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(54) HEATING SYSTEMS FOR ROTOR IN-SITU IN TURBOMACHINES

(57) Heating systems (200) for a rotor (114, 210) in-situ in a turbomachine (90, 190) are provided. In contrast to conventional systems that merely heat from an external turbine (212) casing, embodiments of the disclosure heat the rotor (114, 210). In one embodiment, a heating system (200) includes a heating element (230, 330, 530, 430) to heat a portion of an exterior surface (240) of the rotor (114, 210). In another embodiment, the heating system (200) may include a heating element (s) (230, 330, 530, 430) at least partially positioned within the rotor (114, 210), and the rotor (114, 210) including the heating system (200). Each embodiment may include a controller (340) to control operation of the heating element(s) (230, 330, 530, 430).

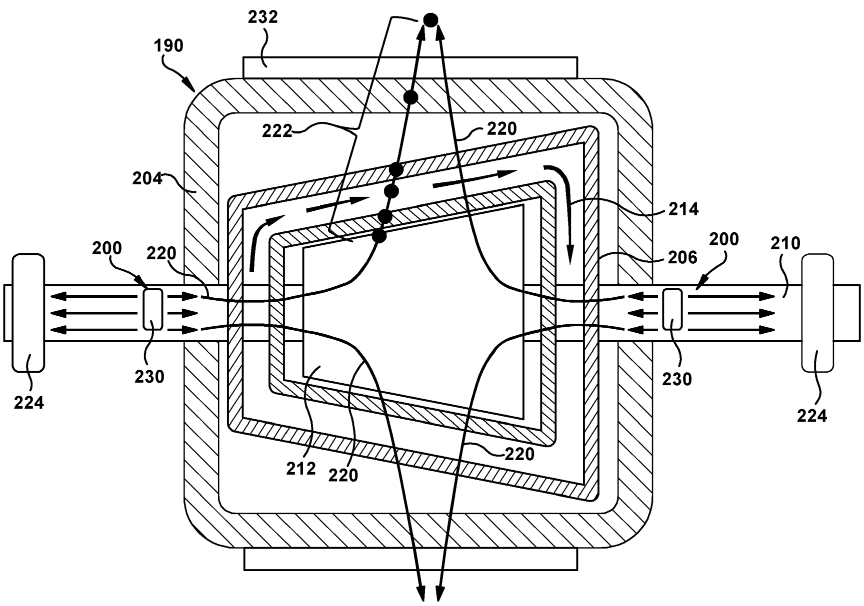

FIG. 3

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Description

BACKGROUND OF THE INVENTION

[0001] The disclosure relates generally to heating systems, and more particularly, to heating systems for a rotor in-situ in a turbomachine, and a related rotor.

[0002] In order to start up certain turbomachines, such as steam turbines, it is typically necessary to ensure that parts of the turbomachine are at appropriate temperatures. Start-up temperature control is desirable regardless of whether the turbomachine is starting from a cold start, warm start or from a hot start, i.e., after power generation has temporarily stopped. Start-up temperature control is necessary to, for example, ensure and optimize proper tolerances and clearances between parts, prevent slow start-up caused by having to heat parts with a working fluid, and control low cycle fatigue that can shorten part life.

[0003] Conventionally, heat blankets are applied to a casing (or shell) of a turbomachine to apply heat, e.g., to the outside of a steam turbine high pressure or intermediate pressure casing. The heat from the blankets is conducted through the casing into various parts of the turbine including the buckets and ideally into and through the rotor. Heat blankets work adequately for single casings, but pose challenges where double-casing units are employed. In particular, as shown in the schematic cross-section of FIG. 1, for a double casing turbine 6, heat transmission 8 from heat blanket 10 is more difficult because the heat needs to be conducted through a separation 12 between outer casing 14 and inner casing 16 before it reaches the internal parts. In addition, the thermal conductivity of different materials/parts present in the turbomachine may create a series of thermal resistances between junctions 20 (dots) having an insulative effect which can be detrimental to the desired heat transmission. For example, a thermal resistance for outer casing 14 may be higher than that of inner casing 16, or the thermal resistance of inner casing 16 may be higher than that of rotor 24, causing temperature drops between each junction set. A heat blanket arrangement also allows heat, which should be conducted to and through rotor 24 to be detrimentally sapped through the working fluid 18 flow path.

BRIEF DESCRIPTION OF THE INVENTION

[0004] A first aspect of the disclosure provides a heating system for a rotor in-situ in a casing of a turbomachine, the heating system comprising: a heating element for heating at least a portion of the rotor in-situ in the casing of the turbomachine.

[0005] A second aspect of the disclosure provides a heating system for a rotor in-situ in a casing of a turbomachine, the heating system comprising: a first heating element configured to heat at least a portion of an external surface of the rotor in-situ in the casing of the turbomachine; and a controller for controlling operation of the first heating element.

[0006] A third aspect of the disclosure provides a rotor for a turbomachine, the rotor comprising: an elongated body; and a heating element at least partially positioned in the elongated body for heating at least a portion of the rotor in-situ in the turbomachine.

[0007] A fourth aspect may include a heating system for a rotor in-situ in a casing of a turbomachine, the heating system comprising: a heating element configured to be at least partially positioned within the rotor for heating an internal portion of the rotor in-situ in the casing of the turbomachine; and a controller a controller controlling operation of the heating element.

[0008] The illustrative aspects of the present disclosure are designed to solve the problems herein described and/or other problems not discussed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] These and other features of this disclosure will be more readily understood from the following detailed description of the various aspects of the disclosure taken in conjunction with the accompanying drawings that depict various embodiments of the disclosure, in which:

FIG. 1 shows a schematic cross-sectional view of a conventional turbomachine employing a heat blanket.

