(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
11 October 2012 (11.10.2012)

WIPO | PCT

(10) International Publication Number
WO 2012/138545 A2

(51) International Patent Classification:
F04D 29/048 (2006.01) *F04D 1/06* (2006.01)
F04D 29/08 (2006.01) *F04D 29/58* (2006.01)

(21) International Application Number:
PCT/US2012/031240

(22) International Filing Date:
29 March 2012 (29.03.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/473,467 8 April 2011 (08.04.2011) US

(71) Applicant *(for all designated States except US)*: **DRESSER-RAND COMPANY** [US/US]; 1101 Paul Clark Drive, P.O. Box 560, Olean, New York 14760 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **TECZA, Joseph A.** [US/US]; 4304 Fuller Avenue, Scio, New York 14880 (US). **KIDD, H. Allan** [US/US]; 984 Bell Run Rd, Shinglehouse, Pennsylvania 16748 (US).

(74) Agents: **NOLTE, N. Alexander** et al.; Edmonds & Nolte, PC, 10411 Westheimer Road, Suite 201, Houston, Texas 77042 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

(54) **Title**: CIRCULATING DIELECTRIC OIL COOLING SYSTEM FOR CANNED BEARINGS AND CANNED ELECTRONICS

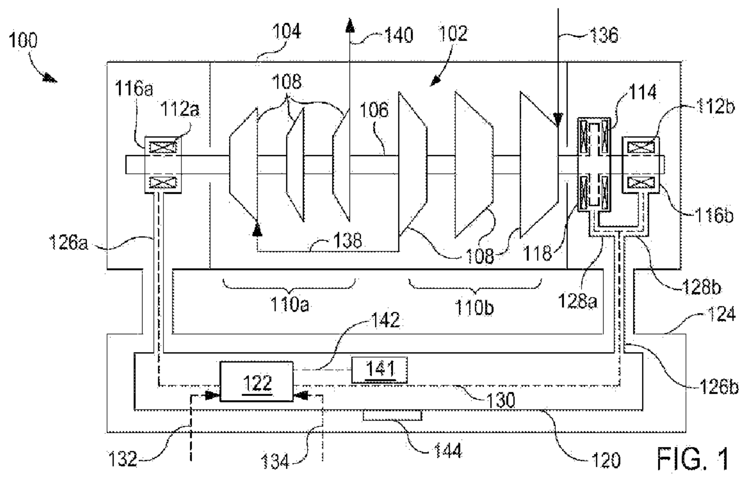

FIG. 1

(57) **Abstract**: A cooling system for a rotating machine, such as a centrifugal compressor. Specifically, the cooling system may be configured to cool radial and axial magnetic bearings in the rotating machine and the bearing control system that controls said bearings. The cooling system includes canned magnetic radial bearings on each end of the rotor and a canned bearing control system. The canned bearings and canned bearing control system may be filled with a dielectric cooling fluid and in fluid communication with each other via sealed conduits. Accordingly, the radial magnetic bearings and the bearing control system may be entirely immersed in the dielectric cooling fluid to regulate heat generation. An axial magnetic bearing may also be canned and fluidly coupled to the cooling system to immerse the axial magnetic bearing in the dielectric cooling fluid.

WO 2012/138545 A2

CIRCULATING DIELECTRIC OIL COOLING SYSTEM FOR CANNED BEARINGS AND CANNED ELECTRONICS

Background

[0001] This application claims priority to U.S. Patent Application Serial No. 61/473,467, which was filed April 8, 2011. This priority application is hereby incorporated by reference in its entirety into the present application, to the extent that it is not inconsistent with the present application.

[0002] Magnetic bearings are used to levitate and support a rotor in a magnetic field and simultaneously provide stiffness and damping to the rotor. In some applications, especially subsea applications, magnetic bearings are often sealed within a housing or chamber to protect the bearings from external contamination. For example, bearings in subsea applications are constantly threatened by the ingress of sea water or other corrosive fluids that could prove fatal to the bearings if not adequately protected by the housing. Such a sealed bearing is generally known as a "canned" bearing.

[0003] The housing of a canned bearing also serves to protect the magnetic bearing from damaging external pressures. To prevent implosion or structural collapse from increased external pressures, the housing is often filled with a "potting material" such as a resin or an epoxy. The potting material fills in the voids around the poles, coils, windings, and instrumentation of the magnetic bearings, such as the position and temperature sensors, and hardens to form a solid structure. The potting material not only provides structural support to the housing to resist pressure escalations, but also acts as an electrical and thermal insulator for the bearings.

[0004] One drawback to conventional canned magnetic bearings, however, is the need to replace the entire bearing when an integral component fails. Because the potting material forms a hardened structure all about the magnetic bearing, simple repairs or replacements of bearing components, such as coils or poles, is essentially impossible. Instead, the canned magnetic bearing must be disposed of and replaced with a new bearing. Another drawback to conventional canned magnetic bearings is a poor heat transfer capacity. While magnetic bearings do not generate enormous amounts of heat, it is nonetheless beneficial to remove bearing heat in order to extend the life of the bearing. Canned magnetic bearings with potting material, however, depend heavily on conduction heat transfer which can be relatively inefficient since the heat is required to pass through the insulating potting material before being transferred to the external environment.

[0005] What is needed, therefore, is a cooling system for canned magnetic bearings that overcomes the disadvantages described above, and still provides for adequate support for the magnetic bearing.

Summary

[0006] Embodiments of the disclosure may provide a cooling system for a rotating machine. The cooling system may include a first radial bearing housing arranged about a rotor and having a first radial magnetic bearing sealed therein for levitating the rotor, and a second radial bearing housing arranged about the rotor and having a second radial magnetic bearing sealed therein for levitating the rotor. The cooling system may further include a sealed controller can fluidly coupled to the first and second radial bearing housings and having a bearing control system disposed therein, and a coolant within the first and second radial bearing housings and the controller can such that the first and second radial magnetic bearings and the bearing control system are immersed in the coolant.

[0007] Embodiments of the disclosure may further provide a method for cooling a rotating machine. The method may include arranging a first radial bearing housing about a rotor, the first radial bearing housing having a first radial magnetic bearing sealed therein for levitating the rotor, and arranging a second radial bearing housing about the rotor, the second radial bearing housing having a second radial magnetic bearing sealed therein for levitating the rotor. The method may further include fluidly and sealingly coupling a controller can to the first and second radial bearing housings, the controller can having a bearing control system disposed therein, and immersing the first and second radial magnetic bearings and the bearing control system in a dielectric liquid coolant.

