herein, the article "a" is intended to include one or more items. Further, the phrase "based on" is intended to mean "based, at least in part, on" unless explicitly stated otherwise.

[0056] The invention is further described in the following items.

1. A stator for a progressive cavity device, comprising:

    a plurality of modular stator segments, each of the modular stator segments including:

        a front surface;
        a rear surface;
        an internal helical cavity extending longitudinally from the front surface to the rear surface;
        a set of bolt holes extending longitudinally from the front surface to the rear surface; and
        a set of connection holes opening at the front surface and extending at least partially longitudinally from the front surface to the rear surface,

    wherein the plurality of modular stator segments are connected such that the internal helical cavities form a continuous helical chamber.

2. The stator of item 1, wherein the set of bolt holes in a first modular stator segment of the plurality of modular stator segments is configured to align with the set of connection holes in a second modular stator segment of the plurality of modular stator segments.

3. The stator of any preceding item, wherein the connection holes are threaded and configured to receive a bolt extending through the bolt hole of another modular stator segment.

4. The stator of any preceding item, wherein the set of bolt holes includes at least two bolt holes, and wherein the set of connection holes includes at least two connection holes.

5. The stator of any preceding item, wherein each of the bolt holes includes an opening to receive an installed bolt head recessed below the front surface.

6. The stator of any preceding item, wherein the internal helical cavity includes an axial rotation of at least 20 degrees and up to 45 degrees.

7. The stator of any preceding item, wherein each of the modular stator segments further includes:
a gasket groove on one or more of the front surface or the rear surface, wherein the gasket groove surrounds an opening of the internal helical cavity.

8. The stator of item 7, further comprising:
a compressible gasket configured to fit within the gasket groove and form a fluid-tight seal when a first modular stator segment, of the plurality of modular stator segments, is connected to a second modular stator segment, of the plurality of modular stator segments, with the compressible gasket therebetween.

9. The stator of any preceding item, wherein at least some of the modular stator segments include an elastomer coating on the internal helical cavity.

10. The stator of item 9, wherein the elastomer coating is cured prior to connecting a first modular stator segment to a second modular stator segment.

11. The stator of any preceding item, further comprising:
bolts configured to fit within the set of bolt holes of a first modular stator segment and extend into the connection holes of a second modular stator segment.

12. The stator of any preceding item, further comprising:
a center stator segment configured to adjoin to a first rear surface of a first modular stator segment, of the plurality of modular stator segments, and adjoin to a second rear surface of a second modular stator segment, of the plurality of modular stator segments.

13. The stator of any preceding item, wherein each of the modular stator segments, of the plurality of modular stator segments, are identical.

14. The stator of any preceding item, wherein the at least a first one of the plurality of modular stator segments includes an elastomer coating on the internal helical cavity, and wherein the elastomer coating is configured to provide an interference fit with a rotor within the continuous helical chamber.

15. The stator of item 14, wherein at least a second one of the plurality of modular stator segments is configured to provide an interference fit with the rotor within the continuous helical chamber.

16. A method of assembling a stator for a progressive cavity device, the method comprising:

providing a plurality of modular stator segments, each of the modular stator segments including:

a front surface,
a rear surface,
an internal helical cavity extending longitudinally from the front surface to the rear surface,
a gasket groove on one or more of the front surface or the rear surface, wherein the gasket groove surrounds an opening of the internal helical cavity,
a set of bolt holes extending longitudinally from the front surface to the rear surface, and
a set of connection holes opening at the front surface and extending at least partially longitudinally from the front surface to the rear surface;

inserting, into the gasket groove of a first modular stator segment or a second modular stator segment, of the plurality of modular stator segments, a compressible gasket configured to fit within the gasket groove;
aligning the bolt holes of the first modular stator segment with the connection holes of the second modular stator segment;
inserting bolts through the bolt holes of the first modular stator segment and into the connection holes of the second modular stator segment; and
tightening the bolts to compress the compressible gasket and form a fluid-tight seal between the first modular stator segment and the second modular stator segment, wherein the first modular stator segment and the second modular stator segment are connected such that the internal helical cavities form a continuous helical chamber.

17. The method of item 16, wherein the first modular stator segment includes an elastomer coating on the internal helical cavity of the first modular stator segment, and wherein the second modular stator segment has exposed metal on the internal helical cavity of the second modular stator segment.

18. The method of item 16 or 17, further comprising: connecting to at least one of the plurality of modular stator segments, a connecting flange using the bolt holes or the connection holes of the at least one of the plurality of modular stator segments.

19. A stator segment for a stator, the stator segment including:

a front surface;
a rear surface;
an internal helical cavity extending longitudinally from the front surface to the rear surface;
a set of bolt holes extending longitudinally from the front surface to the rear surface; and
a set of connection holes opening at the front surface and extending at least partially longitudinally from the front surface to the rear surface,

wherein the modular stator segment is configured to connect to other modular stator segments such that the internal helical cavities of the stator segments form a continuous helical chamber.

20. The stator segment of item 19, further comprising:
a gasket groove on one or more of the front surface or the rear surface, wherein the gasket groove surrounds an opening of the internal helical cavity.

Claims

1. A stator (200, 1300) for a progressive cavity device, comprising:

   a plurality of modular stator segments (100, 1200), each of the modular stator segments including:

      a front surface (104);
      a rear surface (106);
      an internal helical cavity (102) extending longitudinally from the front surface to the rear surface;
      a set of bolt holes (122) extending longitudinally from the front surface to the rear surface; and
      a set of connection holes (132) opening at the front surface and extending at least partially longitudinally from the front surface to the rear surface,

   wherein the plurality of modular stator segments (100) are connected such that the internal helical cavities form a continuous helical chamber (152).

2. The stator of claim 1, wherein the set of bolt holes in a first modular stator segment of the plurality of modular stator segments is configured to align with the set of connection holes in a second modular stator segment of the plurality of modular stator segments.

3. The stator of any preceding claim, wherein the connection holes are threaded and configured to receive a bolt extending through the bolt hole of another modular stator segment.

4. The stator of any preceding claim, wherein the set of bolt holes includes at least two bolt holes, and wherein the set of connection holes includes at least two connection holes.

5. The stator of any preceding claim, wherein each of the bolt holes includes an opening to receive an installed bolt head recessed below the front surface.

6. The stator of any preceding claim, wherein the internal helical cavity includes an axial rotation of at least 20 degrees and up to 45 degrees.

7. The stator of any preceding claim, wherein each of the modular stator segments further includes:

   a gasket groove (120) on one or more of the front surface or the rear surface, wherein the gasket groove surrounds an opening of the internal helical cavity; and
   a compressible gasket (300) configured to fit within the gasket groove and form a fluid-tight seal when a first modular stator segment, of the plurality of modular stator segments, is connected to a second modular stator segment, of the plurality of modular stator segments, with the compressible gasket therebetween.

8. The stator of any preceding claim, wherein at least some of the modular stator segments include an elastomer coating on the internal helical cavity, wherein the elastomer coating is cured prior to connecting a first modular stator segment to a second modular stator segment.

9. The stator of any preceding claim, further comprising:
   bolts (400) configured to fit within the set of bolt holes of a first modular stator segment and extend into the connection holes of a second modular stator segment.

10. The stator of any preceding claim, further comprising:
   a center stator segment (1100) configured to adjoin to a first rear surface of a first modular stator segment, of the plurality of modular stator segments, and adjoin to a second rear surface of a second modular stator segment, of the plurality of modular stator segments.

11. The stator of any preceding claim, wherein each of the modular stator segments, of the plurality of modular stator segments, are identical.

12. The stator of any preceding claim, wherein the at least a first one of the plurality of modular stator segments includes an elastomer coating (160) on the internal helical cavity, and wherein the elastomer coating is configured to provide an interference fit with a rotor within the continuous helical chamber.