FIG. 2 shows a perspective, partial cut away view of an illustrative turbomachine in the form of a steam turbine employing a heating system according to embodiments of the disclosure.

FIG. 3 shows a schematic cross-sectional view of a turbomachine employing a heating system according to embodiments of the disclosure.

FIG. 4 shows a detailed cross-sectional view of a heating system for an external surface of a rotor according to embodiments of the disclosure.

FIG. 5 shows a detailed cross-sectional view of a heating system for an external surface of a rotor according to another embodiment of the disclosure.

FIG. 6 shows a detailed cross-sectional view of a heating system for an external surface of a rotor according to another embodiment of the disclosure.

FIG. 7 shows a detailed cross-sectional view of a heating system for an internal portion of a rotor according to embodiments of the disclosure.

FIG. 8 shows a detailed cross-sectional view of a heating system for an internal portion of a rotor according to another embodiment of the disclosure.

FIG. 9 shows a detailed cross-sectional view of a heating system for an internal portion of a rotor employing a permanent magnet generator according to embodiments of the disclosure.

FIG. 10 shows a detailed cross-sectional view of a heating system for different internal axial positions of a rotor according to embodiments of the disclosure.

FIG. 11 shows a detailed cross-sectional view of the heating system of FIG. 10 employing various alternative structures according to embodiments of the disclosure.

[0010] It is noted that the drawings of the disclosure are not to scale. The drawings are intended to depict only typical aspects of the disclosure, and therefore should not be considered as limiting the scope of the disclosure. In the drawings, like numbering represents like elements between the drawings.

DETAILED DESCRIPTION OF THE INVENTION

[0011] As indicated above, the disclosure provides heating systems for a rotor in-situ in a turbomachine. In contrast to conventional systems that merely conduct heat from an external casing, embodiments of the disclosure heat the rotor directly. The heating systems may take form in a variety of embodiments. In one embodiment, a heating system includes a heating element to heat a portion of an exterior surface of the rotor in-situ in the turbomachine. In another embodiment, the heating system may include a heating element at least partially positioned within the rotor to heat the rotor in-situ in the turbomachine. Each embodiment may include a controller to control operation of the heating element(s). Heating systems as described herein may provide advantages such as but not limited to: closed loop temperature control to supplement and/or counteract internal heat flow from the heat blankets to maintain a desired component temperature, control temperature ramp rates, control pre-startup and in startup process temperature rates, create component temperatures commensurate with a desired start up profile, and coordination of casing and rotor temperatures to manage and optimize clearances, rotor stress, casing stress and differential cycle fatigue during startup. Additional advantages include recovery of a rotor "bow" condition prior to startup (using rotor heat and turning gear), and reducing startup vibration and startup time from a rotor bowed condition. Embodiments of the disclosure may also be used to reduce rotor to rotor rabbit fit interface temperature differentials during startup (that may, if excessive differential temperature occurs, result in loss of coupled or rabbit fit and turbomachine excessive vibration).

[0012] Referring to the drawings, FIG. 2 shows a perspective partial cut-away of a turbomachine 90 in the exemplary form of a steam turbine 100. Steam turbine 100 includes a rotor 114 and a plurality of axially spaced rotor wheels 118. A plurality of rotating blades 120 are mechanically coupled to each rotor wheel 118. More specifically, blades 120 are arranged in rows that extend circumferentially around each rotor wheel 118. A plurality of stationary vanes 122 extends circumferentially around rotor 114, and the vanes are axially positioned between adjacent rows of blades 120. Stationary vanes 122 cooperate with blades 120 to form a stage and to define a portion of a steam flow path through turbine 100. In operation, steam 124 enters an inlet 126 of turbine 100 and is channeled through stationary vanes 122. Vanes 122 direct steam 124 downstream against blades 120. Steam 124 passes through the remaining stages imparting a force on blades 120 causing rotor 114 to rotate. At least one end of rotor 114 may be attached to a load or machinery (not shown) such as, but not limited to, a generator, and/or another turbine. In one embodiment of the present disclosure as shown in FIG. 2, turbine 100 comprises five stages. The five stages are referred to as L0, L1, L2, L3 and L4. Stage L4 is the first stage and is the smallest (in a radial direction) of the five stages. Stage L3 is the second stage and is the next stage in an axial direction. Stage L2 is the third stage and is shown in the middle of the five stages. Stage L1 is the fourth and next-to-last stage. Stage L0 is the last stage and is the largest (in a radial direction). It is to be understood that five stages are shown as one example only, and each turbine may have more or less than five stages. Also, as will be described herein, the teachings of the invention do not require a multiple stage turbine. Furthermore, it is emphasized that while the teachings of the invention will be described relative to a steam turbine, turbomachine 90 can include any form of turbomachine requiring heating of internal parts, for example during startup thereof, including but not limited to: gas turbines, steam turbines and compressors.