[0008] Embodiments of the disclosure may further provide another cooling system for a rotating machine. The other cooling system may include a first radial bearing housing arranged about a rotor and having a first radial magnetic bearing sealed therein for levitating the rotor, a first sealed conduit extending from the first radial bearing housing, and a second radial bearing housing arranged about the rotor and having a second radial magnetic bearing sealed therein for levitating the rotor. The cooling system may also include a second sealed conduit

extending from the second radial bearing housing, and a controller can having a bearing control system disposed therein, the controller can being coupled to the first and second sealed conduits with first and second connectors that provide a pressure boundary between the controller can and the first and second sealed conduits. The cooling system may further include wiring extending from the bearing control system to the first and second radial bearing housings via the first and second sealed conduits, respectively, and a first coolant within the first and second radial bearing housings and the first and second sealed conduits, the first and second radial magnetic bearings and the wiring within the first and second sealed conduits being immersed in the first coolant. Lastly, the cooling system may include a second coolant within the controller can such that the bearing control system and wiring within the controller can are immersed in the second coolant.

Brief Description of the Drawings

[0009] The present disclosure is best understood from the following detailed description when read with the accompanying Figures. It is emphasized that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

[0010] Figure 1 illustrates a first cooling system for a rotating machine, according to one or more embodiments disclosed.

[0011] Figure 2 illustrates a second cooling system for a rotating machine, according to one or more embodiments disclosed.

[0012] Figure 3 illustrates a flowchart of a method for cooling a rotating machine, according to one or more embodiments disclosed.

[0013] Figure 4 illustrates a third cooling system for a rotating machine, according to one or more embodiments disclosed.

[0014] Figure 5 illustrates a partial end view of the cooling system of Figure 2, according to one or more embodiments disclosed.

[0015] Figure 6 illustrates an alternative partial end view of the cooling system of Figure 2, according to one or more embodiments disclosed.

Detailed Description

[0016] It is to be understood that the following disclosure describes several exemplary embodiments for implementing different features, structures, or functions of the invention. Exemplary embodiments of components, arrangements, and configurations are described below to simplify the present disclosure; however, these exemplary embodiments are provided merely as examples and are not intended to limit the scope of the invention. Additionally, the present disclosure may repeat reference numerals and/or letters in the various exemplary embodiments and across the Figures provided herein. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various exemplary embodiments and/or configurations discussed in the various Figures. Moreover, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed interposing the first and second features, such that the first and second features may not be in direct contact. Finally, the exemplary embodiments presented below may be combined in any combination of ways, *i.e.*, any element from one exemplary embodiment may be used in any other exemplary embodiment, without departing from the scope of the disclosure.

[0017] Additionally, certain terms are used throughout the following description and claims to refer to particular components. As one skilled in the art will appreciate, various entities may refer to the same component by different names, and as such, the naming convention for the elements described herein is not intended to limit the scope of the invention, unless otherwise specifically defined herein. Further, the naming convention used herein is not intended to distinguish between components that differ in name but not function. Additionally, in the following discussion and in the claims, the terms "including" and "comprising" are used in an open-ended fashion, and thus should be interpreted to mean "including, but not limited to." All numerical values in this disclosure may be exact or approximate values unless otherwise specifically stated. Accordingly, various embodiments of the disclosure may deviate from the numbers, values, and ranges disclosed herein without departing from the intended scope. Furthermore, as it is used in the claims or specification, the term "or" is intended to encompass both exclusive and inclusive cases, *i.e.*, "A or B" is intended to be synonymous with "at least one of A and B," unless otherwise expressly specified herein.

[0018] Figure 1 illustrates an exemplary cooling system 100 for a rotating machine 102, according to one or more embodiments disclosed herein. In one embodiment, the rotating machine 102 may be a multistage centrifugal compressor, but in other embodiments, the rotating machine 102 may be any other type of rotating machinery, such as a canned pump or a turbine. As illustrated, the rotating machine 102 may include a casing 104 adapted to house the machine 102 components.

[0019] A rotor 106 may be arranged within the casing 104 and extend substantially the whole length thereof. In the case where the rotating machine 102 is a compressor, a plurality of impellers 108 may be mounted to the rotor 106 for rotation therewith. As illustrated, a total of six impellers 108 are mounted to the rotor 106, but it will be appreciated that any number of impellers 108 may be used without departing from the scope of the disclosure. The impellers 108 may be arranged in a back-to-back configuration, as illustrated, having a low pressure side 110b and a high pressure side 110a.

[0020] The rotor 106 may be supported or otherwise suspended for rotation by a first radial bearing 112a and a second radial bearing 112b positioned at or near the terminating ends of the rotor 106. In other embodiments, however, the rotor 106 may be supported with additional radial bearings positioned along the length of the rotor 106. Each radial bearing 112a,b may support to the rotor 106 and the successive stages of impellers 108 and provide dampening of rotordynamic anomalies. In one embodiment, each radial bearing 112a,b may be an active magnetic bearing. In other embodiments, however, one of the radial bearings 112a,b may be a passive magnetic bearing while the other is an active magnetic bearing. In addition, at least one axial thrust bearing 114 may be provided on the rotor 106 and positioned at or near an end thereof. In one embodiment, the axial thrust bearing 114 may be an active magnetic bearing and be configured to bear axial thrusts generated by the impellers 108. In other embodiments, the axial thrust bearing 114 may be a passive magnetic bearing. As illustrated, the axial thrust bearing 114 is arranged inboard from the second radial bearing 112b. In other embodiments, however, the axial thrust bearing 114 may be arranged outboard of the second radial thrust bearing 112b, without departing from the disclosure.

[0021] The cooling system 100 may include a first and second radial bearing housings 116a and 116b for housing the first and second radial bearings 112a and 112b, respectively. The cooling system 100 may further include an axial bearing housing 118 configured to house the axial thrust bearing 114. Each bearing housing 116a,b and 118 may be fluid-tight containers configured to seal the bearings 112a,b and 114 therein and shield the bearings from external contaminants such as process gas, liquids, oils, etc., which may potentially damage the bearings 112a,b and 114. Accordingly, each of the bearings 112a,b and 114 may be characterized as a type of "canned" bearing, where the bearing housings 116a,b and 118 are directly or indirectly supported by the casing 104.

[0022] The cooling system 100 may further include a controller can 120 adapted to house or otherwise seal a bearing control system 122 therein. Accordingly, the bearing control system 122 may be characterized as a canned bearing control system. In one embodiment, the controller can 120 may be housed or otherwise arranged in a separate portion 124 of the casing 104 but nonetheless in fluid communication with the remaining portions of the casing 104. In other embodiments, the controller can 120 may be arranged external to the casing 104, such as being attached to the exterior of the casing 104 or arranged proximal thereto.

[0023] The controller can 120 may be in fluid communication with each bearing housing 116a,b and 118 via first and second sealed conduits 126a and 126b. In other words, the controller can may be fluidly and sealingly coupled to each bearing housing 116a,b. As illustrated, the second sealed conduit 126b may be split and form two additional sealed conduits 128a and 128b that fluidly connect to the axial bearing housing 118 and the second radial bearing housing 116b, respectively. In one embodiment, the sealed conduits 126a and 128a,b may be coupled to the corresponding bearing housings 116a, 118, and 116b with compression fittings or flange connections. In other embodiments, however, the sealed conduits 126a and 128a,b may be welded directly to the corresponding bearing housings 116a, 118, and 116b. In yet other embodiments, the various connections may be made with a combination of compression fittings, flange connections, and/or welding. Likewise, each sealed conduit 126a,b may be coupled to the controller can 120 with compression fittings, flange connections, welding, or combinations thereof.