13. A method (1000) of assembling a stator (200, 1300) for a progressive cavity device, the method comprising:

   providing (1010) a plurality of modular stator segments (100, 1200), each of the modular stator segments including:

      a front surface (104),
      a rear surface (106),
      an internal helical cavity (102) extending longitudinally from the front surface to the rear surface,
      a gasket groove (120) on one or more of the front surface or the rear surface, wherein

the gasket groove surrounds an opening of the internal helical cavity,
a set of bolt holes (122) extending longitudinally from the front surface to the rear surface, and
a set of connection holes (132) opening at the front surface and extending at least partially longitudinally from the front surface to the rear surface;

inserting (1020), into the gasket groove of a first modular stator segment or a second modular stator segment, of the plurality of modular stator segments, a compressible gasket configured to fit within the gasket groove;
aligning (1030) the bolt holes of the first modular stator segment with the connection holes of the second modular stator segment;
inserting (1040) bolts (400) through the bolt holes of the first modular stator segment and into the connection holes of the second modular stator segment; and
tightening (1050) the bolts to compress the compressible gasket and form a fluid-tight seal between the first modular stator segment and the second modular stator segment, wherein the first modular stator segment and the second modular stator segment are connected such that the internal helical cavities form a continuous helical chamber (152).

14. The method of claim 13, further comprising: connecting (1070) to at least one of the plurality of modular stator segments, a connecting flange using the bolt holes or the connection holes of the at least one of the plurality of modular stator segments.

15. A stator segment (100, 1200) for a stator, the stator segment including:

a front surface (104);
a rear surface (106);
an internal helical cavity (102) extending longitudinally from the front surface to the rear surface;
a set of bolt holes (122) extending longitudinally from the front surface to the rear surface; and
a set of connection holes (132) opening at the front surface and extending at least partially longitudinally from the front surface to the rear surface,

wherein the modular stator segment is configured to connect to other modular stator segments such that the internal helical cavities of the stator segments form a continuous helical chamber (152).