[0013] FIG. 3 shows a schematic cross-sectional view of an illustrative turbomachine 190, e.g., a steam turbine, employing a heating system 200 according to embodiments of the disclosure. Turbomachine 190 may include any section of a larger turbomachine system, e.g., a gas turbine, a high, intermediate or low pressure section of a steam turbine system, a compressor, etc. Illustrative turbomachine 190 is shown including an outer casing 204 and an inner casing 206. It is emphasized, however, that the teachings of the invention are not limited to a double shell turbomachine and can be equally applied to a single shell machine. A rotor 210 is shown positioned in-situ in turbomachine 190, i.e., in an operative position in casings 204, 206. Turbine 212 is coupled to rotor 210 and may include blade/vane stages of turbomachine 190 (collectively indicated by a trapezoid), as described relative to turbomachine 90 of FIG. 2. A working fluid 214 (e.g., steam, air, combusted fuel, etc.) is shown moving through and /or about turbine 212. Heat transmission paths according to embodiments of the disclosure are illustrated with curved arrows 220, and thermal resistance junctions 222, e.g., discrete temperature positions in the turbomachine, are shown in the form of dots. A number of bearings 224 may be employed along an axial length of rotor 210 in a conventional fashion.

[0014] In the embodiment shown in FIG. 3, a heating system 200 is illustrated according to embodiments of the disclosure for heating rotor 210 in-situ in casing 204 and/or 206 of turbomachine 190. In general, heating system 200 may include any form of heating element 230 for heating at least a portion of rotor 210 in-situ in the casing of the turbomachine - illustrative embodiments of which will be further described herein. As illustrated, in contrast to conventional systems, heat is created within rotor 210 and is transmitted axially therethrough and into internal parts such as casings 204, 206 such that it travels radially outward as indicated by arrows 220. As will be described herein, where a heat blanket 232 is also employed, heating system 200 may act to balance heat transmission and/or improve heat transmission through turbomachine 190, e.g., through thermal resistance junctions 222.

[0015] Referring to FIGS. 4-11, illustrative embodiments of heating systems 200 according to the disclosure are provided. FIGS. 4-6 show enlarged detailed cross-sectional views of rotor 210 where a heating element 330, 430 is configured to heat at least a portion of an exterior surface 240 of the rotor; and FIGS. 7-11 show enlarged detailed cross-sectional views of rotor 210 where a heating element 530 is configured to heat at least a portion of an interior of the rotor.

[0016] Referring to FIG. 4, in one embodiment, heating element 330 for heating a portion of exterior surface 340 of rotor 210 may include an induction heating coil 332 positioned adjacent the at least a portion of exterior surface 240 of rotor 210. (Heating coil 332 extends into and out of the page as it surrounds rotor 210). Heating coil 332 may encompass as much of rotor 210 as is necessary to provide the desired heating, e.g., 90°, 180°, 350°, 360°. Induction heating is a well-known technique in which an electronic oscillator passes a high frequency current (AC) through a metal induction heat coil 332. This current causes an electromagnetic flux within the volume encompassed by the coil. If an object with low electrical resistance (e.g., metal) is placed within this volume, an eddy current will be generated on the outer surface of the object to oppose the incoming coil flux. The eddy current then heats the object due to Joule heating. A controller 340 may be coupled to heating element 330 to control operation thereof. One or more temperature sensors 334 may be provided and configured to sense a temperature of the at least a portion of the exterior surface of rotor 210. Temperature sensors 334 as described throughout the disclosure may include any now known or later developed temperature sensors such as thermocouples, infrared sensors, fiber optic sensors, etc. As will be described relative to a later embodiment, temperature sensors 334 may also be provided in the form of a fiber optic temperature sensor.

[0017] In another embodiment shown in FIG. 5, a susceptor member 432 may be provided surrounding at least a portion of exterior surface 240 of rotor 210, e.g., 90°, 180°, 350°, 360°, etc. Susceptor member 432 may include any material capable of absorbing energy from induction heating coil 334A and/or electrical resistance heater 434 and transmitting heat therefrom and/or converting energy to heat, e.g., a metal. In the FIG. 5 embodiment, a seal pack 338 is also provided to seal outer casing 204 and rotor 210. Seal pack 338 may include any now known or later developed seal pack structure. Use of susceptor member 432 with seal pack 338 applies heat to both rotor 210 and outer casing 204, providing additional heat loss blocking compared to the FIG. 4 embodiment. Further, because heat enters susceptor member 432 first and then enters rotor 210, use of susceptor member 432 may act to spread heat better compared to the FIG. 4 embodiment and thus may reduce overheating of rotor 210 and/or bearing 224. In the FIG. 5 embodiment, susceptor member 432 may include a heating element 430 therein. As shown in FIG. 5, in one embodiment, heating element 430 may include a resistance heater 434, i.e., any element capable of creating heat by passing an electric current therethrough. Alternatively, as shown in FIG. 6, heating element 430 may include resistance heater 434 and an inductance heater 436 (similar to inducting heating coil 332 (FIG. 4)). In any event, each heater 434 and/or 436 may be coupled to a controller 340 for controlling operation of the heater(s). As shown in FIGS. 4-6, one or more temperature sensors 334 may be configured to sense a temperature of rotor 210 or other parts. Controller 340 can control operation of the heating element(s) 434 and/or 436 based on the sensed temperature(s).

[0018] Temperature sensor(s) 334 can be positioned in any number of locations where temperature monitoring is desired. In one embodiment, as shown in FIGS. 5-6, a temperature sensor(s) 334A is in or on the susceptor member 432. In addition thereto or as an alternative, where a seal pack 338 is positioned adjacent rotor 210 for sealing a portion of outer casing 204 with rotor 210, a temperature sensor 334B may be positioned in or on the seal pack. Although not shown in the cross-sectional views, it is understood that temperature sensors 334 may be positioned anywhere about rotor 210.