[0024] The bearings 112a,b and 114 may be controlled jointly or separately by the bearing control system 122. To accomplish this, the bearing control system 122 may be communicably coupled to one or all of the bearings 112a,b and 114 via wiring 130 that extends from the bearing control system 122, through each sealed conduit 126a,b and 128a,b, and eventually to each bearing 112a,b and 114. The wiring 130 also provides the necessary power to operate the bearings 112a,b and 114. External power is provided to the bearing control system 122 via line 132 may penetrate the separate portion 124 of the casing 104 and the controller can 120.

Also, a communications link 134 may be provided to the control system 122 to supply instructions for the operation of the bearings 112a,b and 114 and to report general conditions of the system 100 to a user. In one embodiment, the communications link 134 may be an Ethernet link, or any other suitable communications link. In other embodiments, however, the communications link 134 does not penetrate the casing 104 or controller can 120, but instead communication signals may be sent and received via a light source through a quartz or glass window (*e.g.*, a fiber optic window) integrally-formed into the casing 104.

[0025] In operation, the rotor 106 is driven and the impellers 108 simultaneously rotate. A process gas may be introduced into the machine 102 via an inlet 136. The process gas may include, but is not limited to, a mixture of hydrocarbon gas, such as natural gas or methane derived from a production field or via a pressurized pipeline. In other embodiments, the process gas may include air, CO_2, N_2, ethane, propane, i-C_4, n-C_4, i-C_5, n-C_5, and/or combinations thereof. The impellers 108 in the low pressure side 110b may be configured to receive the process gas and direct a partially pressurized process gas to the high pressure side 110a via a conduit 138. The impellers 108 in the high pressure side 110a may be configured to increase the pressure of the process gas received from the low pressure side 110b and discharge a high pressure process gas from the casing 104 via a discharge 140.

[0026] As the rotor 106 rotates, heat may be generated by one or more of the bearings 112a,b and 114 and/or the bearing control system 122. To reduce or otherwise dissipate the heat generated, the bearing housings 116a,b and 118 and the controller can 120 may each be filled with a coolant. Consequently, the bearings 112a,b and 114 and the bearing control system 122 may be entirely immersed in the coolant. The sealed conduits 126a,b 128a,b may also be filled with the coolant, thereby entirely immersing the wiring 130 and also providing fluid communication between the bearing housings 116a,b and 118 and the controller can 120.

[0027] In one embodiment, the coolant is a dielectric liquid coolant, such as FLUORINERT® cooling liquids commercially-available from 3M®. In other embodiments, the dielectric liquid coolant may include mineral oil, silicone oil, natural ester-based oils (including soybean-based oils), synthetic ester-based oils, TRANSIL™ oils, BETA FLUID™ (available from Dielectric Systems, Inc.), ENVIROTEMP® (available from Cooper Power Systems, Inc.), and/or combinations thereof or the like. In yet other embodiments, the coolant is a dielectric fluid that is a gas such as, but not limited to, clean air, nitrogen, and other inert gases (*e.g.*, argon or neon).

[0028] The bearings 112a,b and 114 and the control system 122 may be cooled by convection heat transfer through the surrounding coolant throughout the cooling system 100. The coolant may transfer any generated heat to the bearing housings 116a,b and 118 and the controller can 120 to be transferred to the external environment. In one embodiment, an in-line pump 140 may be included in the cooling system 100 to circulate the coolant and thereby increase the heat transfer rate. In other embodiments, any suitable pump may be used to circulate the coolant, such as a blower. The pump 141 may be arranged in any part of the system 100, but may in at least one embodiment be placed in the controller can 120. The pump 141 may be powered and controlled by the control system 122 via line 142.

[0029] The fluid pressure in the cooling system 100 may be regulated with at least one pressure equalizer 144. In one embodiment, the pressure equalizer 144 may be coupled to the controller can 120 and powered and controlled by the control system 122. The pressure equalizer 144 may include any type of pressure equalizing or regulating device, such as an equalizing bellows or the like.

[0030] In operation, the pressure equalizer 144 may be configured to maintain the pressure in the controller can 120 and bearing housings 116a,b and 118 generally equal to the inlet pressures of the rotating machine 102. As the pressure equalizer 144 operates, the pressure in the cooling system 100 is maintained such that there is little or no net pressure differential between the interior of the casing 104 and the interior of controller can 120 and bearing housings 116a,b and 118. Consequently, the pressure equalizer 144 may be configured to prevent the implosion of the controller can 120 and bearing housings 116a,b and 118 by external pressures present in the interior of the casing 104 and surrounding environment.

[0031] Referring now to Figure 2, illustrated is another exemplary cooling system 200 that may be implemented to cool portions of the rotating machine 102, according to one or more embodiments disclosed. The cooling system 200 is similar in several respects to the cooling system 100 of Figure 1. Accordingly, the cooling system 200 may be best understood with reference to Figure 1, where like numerals correspond to like components and therefore will not be described again in detail. Similar to the cooling system 100 described above, the bearing housings 116a,b and 118 may be filled with a coolant, such as a dielectric fluid, thereby immersing the bearings 112a,b and 114 in the coolant to regulate the temperature of each bearing 112a,b and 114. In one embodiment, the dielectric fluid is a dielectric liquid coolant, such as those described above with reference to Figure 1. The sealed conduits

126a,b may also be filled with the dielectric fluid, thereby providing fluid communication between the first sealed conduit 126a and the first radial bearing housing 116a, and fluid communication between the second sealed conduit 126b and the second radial bearing housing 116b and axial bearing housing 118.

[0032] The pressure in each bearing housing 116a,b and 118 may be regulated by one or more pressure equalizers, such as first and second pressure equalizers 202a and 202b. As illustrated, the pressure equalizers 202a,b may be fluidly coupled to the bearing housings 116a,b, respectively. In other embodiments, however, the pressure equalizers 202a,b may be fluidly coupled to any other portion of the cooling system 200 in fluid communication with the bearing housings 116a,b and 118. Similar to the pressure equalizer 144 described above with reference to Figure 1, the pressure equalizers 202a,b may include an equalizing bellows or other similar pressure regulating devices. In operation, the pressure equalizers 202a,b may be configured to prevent the general implosion of each bearing housing 116a,b and 118 by avoiding pressure differentials between the interior of the casing 104 and the interior of each bearing housing 116a,b and 118.