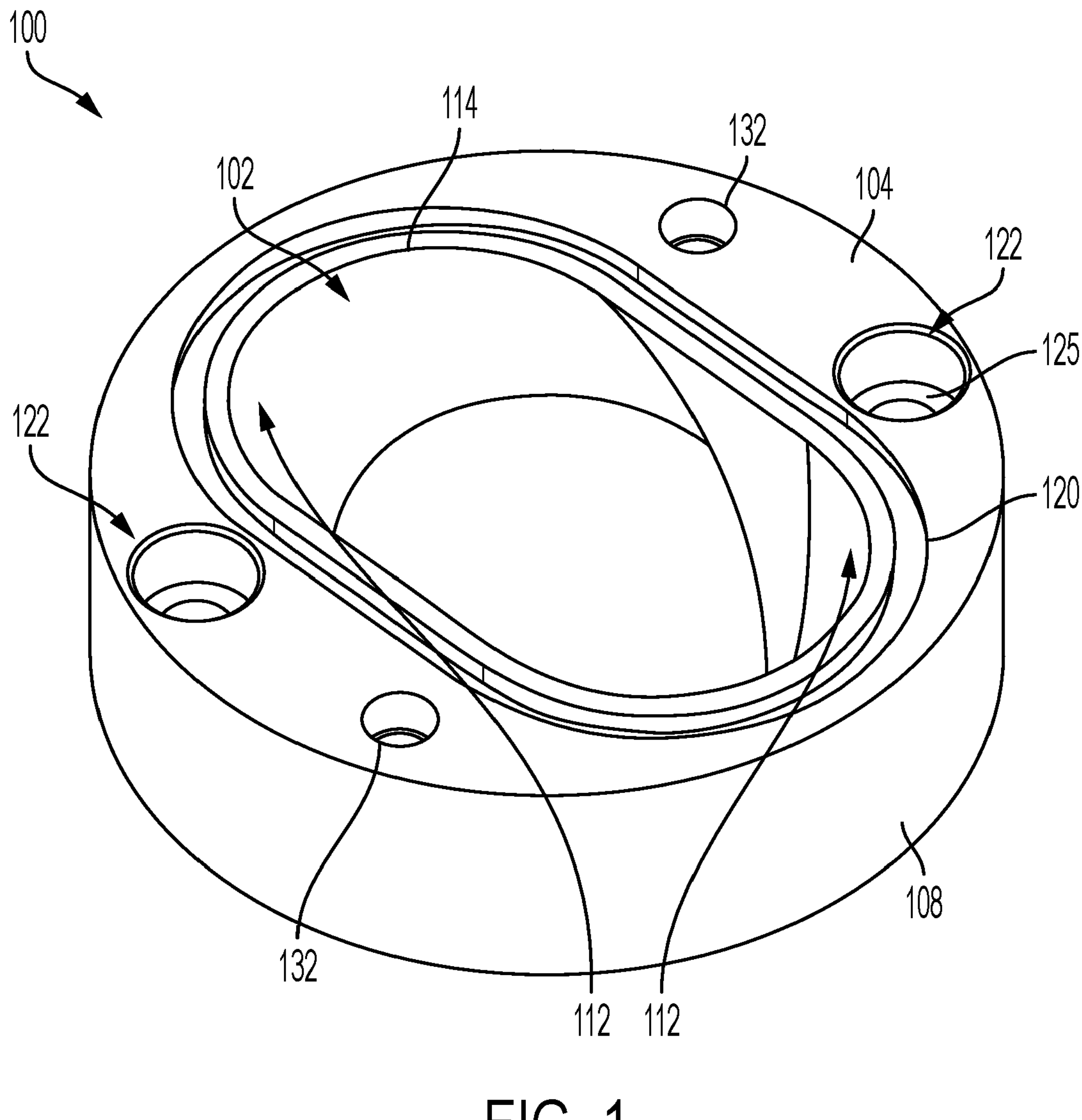


FIG. 1

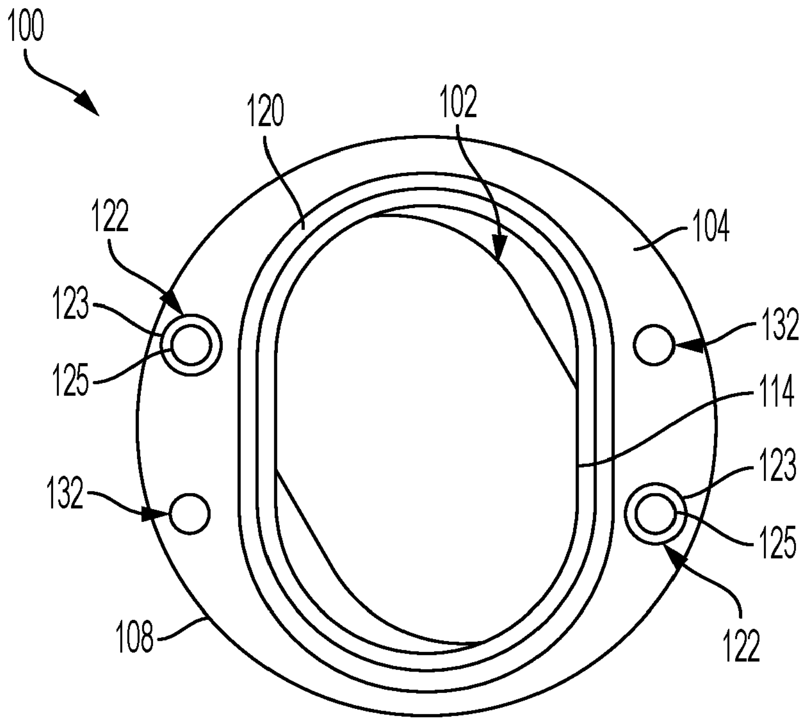

100
120
102
122
104
123
132
125
114
132
123
125
108
122

FIG. 2

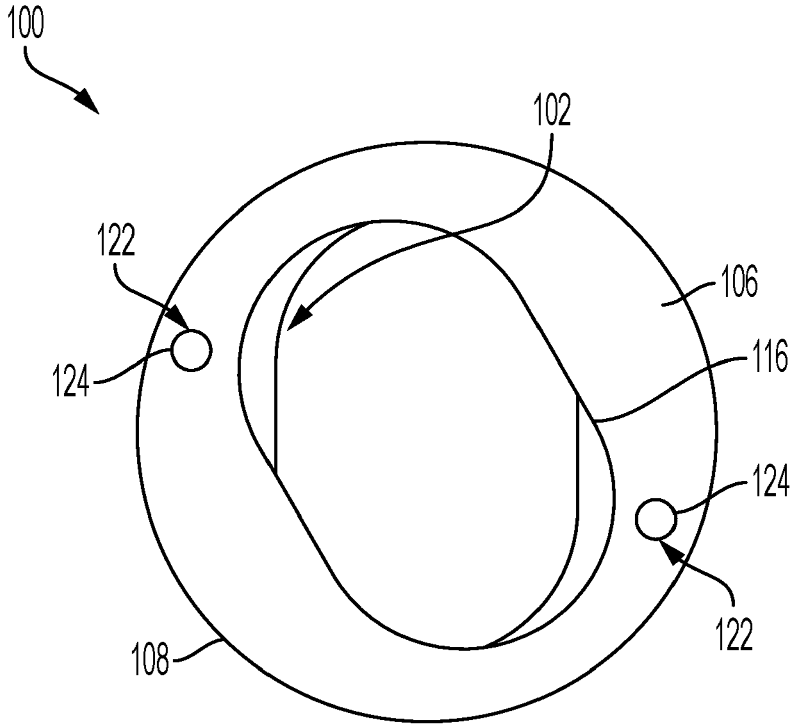

100
102
122
106
124
116
124
108
122

FIG. 3

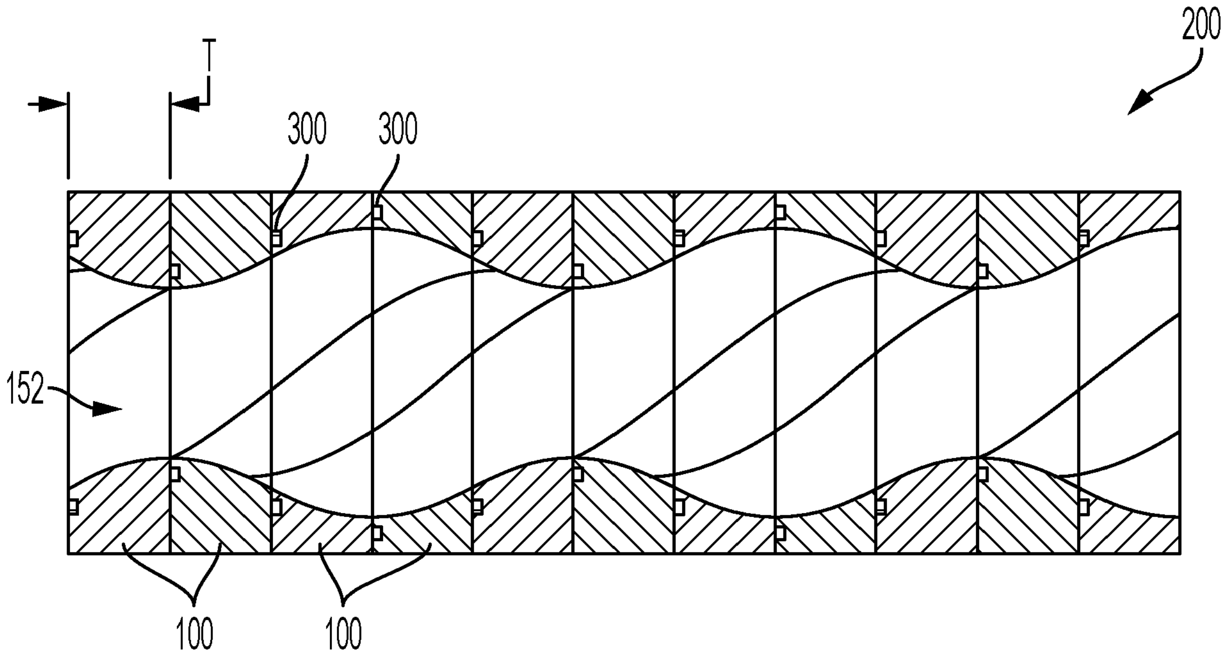


FIG. 4

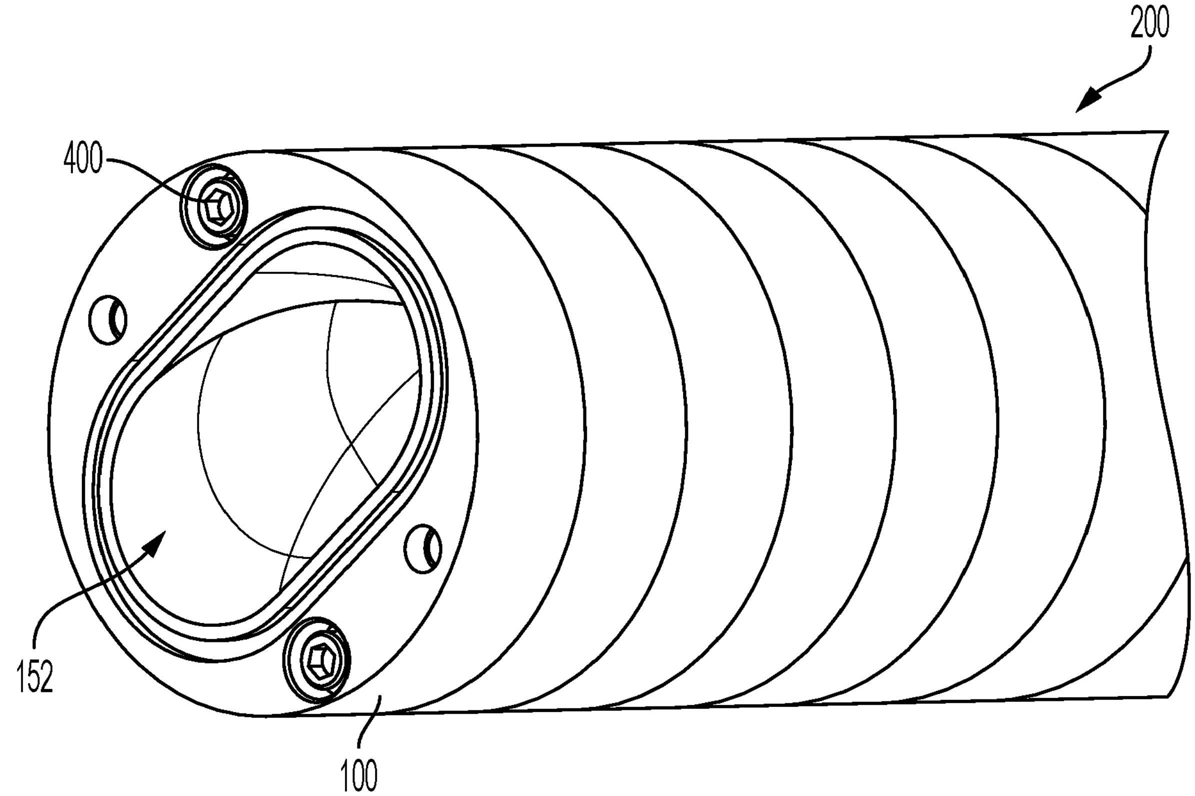