[0019] With further regard to the FIGS. 4-6 embodiments, while one axial position is shown being heated at one end of casing 204, it is emphasized that any number of axial positions of rotor 210 may be heated using a heating element(s) 230, 330, 430, as described herein. For example, as shown in FIG. 3, rotor 210 may be heated at each end of casing 204. Alternatively, as shown in FIG. 4, more than one axial position on one end of casing 204 may be heated, e.g., using heating elements 330 and 330' (in phantom). Similar, multiple axial positions heating can be applied with the FIGS. 5 and 6 embodiments.

[0020] Controllers as used in the various embodiments described herein, e.g., controller 340 in FIGS. 4-6, may include any now known or later developed industrial machine control processor capable of controlling the heating element(s) based on a feedback from one or more temperature sensors used. Controller 340 can be a stand-alone controller, or can be integrated with other turbomachine 190 controls. For example, with the FIGS. 4-6 embodiments, controller 340 may automatically control operation of heating element 330, 430 and/or 330' (FIG. 4) based on the sensed temperature(s) to generate the desired heat and prevent overheating, e.g., of bearing(s) 224. Controller 340 can operate the heating element(s) to achieve any of a wide variety of goals such as but not limited to: provide closed loop temperature control to supplement and/or counteract internal heat flow from the heat blankets 232 (FIG. 3)(where provided) to maintain a desired temperature, control temperature ramp rates, control pre-startup and in startup process temperature rates, create a temperature commensurate with a desired start up temperature, coordination of casing and/or rotor temperatures to manage and optimize clearances during startup, manage rotor temperature to eliminate rotor bow. In another example, controller 340 may control rotor temperature during startup early stages to optimize clearances and to minimize cooling effect of first entry steam. While a particular number of wires/lines from controller to various other components have been illustrated herein, it is emphasized that the number of wires may vary depending on the embodiment(s) used. For example, where a rotor is grounded, the number of calrod rotating electrical connections could be reduced, e.g., from 2 to 1 per calrod, as the rotor body could be used for the electrical current return path.

[0021] The non-contact nature of the FIGS. 4-6 embodiments provides a number of advantages. For example, heating element 330, 430 and/or 330' can be easily installed in a new turbomachine or retrofit to a rotor already in the field where space allows. Further, heat can be applied to a rotating member such as rotor 210 without any changes to rotor 210.

[0022] Referring to FIGS. 7-11, in another embodiment, a heating element 530 may be at least partially positioned within rotor 210. As used herein, "positioned within" indicates the heating element is at least partially inside an elongated body of rotor 210 in such a manner that heat from the heating element may be transmitted into the rotor; the heating element need not necessarily be completely in contact or encompassed by the material of the rotor. That is, an opening or bore 532 in rotor 210 in which heating element 530 is positioned may be in close proximity or in contact with heating element 530, as shown in FIG. 7, or may simply surround heating element 530 as shown in FIG. 8, or some combination thereof.

[0023] In FIGS. 7-11, heating element 530 may include at least one calrod 540. A "calrod" can be any variety of well-known wire heating elements in the form of tubes, coils or other configurations in which heat is resistively (Joule heating) produced by an electric current. Calrods 540 may be employed in a number of ways such as, but not limited to, cartridge heaters available from, for example, Watlow Electric Manufacturing Co. under the FIREROD® brand. Cartridge heaters typically include a casing that encloses calrod and any necessary electrical connections thereto. In the embodiments illustrated, each calrod 540 extends from an end of rotor 210 and into the rotor (bore 532). Each calrod 540 may include at least one electrical contact 542 external to rotor 210 to provide power to the calrod as rotor 210 rotates. In one embodiment, as shown in FIG. 7, where a single calrod 540 is employed, electrical contact 542 may include a brush electrical connection 544 that electrically contacts an exterior of a respective calrod 540 as it rotates with rotor 210. Brush electrical connection 544 is operatively coupled to controller 340, which may include an alternating current (AC) power supply sized to power calrod 540. In another embodiment, as shown in FIG. 8, electrical contact 542 may include an induction transformer 550 operatively coupled to calrod 540 for powering the calrod. Induction transformer 550 may include any now known or later developed device for electromagnetically inducting power between a stationary part and a rotating part on rotor 210. Induction transformer 550 is also operatively coupled to controller 340, which may include an alternating current (AC) power supply sized to power calrod(s) 540. Each calrod 540 may have its own coupling to induction transformer 550, or calrods may share couplings.

[0024] In another embodiment, shown in FIG. 9, as an option, a permanent magnet generator 560 may be operatively coupled to rotor 210 to power, e.g., heating element(s) 530 and/or controller 340. Generator 560 interacts with rotor 210 to generate power for controller 340 and/or heating element 530 in a known fashion. Controller 340 may control power generated by generator 560 and delivered to heating element(s) 530. While FIG. 9 shows heating system 200 including an induction transformer 550, it is emphasized that generator 560 may be employed with any of the embodiments described herein.

[0025] Referring to FIG. 10, in another embodiment, heating element 530 may include a plurality of heating sub-elements 570, e.g., calrods 540 in the form of cartridge heaters, at least partially positioned in rotor 210. In this case, each heating sub-element 570 heats a different axial position of rotor 210. That is, each heating sub-element 570 may extend a different distance into rotor 210 to heat a different axial position of rotor 210. In this fashion, rotor 210 can be very precisely heated. A controller 340 may control operation of each heating sub-element 570. Multiple calrods also increase rotor heating system reliability, because the rotor can still be heated as long as one calrod is operational.