[0033] For example, the first radial bearing housing 116a may be pressurized by the first pressure equalizer 202a to withstand the surrounding, adjacent pressures within the casing 104 or, in other words, the inlet pressure of the nearest impeller 108 in the high-pressure side 110a. Likewise, the second radial bearing housing 112b and axial bearing housing 118 may be pressurized by the second pressure equalizer 202b to withstand the surrounding, adjacent pressures within the casing 104 or, in other words, the inlet pressure of the nearest impeller 108 in the low-pressure side 110b (*e.g.*, the fluid pressure of the inlet 136).

[0034] The cooling system 200 may also include connectors 204a and 204b that couple the controller can 120 to the first and second sealed conduits 126a and 126b, respectively. Each connector 204a,b may be configured as a pressure boundary that separates the coolant in the bearing housings 116a,b and 118 from a different coolant within the controller can 120. For example, the controller can 120 may be filled with a gas that immerses the bearing control system 122 in a benign, non-corrosive environment. In one embodiment, the gas within the controller can 120 may also be a dielectric fluid, such as clean air, nitrogen, or other inert gases (*e.g.*, argon) that facilitate convection heat transfer from the bearing control system 122 to the external environment.

[0035] The pressure equalizer 144 may be used to equalize the pressure the controller can 120 to the pressure within the separate portion 124 of the casing 104, thereby avoiding potential implosion of the controller can 120. In other embodiments, however, the pressure equalizer 144 may maintain the pressure in the controller can 120 at approximately ambient pressure, thereby protecting the bearing control system from damage caused by extreme pressures. Such an embodiment may prove advantageous in applications where the bearing control system 122 is required to remain dry, but nonetheless kept in a non-corrosive environment at a specific pressure.

[0036] Referring now to Figure 3, illustrated is a flowchart of a method 300 for cooling a rotating machine. The method 300 may include arranging a first radial bearing housing about a first end of a rotor, as at 302. The first radial bearing housing may have a first radial magnetic bearing sealed therein for levitating the first end of the rotor. A second radial bearing housing may be arranged about a second end of the rotor, as at 304. The second radial bearing housing may have a second radial magnetic bearing sealed therein for levitating the second end of the rotor. The method may further include fluidly coupling a controller can to the first and second radial bearing housings, as at 306. In one embodiment, the controller can has a bearing control system disposed therein for controlling the first and/or second radial bearings. The first and second radial magnetic bearings and the bearing control system may then be immersed in a dielectric liquid coolant, as at 308. The dielectric liquid coolant may be configured to facilitate convection heat transfer from the bearings and bearing control system to the external environment.

[0037] Referring now to Figure 4, illustrated is another exemplary cooling system 400 that may be implemented to cool portions of the rotating machine 102. The cooling system 400 is similar in several respects to the cooling systems 100 and 200 of Figures 1 and 2, respectively, and therefore may be best understood with reference to Figures 1 and 2, where like numerals correspond to like components and therefore will not be described again in detail. The rotating machine 102 of the cooling system 400 may be a straight-through compressor or pump having a plurality of impellers 108 (in this case, six) configured to successively compress a process gas. The number of impellers 108 may be more or less than illustrated, depending on the application or size of the machine 102. As with prior embodiments, the process gas enters the stages of impellers 108 via the suction inlet 136 and exits the rotating machine 102 via the discharge 140.

[0038] The cooling system 400 may also have the axial thrust bearing 114 disposed outboard from the second radial bearing 112b, such that the sealed conduit 128a is fluidly coupled to the second radial bearing housing 116a and the sealed conduit 128b is fluidly coupled to the axial bearing housing 118. In other embodiments, the axial thrust bearing 114 may be arranged on the opposite side of the machine 102 and axially adjacent the first radial bearing 112a.

[0039] It will be appreciated that the features of the system 400 described above may be equally applicable in any of the systems disclosed herein. Also, any combination of the several features of the systems described herein may be had in any single embodiment, without departing from the scope of the disclosure.

[0040] Referring to Figure 5, illustrated is a partial end view of the first radial bearing 112a enclosed in the first radial bearing housing 116a, taken along the lines shown in Figure 2. Also shown is a cross-sectional view of the rotor 106 surrounded by the first radial bearing 112a. Specifically, the radial bearing housing 116a has an inside surface 502 and an outer surface 504, where the inside surface 502 is radially-offset from the rotor 106. It will be appreciated that the following discussion, elements, and processes will be equally applicable to the second radial bearing 112b and accompanying second radial bearing housing 116a. Moreover, the elements and processes described below with reference to Figure 5 may also be applied to the axial thrust bearing 114 and accompanying thrust bearing housing 118, without departing from the scope of the disclosure.

[0041] In the illustrated embodiment, the first sealed conduit 126a may include or otherwise be shown as parallel sealed conduits 506a and 506b, each fluidly coupled to the bearing housing 116a and terminating at parallel connectors 508a and 508b. The parallel connectors 508a,b may be substantially similar to the first connector 204a, as described above with reference to Figure 2, and may couple the corresponding parallel sealed conduits 506a,b to the controller can 120 (not shown).

[0042] The radial bearing 112a may be an active magnetic bearing having a plurality of coils 510 (four shown) circumferentially-spaced about the inner-radial surface thereof. The coils 510 may be provided with power for levitating the shaft via the wiring 130. Specifically, the wiring 130 extends from each coil 510 through either sealed conduit 506a,b and corresponding connector 508a,b. Once extended through either connector 508a,b, the wiring 130 may be directed to the bearing control system 122, as described above with reference to Figures 1 and 2.

[0043] The wiring 130 may further include sensor wiring 512 extending from a pair of sensors 514 disposed within the radial bearing housing 116a. As known in the art, the sensors 514 may be configured to sense the general location of the rotor 106 and send signals to the bearing control system 122 to adjust the power output from various coils 510 in order to maintain the rotor 106 centrally-located within the radial bearing 112a. Accordingly, the sensor wiring 512 may extend through either sealed conduit 506a,b and corresponding connector 508a,b and thereafter be directed to the bearing control system 122.

[0044] The radial bearing 112a may be cooled by natural convection within the bearing housing 116a which rejects heat to the exterior. To aid in the natural convection process, the radial bearing housing 116a may be fluidly coupled to a pump 514 and a heat exchanger 516. The pump 514 may be configured to circulate the coolant throughout the bearing housing 116a and sealed conduits 506a,b, as indicated by arrows A. The heat exchanger 516 may be any device adapted to reduce the temperature of a fluid such as, but not limited to, a direct contact heat exchanger, a gas-to-gas heat exchanger, a trim cooler, a mechanical refrigeration unit, and/or any combination thereof. Accordingly, as the coolant is circulated with the pump 514, it is simultaneously cooled in the heat exchanger 516 and helps to pull heat away from the radial bearing 112a by forced convection cooling.