FIG. 5

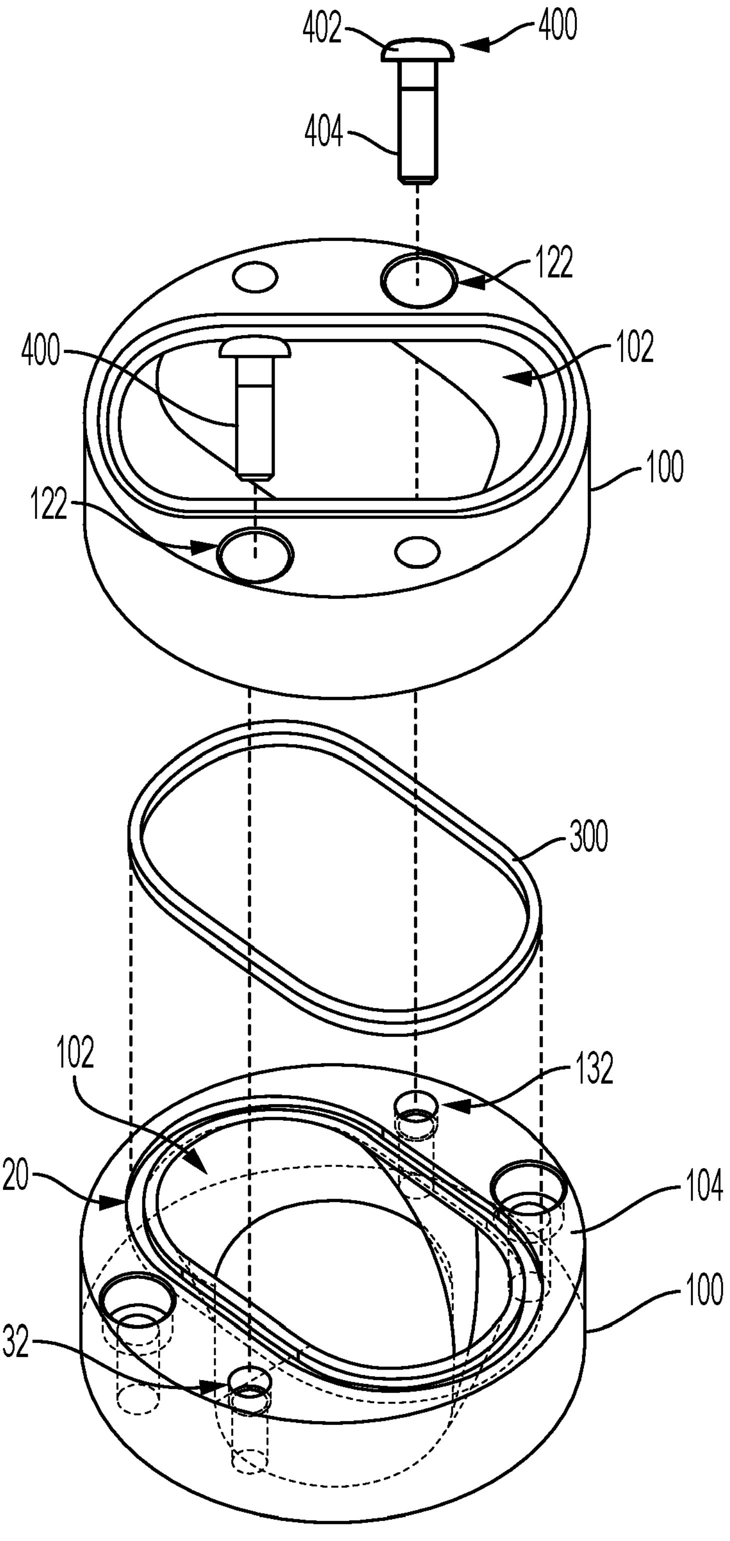


FIG. 6A

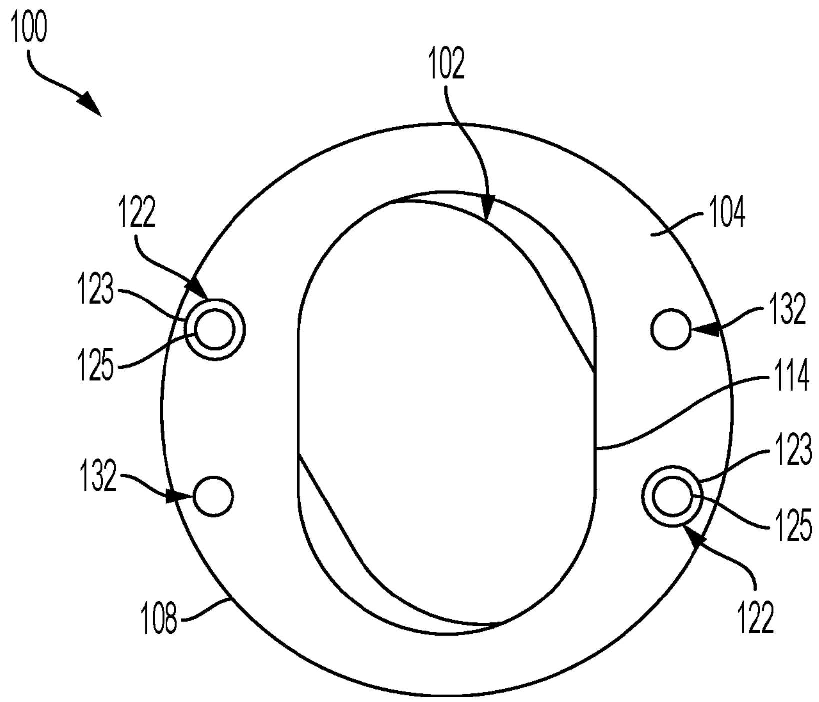

100
102
104
122
123
125
132
114
123
125
122
132
108

FIG. 6B

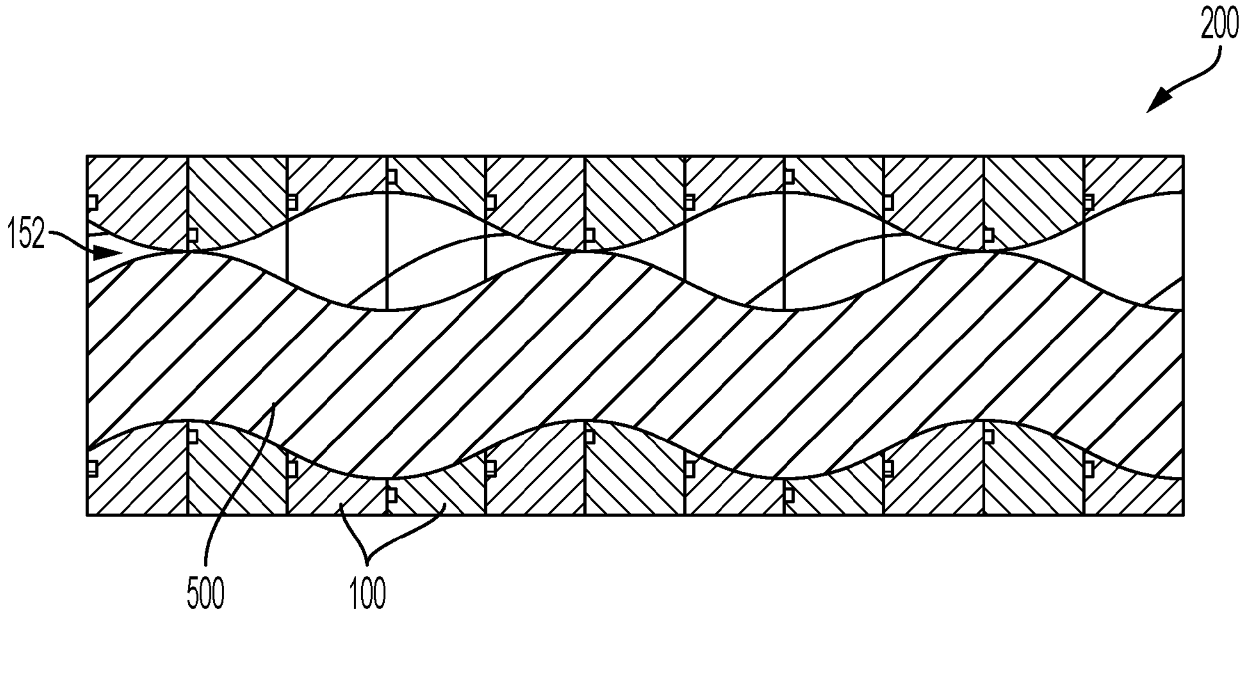

200
152
500
100

FIG. 7

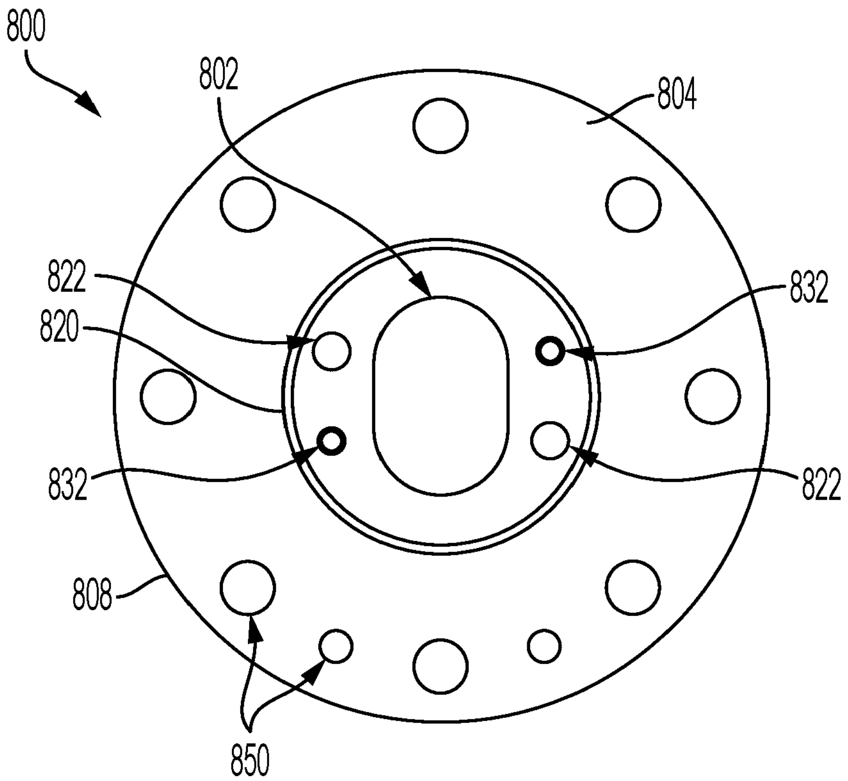
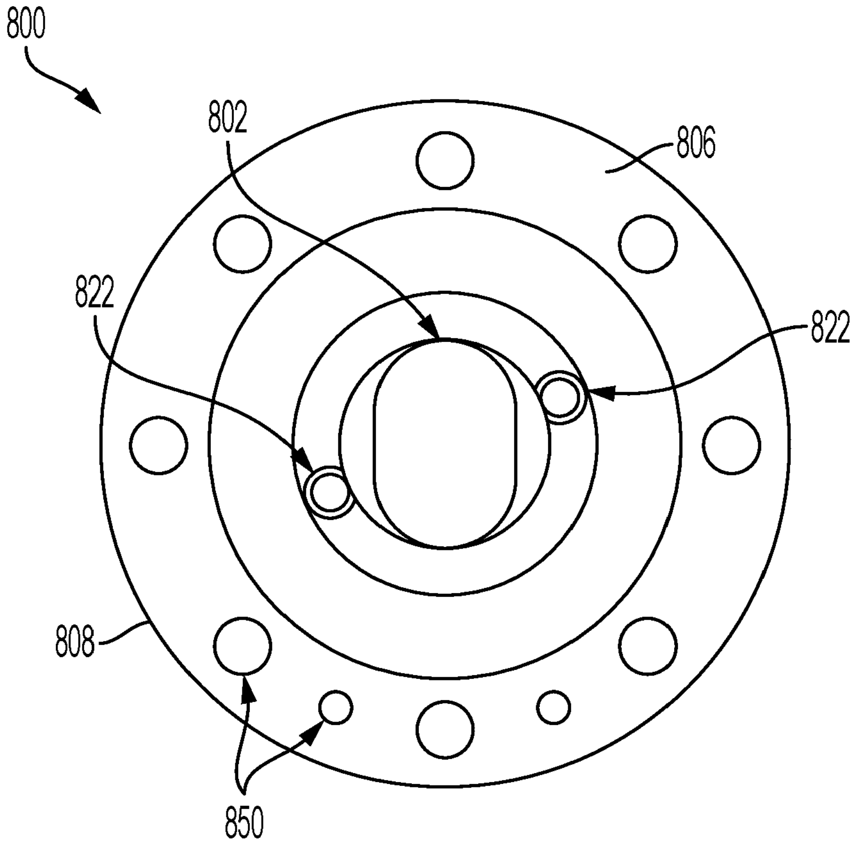

800