[0026] A plurality of temperature sensors 334 may be employed with each temperature sensor 334 configured to sense a temperature of rotor 210 at a respective one of the different axial positions. Controller 340 may control operation of each heating sub-element 570 based on the sensed temperatures of the different axial positions, e.g., its respective temperature and/or those around it. Temperature sensors 334 may be implemented in a number of fashions, e.g., thermocouples on rotor 210, light-based sensors focused on different exterior axial positions for rotor 210. In one embodiment, shown in FIG. 10, plurality of temperature sensors 334 such as thermocouples or fiber optic temperature sensors are positioned within rotor 210. As understood in the art, fiber optic temperature sensor 580 may include one or a number of fiber optic strands 582 (see FIG. 11), the ends of which are positionable at selected axial positions of rotor 210 to measure a temperature thereat. Fiber optic temperature sensor 580 can provide rotor temperature monitoring along the rotor axis internal to rotor opening 532 at multiple locations with single fiber optic cable. Although shown only with the FIGS. 10 and 11 embodiments, fiber optic temperature sensor 580 may be applied to any embodiment described herein.

[0027] Referring to FIG. 11, in another embodiment, variations of heating system 200 described herein may be combined, which may be advantageous, for example, to reduce capacity of internal heating element(s) 530 or as a backup system to provide supplemental heat during turbine 212 (FIG. 3) startup. Combined systems may be particularly beneficial for a forward end of a steam turbine rotor. FIG. 11 shows one example of a combined heating element, which may include at least one first heating subelement 570 positioned in rotor 210, as in FIGS. 7-10, and at least one second heating element 330 (e.g., induction heating coil) configured to heat at least a portion of an exterior surface 240 of rotor 210, as in FIGS. 4-6. Although particular embodiments of the internal and external heating elements are shown in FIG. 11, it is emphasized that any of the embodiments can be used together. As also shown in FIG. 11, any of the above-described embodiments may also be employed with a heating blanket 583 configured to heat an exterior of outer casing 204.

[0028] Controller 340 may also be operatively coupled to control a turning gear 584, part of turbomachine 190, for rotating rotor 210 during the heating, which may assist in more evenly heating the rotor and preventing hot spots. Controller 340 may also be operatively coupled to control flow of a working fluid into turbomachine 190, e.g., through controlling flow valves directly or through an overall turbomachine controller, thus allowing it to further control heating of the turbomachine by controlling working fluid flow.

[0029] Embodiments of the disclosure, as shown in FIGS. 7-11, may also include rotor 210 for turbomachine 190. Rotor 210 may include an elongated body 218 (FIG. 10), and a heating element 530, as described herein, positioned at least partially in the elongated body for heating at least a portion of the rotor. A heating system 200 for rotor 210 in-situ in casing 204 of turbomachine 190 is also provided in which heating element 530 is configured to be positioned at least partially within the rotor for heating an internal portion of the rotor. Controller 340 controls operation of heating element 530.

[0030] Embodiments of the disclosure that provide internal heating to rotor 210, FIGS. 7-11, provide a number of additional advantages compared to the external heaters of FIGS. 4-6. For example, internal heating provides heat directly to a core of turbine 212 (FIG. 3), where it is most effectively applied via a centralized bore (opening) 532 (FIG. 10) along an axis of rotor 210. Internal heating may also be safer because heating element(s) 530 are positioned in low-stress region of rotor 210. Internal heating elements 530 also allow for easy heating element addition, removal and replacement, e.g., during routine maintenance. Internal heating elements 530 may also improve "rotor bow" recovery time and reduce rotor vibration due to rotor bow during slow roll and/or turning gear operation. Further, internal heating provides internal turbine or compressor casing temperature (indirect or radiated) heating from rotor 210, thereby reducing thermal gradients during startup, allowing for reduced startup rates and time. It also allows management of rotor-to-casing thermal growths, and optimization of rotor, casing, seal pack and related component clearances, thus reducing thermal growth transient clearance extremes and improving startup thermal performance. Consequently, it also improves rotating bucket, blade, airfoil and nozzle/diaphragm airfoil life cycle through reduced thermal gradients and shocking during steam turbine startup thereby improving low cycle fatigue (LCF) concerns and component life cycles.

[0031] Use of multiple heating elements 530 internal to rotor 210, as described relative to FIGS. 10-11, also provides a number of additional advantages. For example, multiple heating elements minimizes bearing 224 heating by allowing selecting of heating positions by choosing appropriate heating element lengths, i.e., to optimize heat transmission away from bearing(s) 224. Heating power can also be readily customized for rotor axial position with multiple heating elements. Varied heating element lengths also allows for "zone rotor temperature control" along an axis of rotor 210 to provide variable heating of rotor 210 along its length, if desired, or increased temperature for turbine startup optimization. Multiple heating elements 530 also provide some level of redundancy for reliability over turbomachine 190 life.

[0032] As noted, embodiments of the disclosure are applicable in any turbomachine setting, e.g., steam turbines, gas turbines, and compressors. Consequently, embodiments of the disclosure can significantly reduce or eliminate rotor cycle stresses including low cycle fatigue and increase rotor life-cycle by eliminating temperature cycles associated with cold startups for a wide variety of trubomachines. Teachings of the disclosure can further be applied to: monitor and control temperatures and temperature rate of change, control temperature transients and maintain desired temperatures, control cooldown rates, and match rotor and casing temperatures. Teachings of the disclosure can be applied to various turbomachine sections to allow for variable heat input to different sections requiring different temperatures, e.g., high, low and intermediate pressures rotors in steam turbine applications.

[0033] While the teachings of the disclosure have been described herein relative to a number of embodiments, it is emphasized that heating can be provided to rotor in a number of alternative ways considered within the scope of the disclosure. For example, a rotor may be heated with other mediums such as pressurized hot water or steam via channels in the rotor.