[0045] Referring now to Figure 6, illustrated is another partial end view of the first radial bearing 112a enclosed in the first radial bearing housing 116a, taken along the lines shown in Figure 2. Figure 6 may be best understood with reference to Figures 1, 2, and 5, where like numerals correspond to like elements and therefore will not be described again in detail. The radial bearing housing 116a shown in Figure 6 may be fluidly coupled to a natural convection loop 602 configured to cool the coolant within the bearing housing 116a. The convection loop 602 may include a warm fluid line 604 fluidly coupled to a heat exchanger 606 and adapted to direct warmed coolant from the bearing housing 116a to the heat exchanger 606 for cooling. The heat exchanger 606 may be substantially similar to the heat exchanger 516 described above with reference to Figure 5. The heat exchanger 606 may discharge a cooled coolant into a cooled fluid line 608 which directs the coolant back into the bearing housing 116a to circulate as indicated by arrows B.

[0046] Baffling and flow passages (not shown) may also be included in the bearing housing 116a to distribute the coolant and maximize convection heat transfer. In one embodiment, the heat exchanger 606 may be located externally from the casing 104 (Figures 1, 2, and 5) and rely on the environment to cool the coolant. This may be particularly advantageous in subsea applications where the sea water may be used to cool the coolant in a heat exchanger receiving sea water as a cooling medium. In other embodiments, the heat exchanger 606 may be in fluid communication with a process gas of the rotating machine 102 (Figures 1, 2, and 5). For example, the heat exchanger 606 may be a gas-to-gas heat exchanger and adapted to receive the process fluid and transfer heat from the coolant to the process gas in order to cool the coolant. The source of the process gas may be the suction process gas at the suction inlet 136 (Figures 1, 2, and 5), but in other embodiments, the source of the process gas may be the discharge process gas exiting the rotating machine 102 via the discharge outlet 140 (Figures 1, 2, and 5).

[0047] The foregoing has outlined features of several embodiments so that those skilled in the art may better understand the present disclosure. Those skilled in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions and alterations herein without departing from the spirit and scope of the present disclosure.

Claims

We claim:

1. A cooling system for a rotating machine, comprising:

a first radial bearing housing arranged about a rotor and having a first radial magnetic bearing sealed therein for levitating the rotor;

a second radial bearing housing arranged about the rotor and having a second radial magnetic bearing sealed therein for levitating the rotor;

a sealed controller can fluidly coupled to the first and second radial bearing housings and having a bearing control system disposed therein; and

a coolant within the first and second radial bearing housings and the controller can such that the first and second radial magnetic bearings and the bearing control system are immersed in the coolant.

2. The system of claim 1, wherein the coolant within the first and second radial bearing housings is a dielectric cooling liquid and the coolant within the controller can is a dielectric gas.

3. The system of claim 1, wherein the coolant is a dielectric cooling liquid.

4. The system of claim 1, further comprising:

a first sealed conduit providing fluid communication between the controller can and the first radial bearing housing;

a second sealed conduit providing fluid communication between the controller can and the second radial bearing housing; and

wiring extending from the bearing control system to the first and second radial bearing housings via the first and second sealed conduits, respectively, the wiring being immersed in the coolant and configured to control the first and second radial magnetic bearings.

5. The system of claim 4, wherein the second sealed conduit is split to form a third sealed conduit and a fourth sealed conduit, the fourth sealed conduit being in fluid communication with the second radial bearing housing.

6. The system of claim 5, further comprising an axial bearing housing arranged about the rotor and having an axial magnetic thrust bearing sealed therein and immersed in the coolant, the axial bearing housing being in fluid communication with the controller can via the third and second sealed conduits.

7. The system of claim 1, further comprising a pump disposed within the controller can and configured to circulate the coolant through the first and second radial bearing housings and the controller can.

8. The system of claim 1, further comprising a pressure equalizer configured to regulate fluid pressure inside the first and second radial bearing housings and the controller can.

9. The system of claim 8, wherein the pressure equalizer is an equalizing bellows.

10. A method for cooling a rotating machine, comprising:

arranging a first radial bearing housing about a rotor, the first radial bearing housing having a first radial magnetic bearing sealed therein for levitating the rotor;

arranging a second radial bearing housing about the rotor, the second radial bearing housing having a second radial magnetic bearing sealed therein for levitating the rotor;

fluidly and sealingly coupling a controller can to the first and second radial bearing housings, the controller can having a bearing control system disposed therein; and

immersing the first and second radial magnetic bearings and the bearing control system in a dielectric liquid coolant.

11. The method of claim 10, further comprising:

controlling the first and second radial bearings with the bearing control system, the bearing control system being communicably coupled to the first radial bearing via a first length of wiring that extends from the bearing control system through a first sealed conduit, the bearing control system also being communicably coupled to the second radial bearing via a second length of wiring that extends from the bearing control system through a second sealed conduit; and

immersing the first and second lengths of wiring in the dielectric liquid coolant.

12. The method of claim 11, further comprising circulating the dielectric liquid coolant with a pump through the first and second radial bearing housings and the controller can.

13. The method of claim 11, further comprising regulating a liquid pressure of the dielectric liquid coolant in the first and second radial bearing housings and the controller can with a pressure equalizer.

14. The method of claim 11, further comprising:

arranging an axial bearing housing about the rotor, the axial bearing housing having an axial magnetic thrust bearing sealed therein and in fluid communication with the controller can; and

immersing the axial magnetic thrust bearing in the dielectric liquid coolant.

15. A cooling system for a rotating machine, comprising:

a first radial bearing housing arranged about a rotor and having a first radial magnetic bearing sealed therein for levitating the rotor;

a first sealed conduit extending from the first radial bearing housing;

a second radial bearing housing arranged about the rotor and having a second radial magnetic bearing sealed therein for levitating the rotor;

a second sealed conduit extending from the second radial bearing housing;

a controller can having a bearing control system disposed therein, the controller can being coupled to the first and second sealed conduits with first and second connectors that provide a pressure boundary between the controller can and the first and second sealed conduits;

wiring extending from the bearing control system to the first and second radial bearing housings via the first and second sealed conduits, respectively;

a first coolant within the first and second radial bearing housings and the first and second sealed conduits, the first and second radial magnetic bearings and the wiring within the first and second sealed conduits being immersed in the first coolant; and

a second coolant within the controller can such that the bearing control system and wiring within the controller can are immersed in the second coolant.

16. The system of claim 15, wherein the first coolant is a dielectric cooling liquid.

17. The system of claim 15, wherein the second coolant is a dielectric gas.

18. The system of claim 15, further comprising:

a first pressure equalizer fluidly coupled to the first radial bearing housing and configured to regulate fluid pressure within the first radial bearing housing and the first sealed conduit; and

a second pressure equalizer fluidly coupled to the second radial bearing housing and configured to regulate fluid pressure within the second radial bearing housing and the second sealed conduit.

19. The system of claim 15, wherein the second sealed conduit is split to form a third sealed conduit and a fourth sealed conduit, the fourth sealed conduit being in fluid communication with the second radial bearing housing.

20. The system of claim 19, further comprising an axial bearing housing arranged about the rotor and having an axial magnetic thrust bearing sealed therein and immersed in the first coolant.