802
804
822
820
832
832
822
808
850

FIG. 8A


800
802
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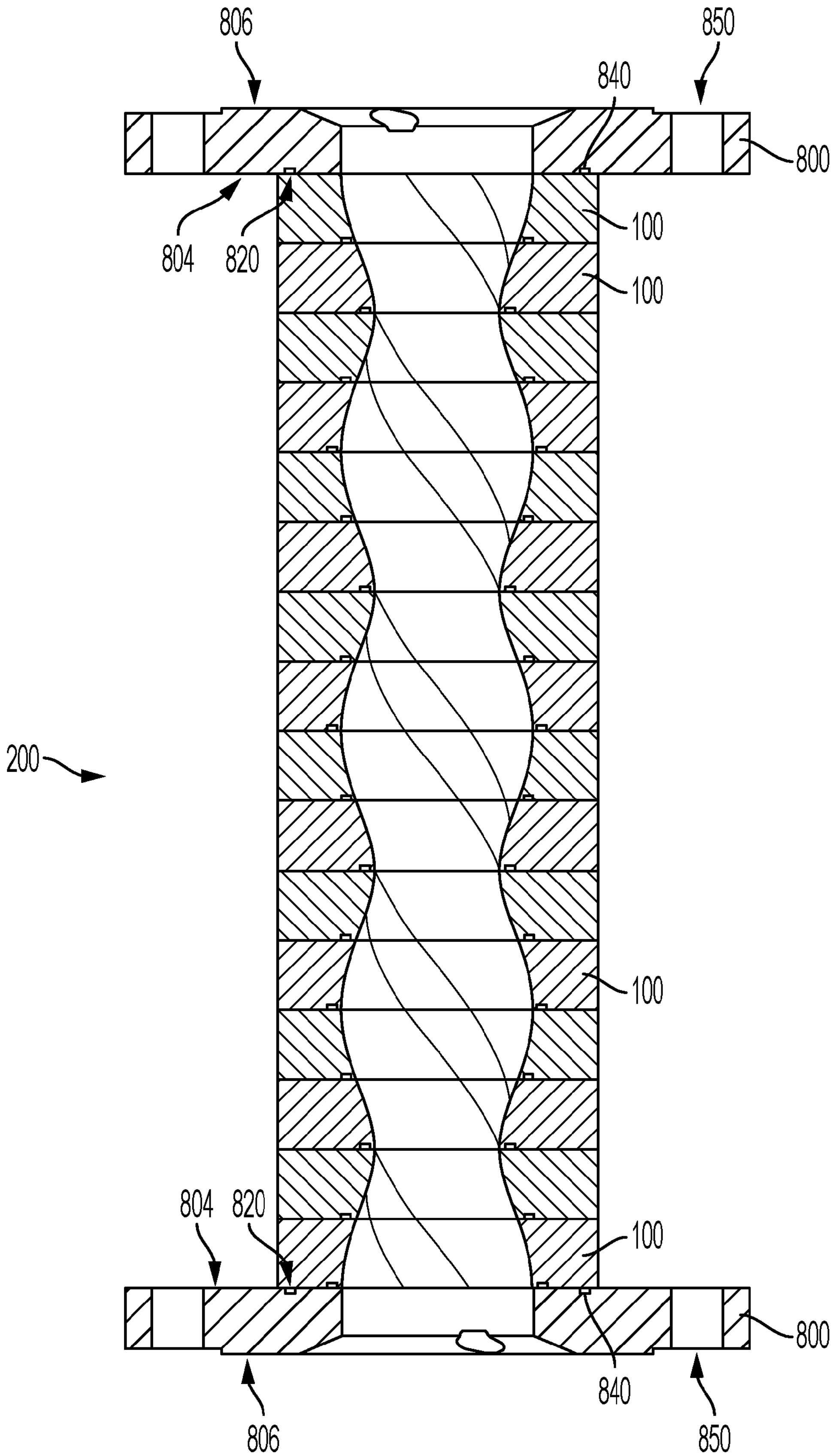
822
822
808
850

FIG. 8B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100
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804
820
200
100
100
804
820
800
840
806
850