[0034] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the disclosure. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0035] The corresponding structures, materials, acts, and equivalents of all means or step plus function elements in the claims below are intended to include any structure, material, or act for performing the function in combination with other claimed elements as specifically claimed. The description of the present disclosure has been presented for purposes of illustration and description, but is not intended to be exhaustive or limited to the disclosure in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the disclosure. The embodiment was chosen and described in order to best explain the principles of the disclosure and the practical application, and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

Claims

1. A heating system (200) for a rotor (114, 210) in-situ in a casing of a turbomachine (90, 190), the heating system (200) comprising:

   a heating element (230, 330, 530, 430) for heating at least a portion of the rotor (114, 210) in-situ in the casing of the turbomachine (90, 190).

2. The heating system (200) of claim 1, wherein the heating element (230, 330, 530, 430) is configured to heat at least a portion of an exterior surface (240) of the rotor (114, 210).

3. The heating system (200) of claim 2, further comprising a temperature sensor (580) configured to sense a temperature of the at least a portion of the exterior surface (240) of the rotor (114, 210) and a controller (340) controlling operation of the heating element (230, 330, 530, 430) based on the sensed temperature.

4. The heating system (200) of claim 2, wherein the heating element (230, 330, 530, 430) includes an induction heating coil (332) positioned adjacent the at least a portion of the exterior surface (240) of the rotor (114, 210).

5. The heating system (200) of claim 2, further comprising a susceptor member surrounding the at least a portion of the exterior surface (240) of the rotor (114, 210), the susceptor member having the heating element (230, 330, 530, 430) therein.

6. The heating system (200) of claim 5, wherein the heating element (230, 330, 530, 430) includes at least one of: a resistance heater and an inductance heater.

7. The heating system (200) of claim 5, further comprising a temperature sensor (580) configured to sense a temperature of the rotor (114, 210) and a controller (340) controlling operation of the heating element (230, 330, 530, 430) based on the sensed temperature.

8. The heating system (200) of claim 7, wherein the temperature sensor (580) is in or on the susceptor member.

9. The heating system (200) of claim 7, further comprising a seal pack adjacent the rotor (114, 210) for sealing a portion of the casing with the rotor (114, 210), and wherein the temperature sensor (580) is in or on the seal pack.

10. The heating system (200) of claim 1, wherein the heating element (230, 330, 530, 430) is at least partially positioned within the rotor (114, 210).

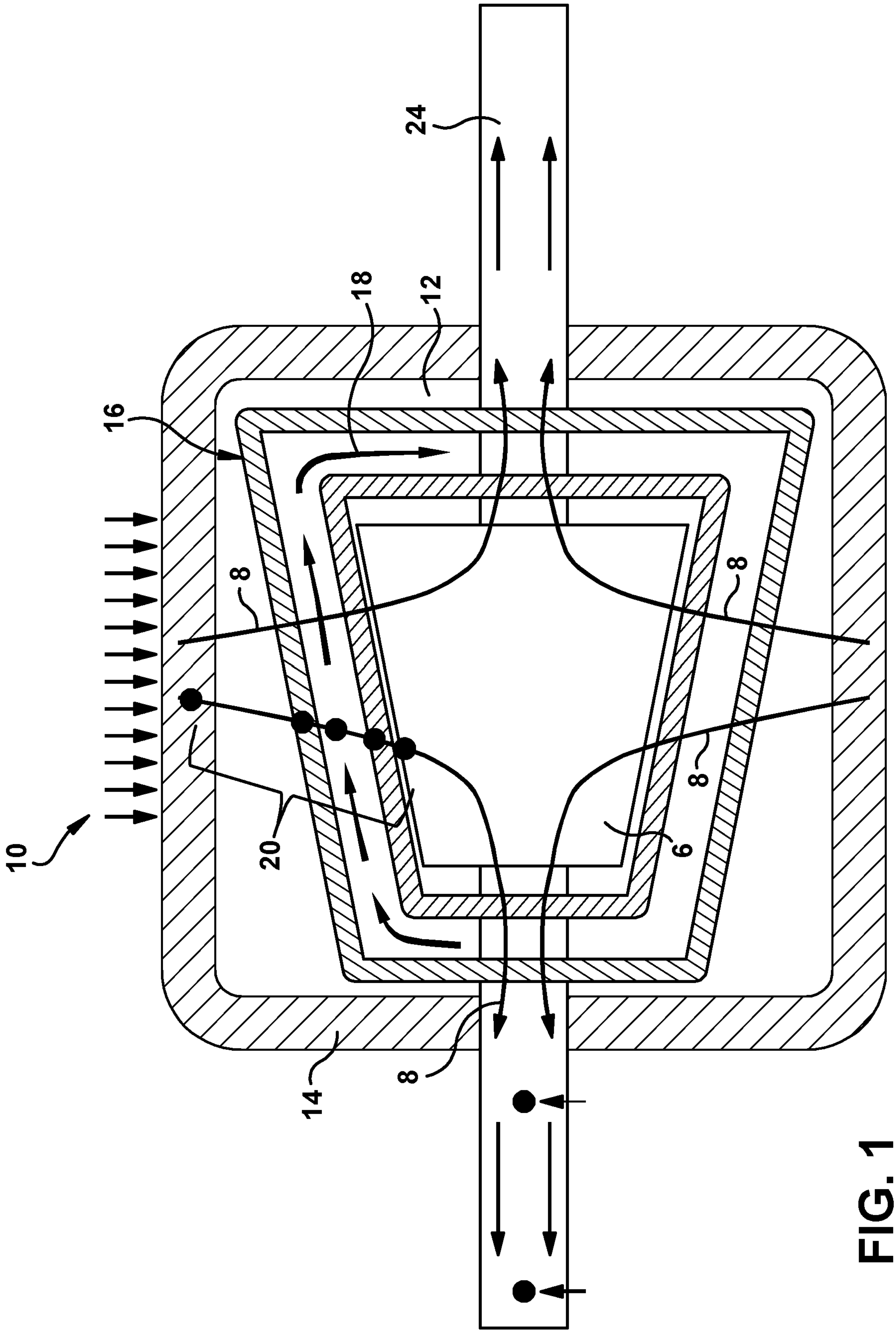

FIG. 1
(Prior Art)