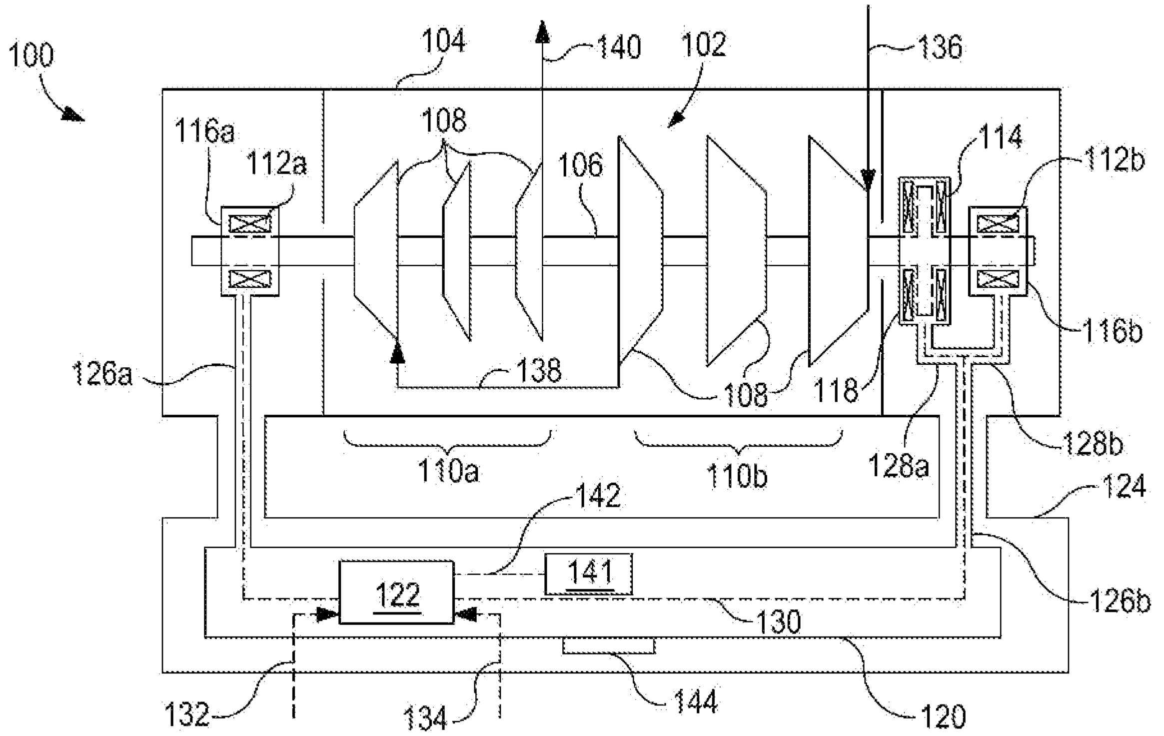
100
104
140
102
136
116a
112a
108
106
114
112b
116b
126a
138
108
118
128b
128a
110a
110b
124
142
122
141
126b
130
132
134
144
120

FIG. 1

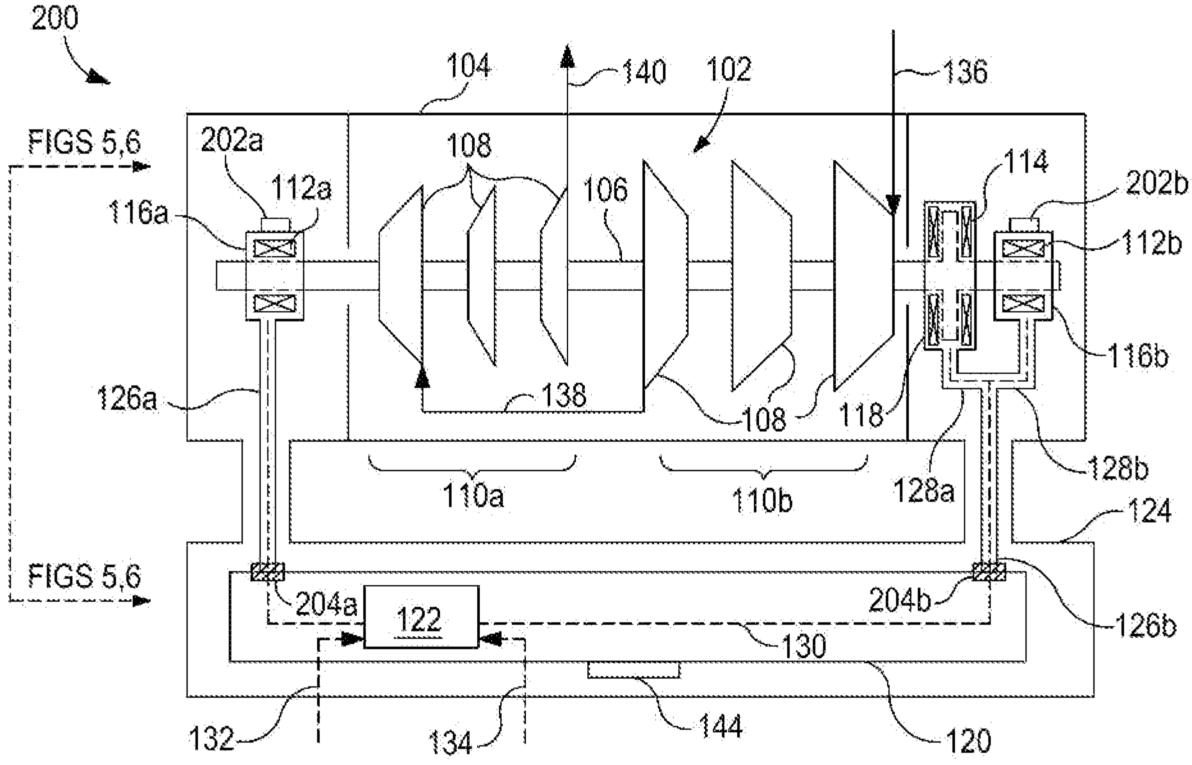
200
104
140
102
136
FIGS 5,6
202a
112a
108
106
114
202b
116a
112b
116b
126a
138
108
118
128b
128a
110a
110b
124
FIGS 5,6
204a
122
204b
126b
130
132
134
144
120