FIG. 8C

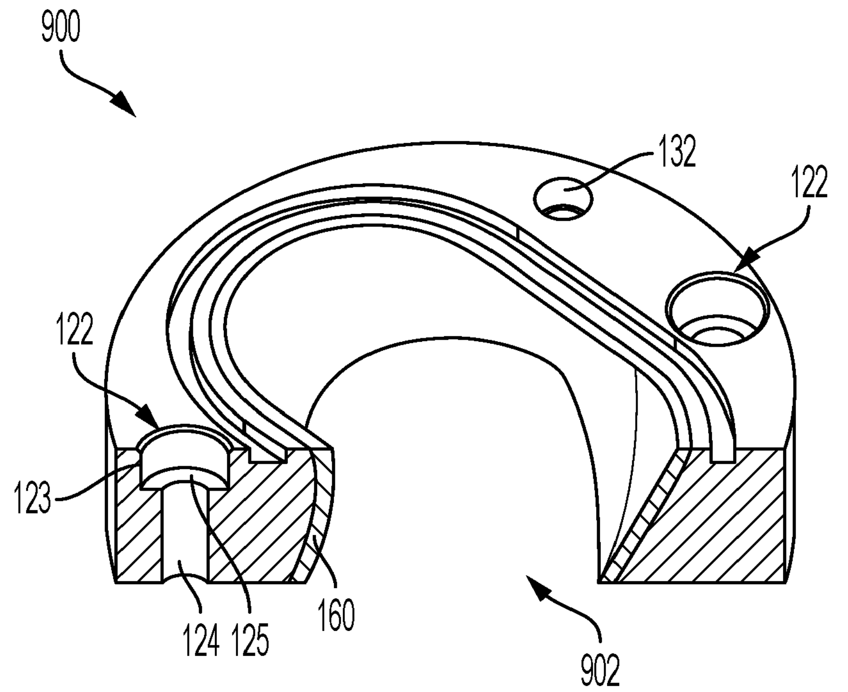

FIG. 9A

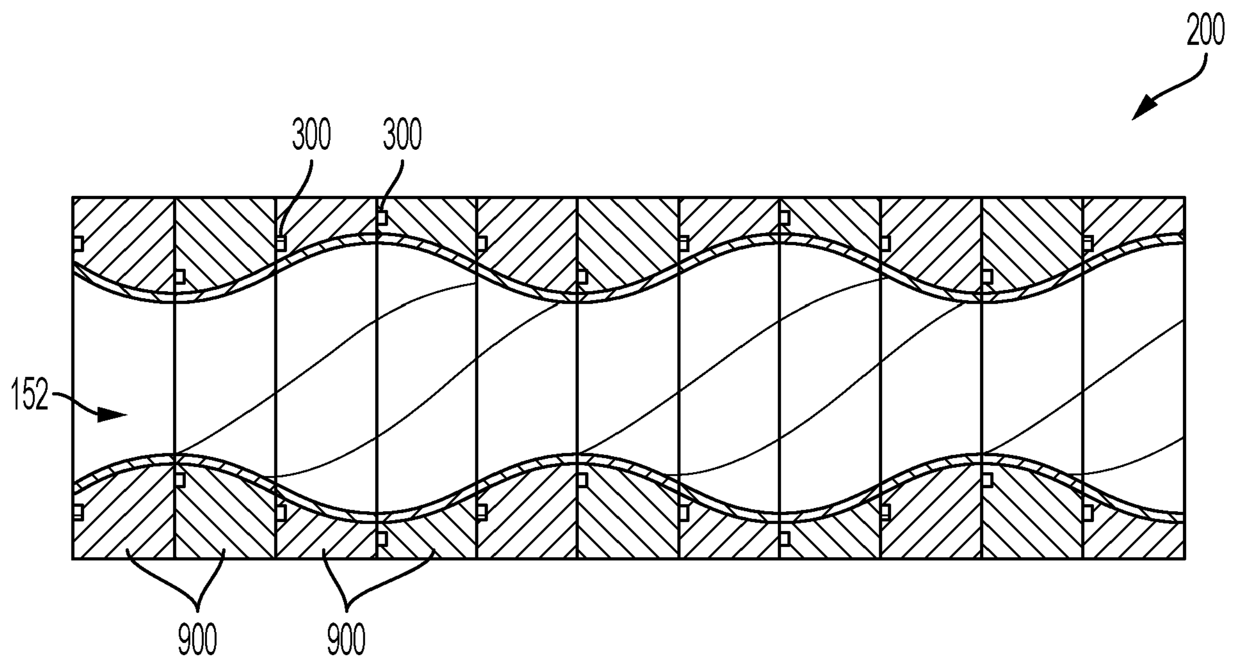

FIG. 9B

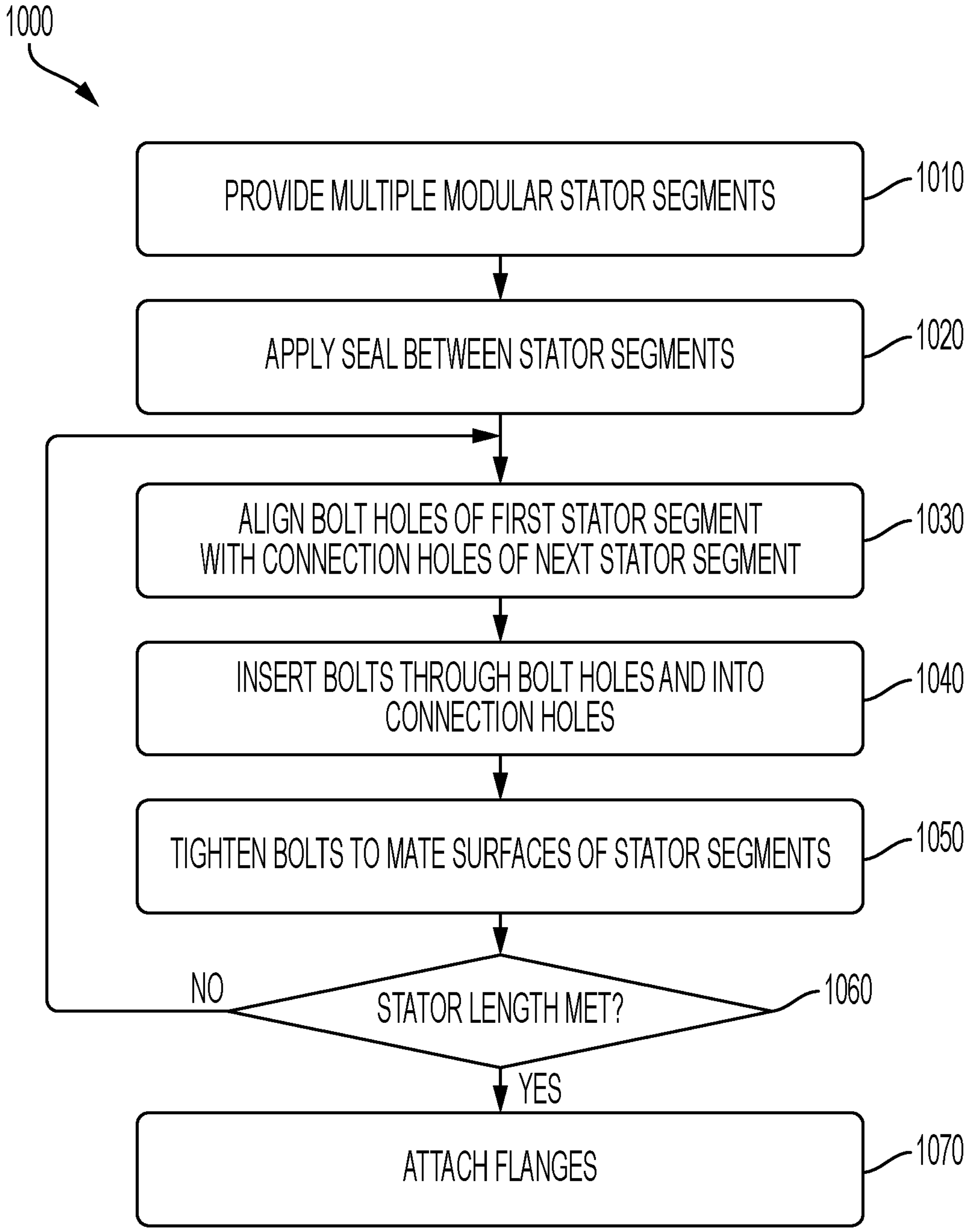
1000
PROVIDE MULTIPLE MODULAR STATOR SEGMENTS
1010
APPLY SEAL BETWEEN STATOR SEGMENTS
1020
ALIGN BOLT HOLES OF FIRST STATOR SEGMENT WITH CONNECTION HOLES OF NEXT STATOR SEGMENT
1030
INSERT BOLTS THROUGH BOLT HOLES AND INTO CONNECTION HOLES
1040
TIGHTEN BOLTS TO MATE SURFACES OF STATOR SEGMENTS
1050
NO
STATOR LENGTH MET?
1060
YES
ATTACH FLANGES
1070