FIG. 2

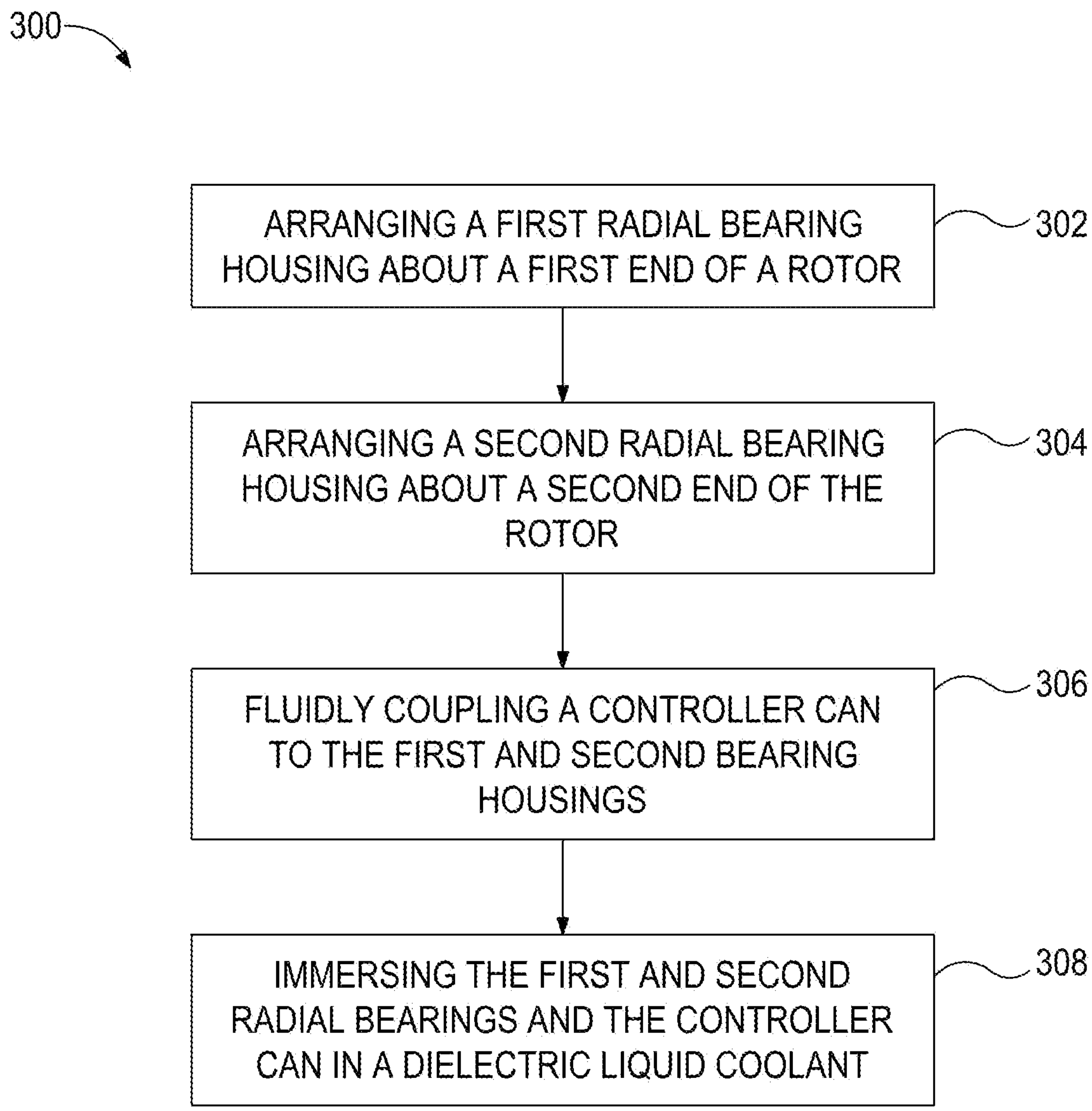
300
ARRANGING A FIRST RADIAL BEARING HOUSING ABOUT A FIRST END OF A ROTOR
302
ARRANGING A SECOND RADIAL BEARING HOUSING ABOUT A SECOND END OF THE ROTOR
304
FLUIDLY COUPLING A CONTROLLER CAN TO THE FIRST AND SECOND BEARING HOUSINGS
306
IMMERSING THE FIRST AND SECOND RADIAL BEARINGS AND THE CONTROLLER CAN IN A DIELECTRIC LIQUID COOLANT
308

FIG. 3

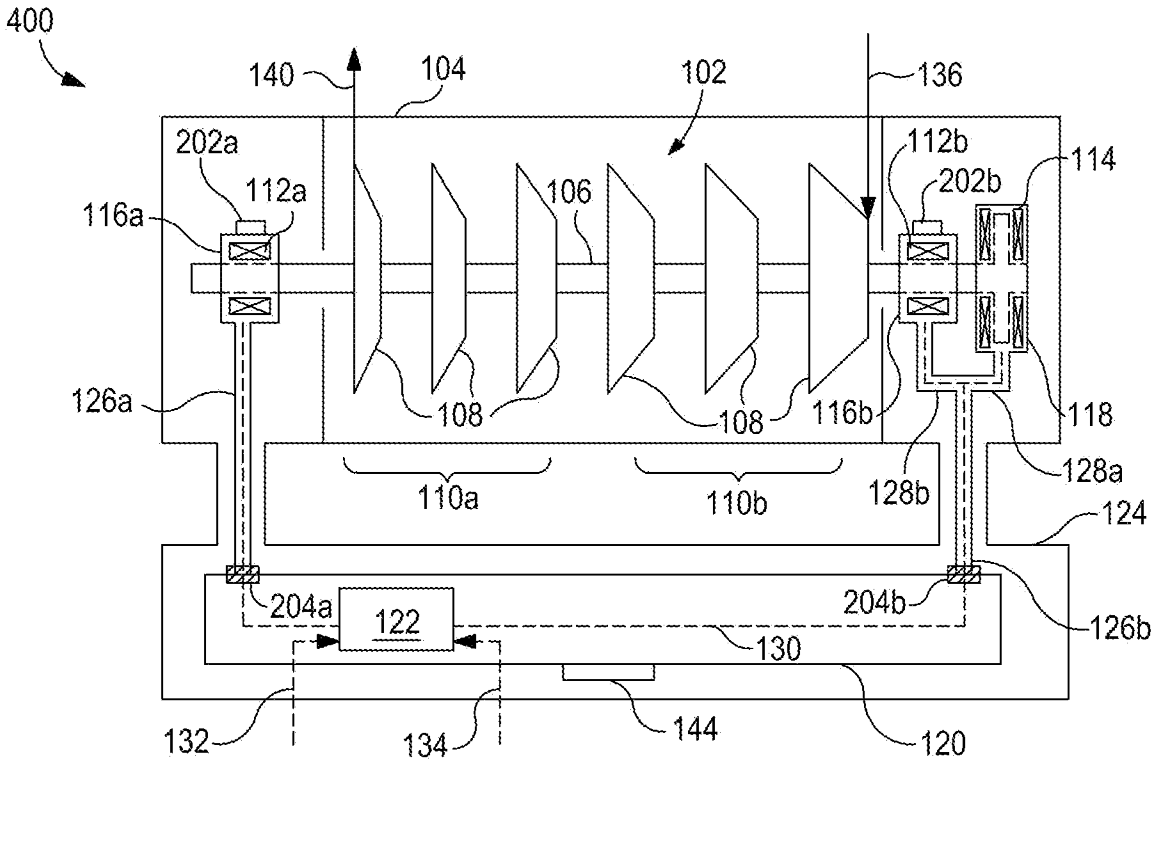
400
140
104
102
136
202a
112a
116a
106
112b
202b
114
126a
108
108
108
108
116b
118
110a
110b
128b
128a
124
204a
122
204b
126b
130
132
134
144
120

FIG. 4

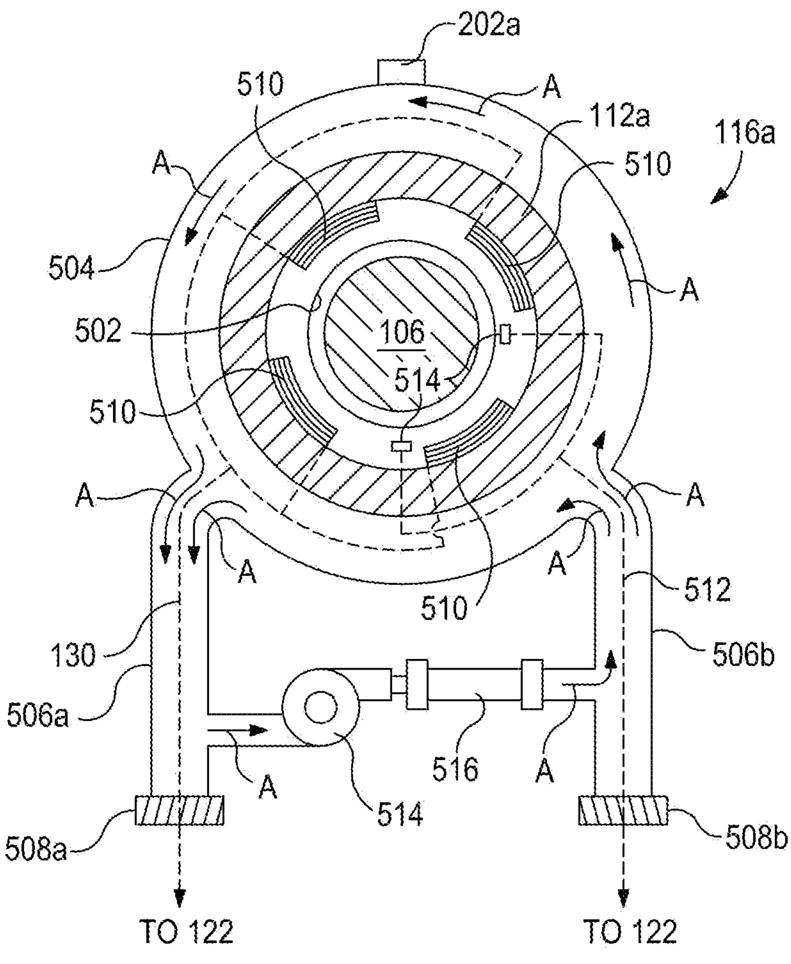
202a
510
A
112a
116a
510
A
504
A
502
106
514
510
A
A
A
A
510
512
130
506b
506a
516
A
A
514
508a
508b
TO 122
TO 122

FIG. 5

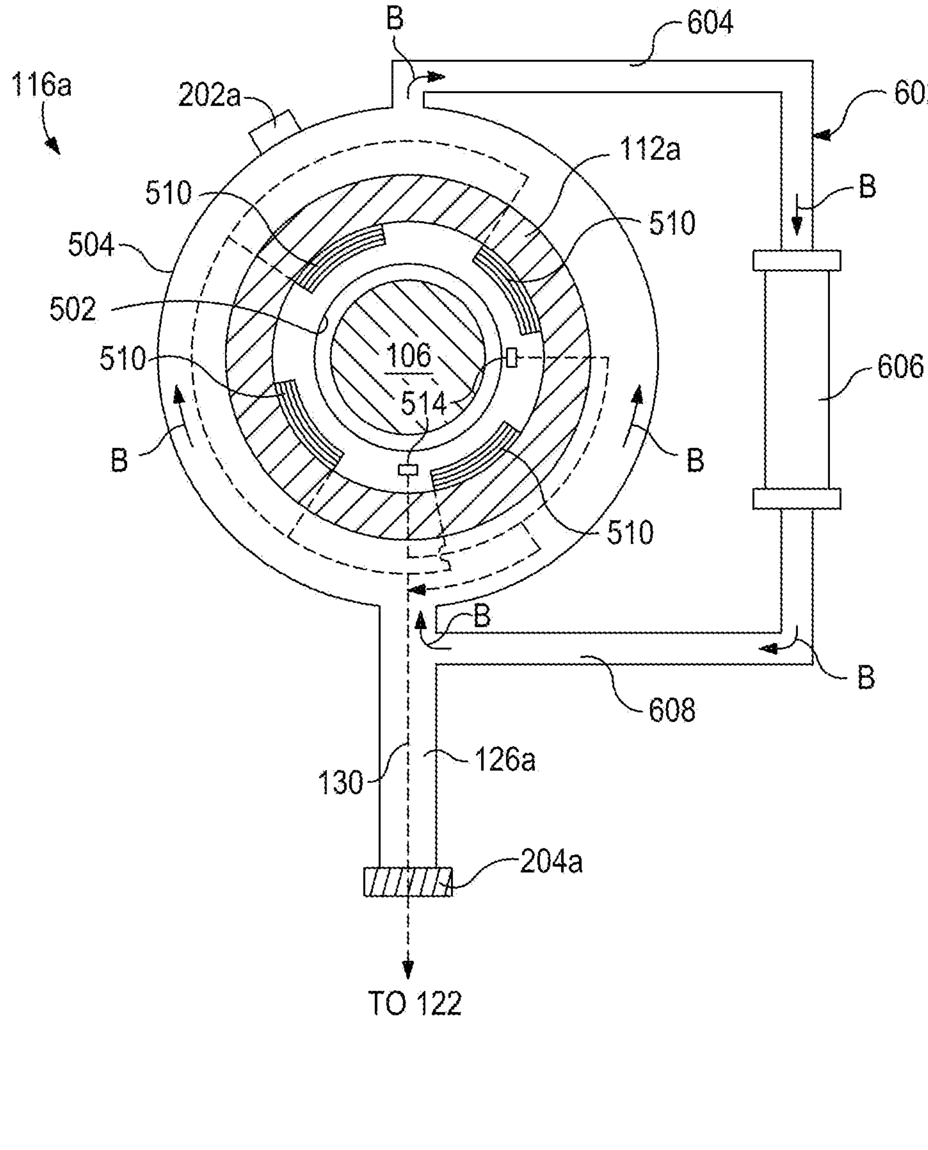
B
604
116a
202a
602
112a
510
B
510
504
502
606
510
106
514
B
B
510
B
B
608
130
126a
204a
TO 122

FIG. 6