FIG. 10

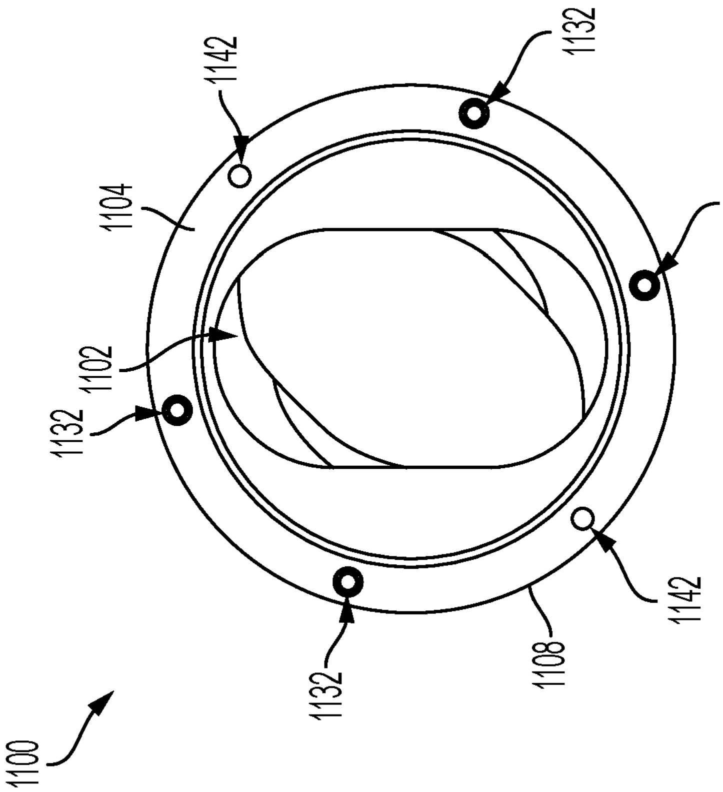

FIG. 11A

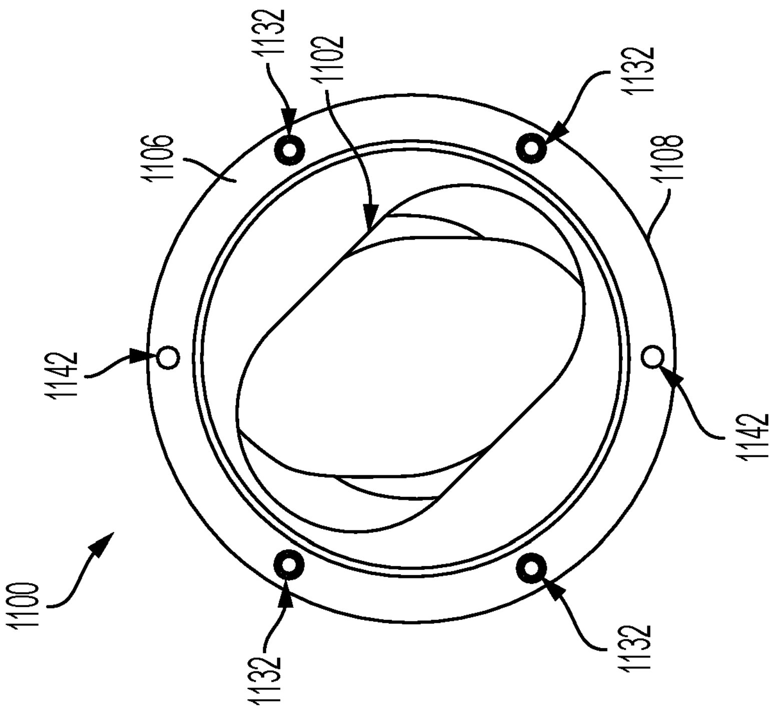

FIG. 11B

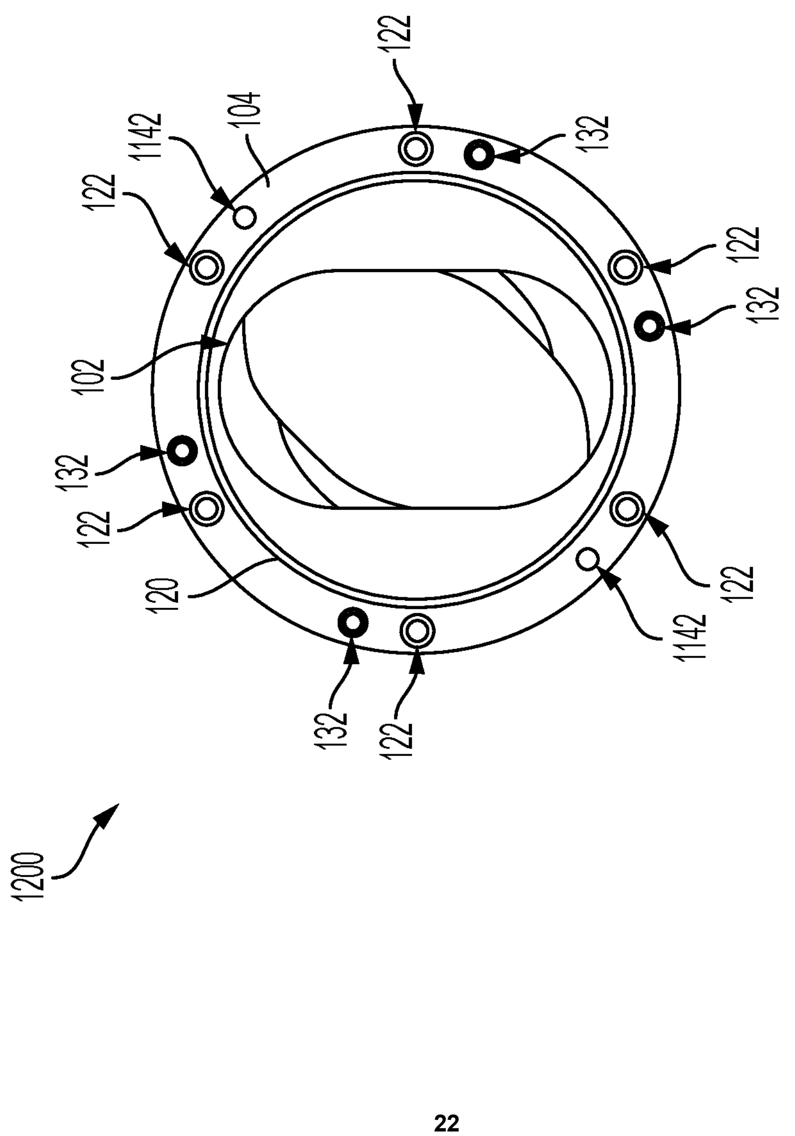

FIG. 12A

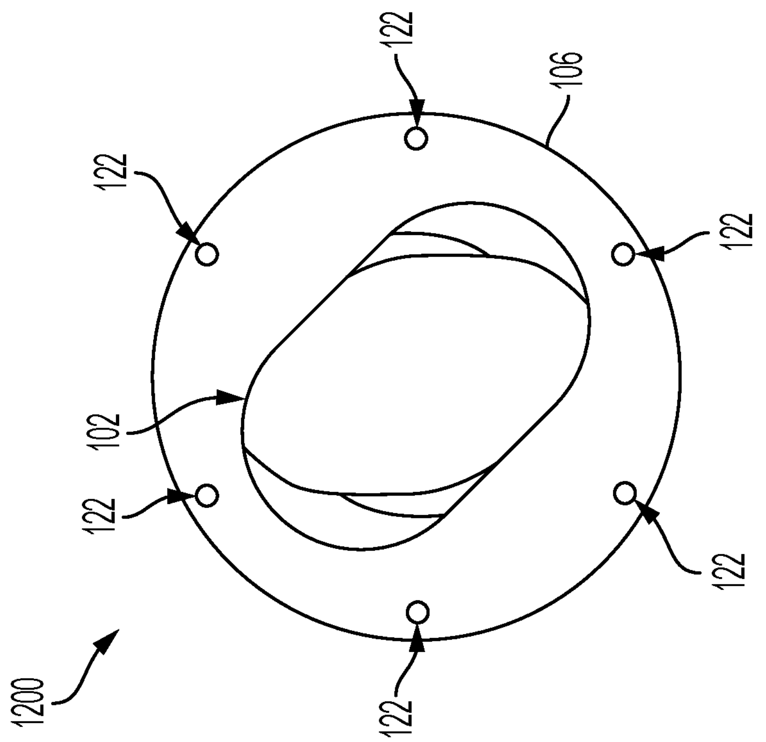

FIG. 12B

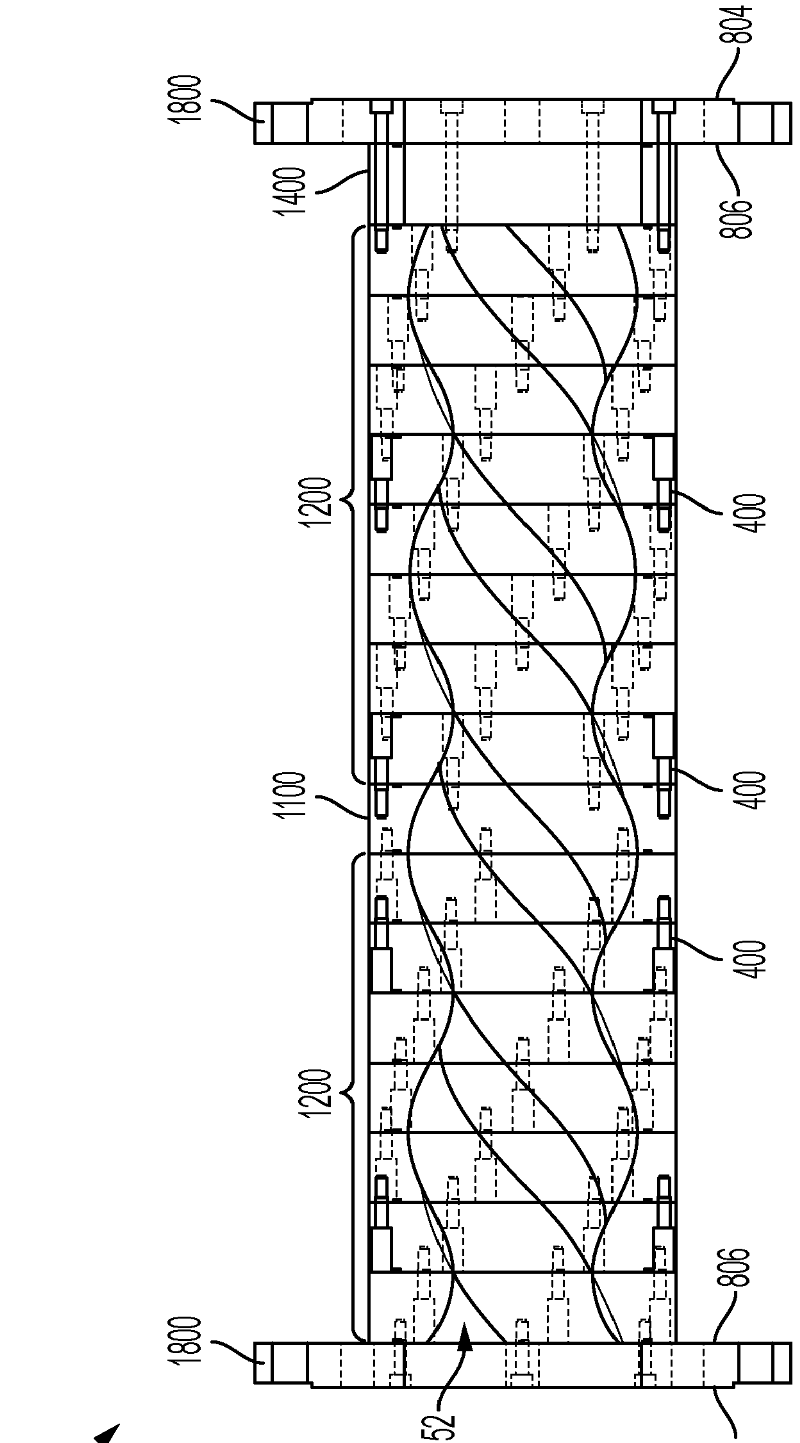
1800
804
806
1400
1200
400
400
1100
400
1200
1800
806
152
804
1300

FIG. 13

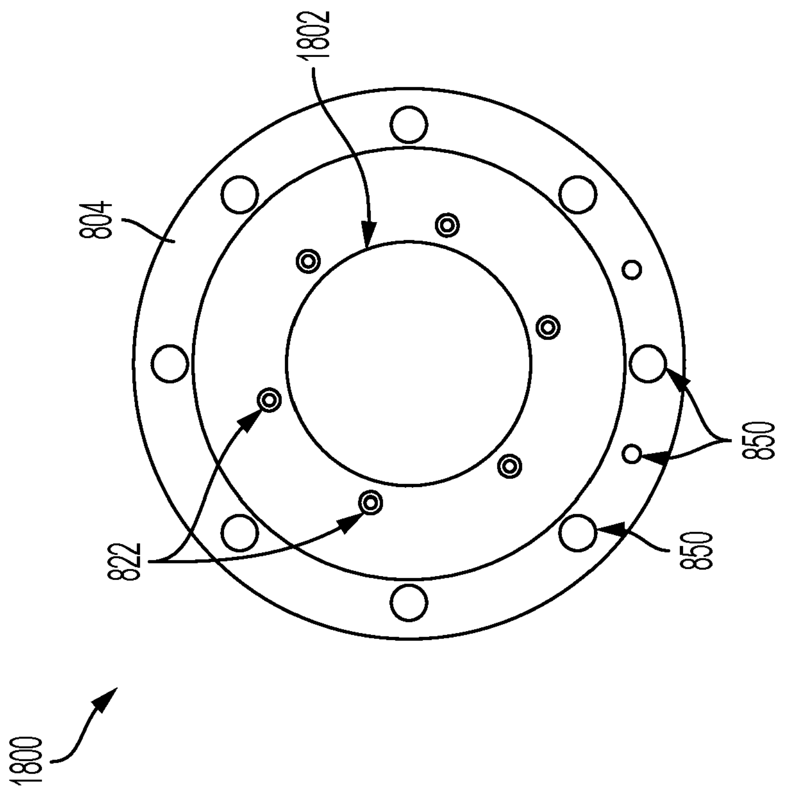

FIG. 14A

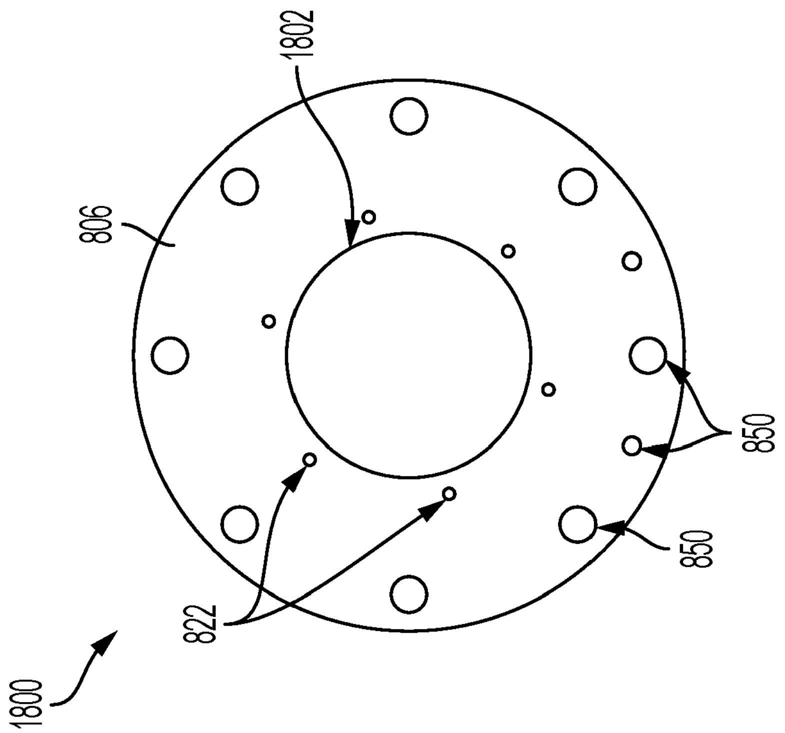

FIG. 14B

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EUROPEAN SEARCH REPORT

Application Number
EP 24 15 1843

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 2018/222490 A1 (PENN UNITED TECH INC [US]) 6 December 2018 (2018-12-06) * the whole document * -----	1-15	INV. F04C2/107
A	US 2006/182643 A1 (DELPASSAND MAJID S [US] ET AL) 17 August 2006 (2006-08-17) * the whole document * -----	1-15	
A	DE 10 2020 111613 A1 (DORSTEWITZ ANJA [DE]) 4 November 2021 (2021-11-04) * the whole document * -----	1-15	
A	US 2010/284842 A1 (JAGER SEBASTIAN [DE]) 11 November 2010 (2010-11-11) * the whole document * -----	1-15	

TECHNICAL FIELDS SEARCHED (IPC)

F04C

The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
Munich	5 June 2024	Alquezar Getan, M

CATEGORY OF CITED DOCUMENTS

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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 24 15 1843

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05-06-2024

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WO 2018222490 A1	06-12-2018	NONE	
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		US 2010284842 A1	11-11-2010

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