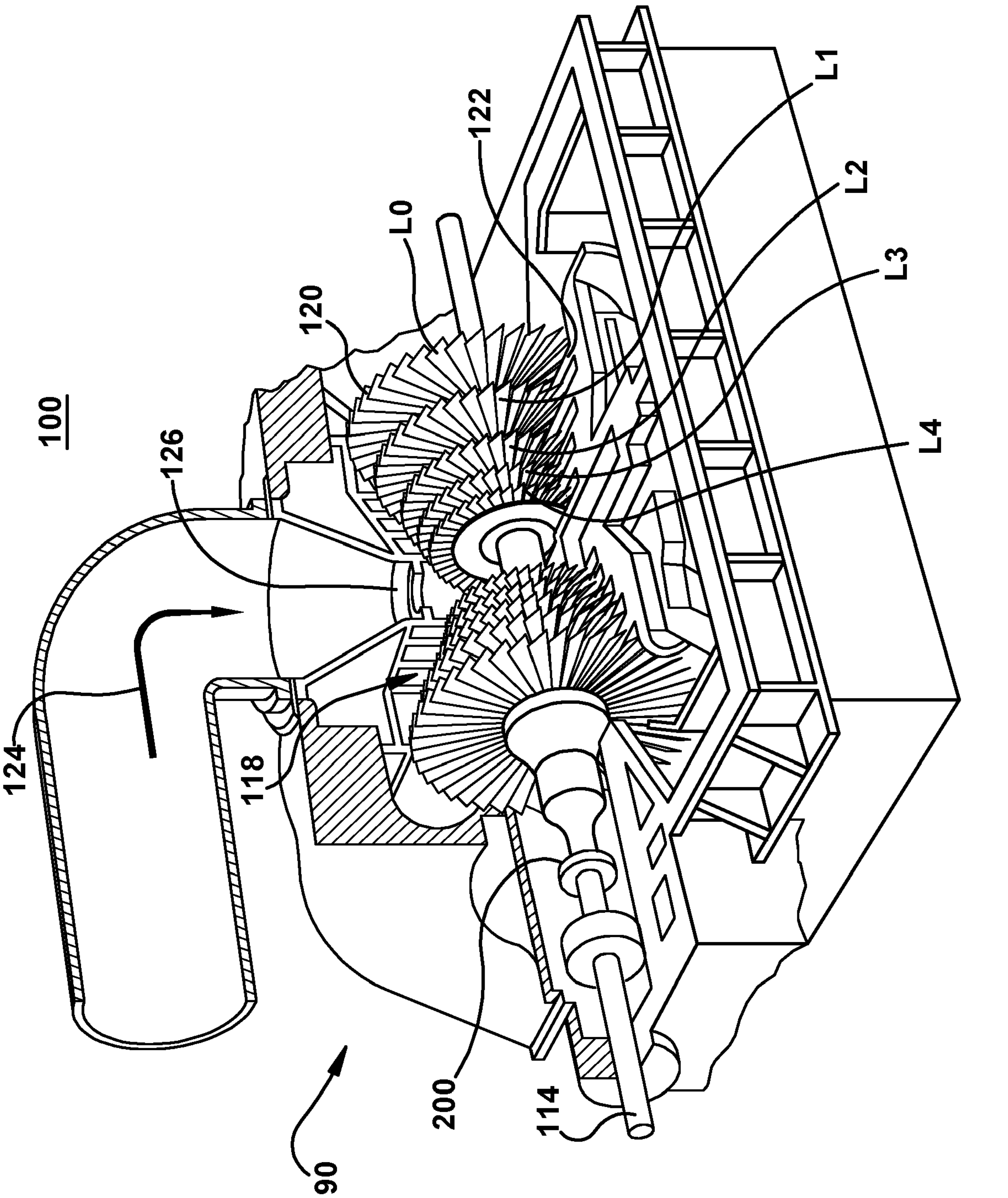

FIG. 2

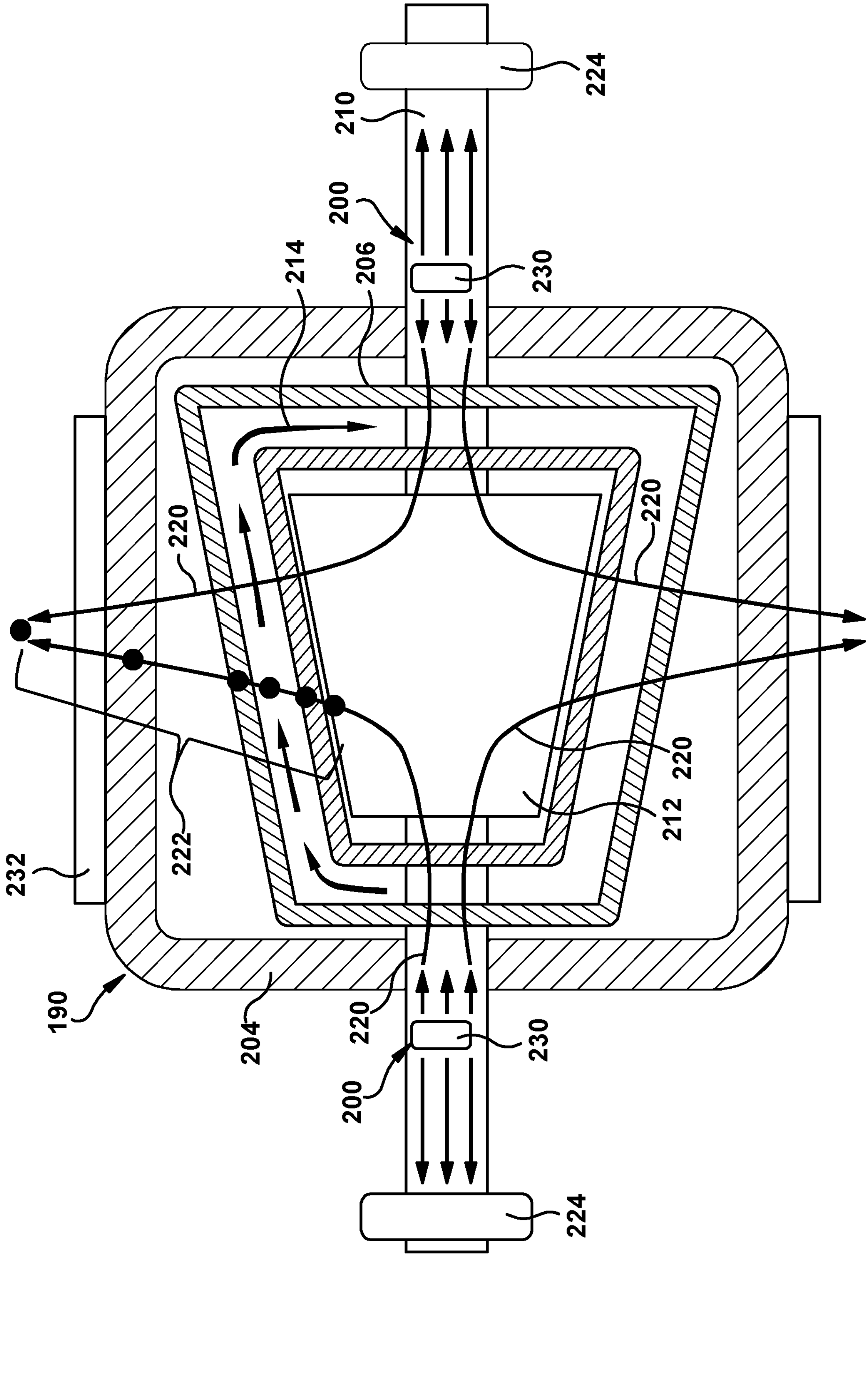
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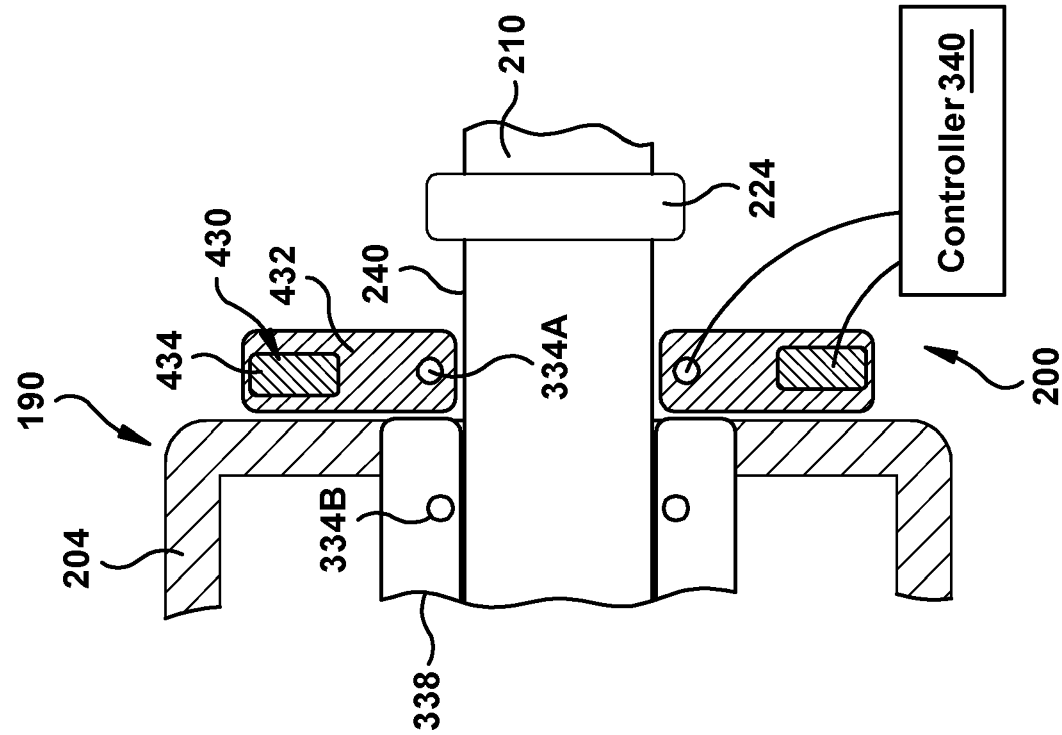
FIG. 3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334B
338
434
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432
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334A
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224
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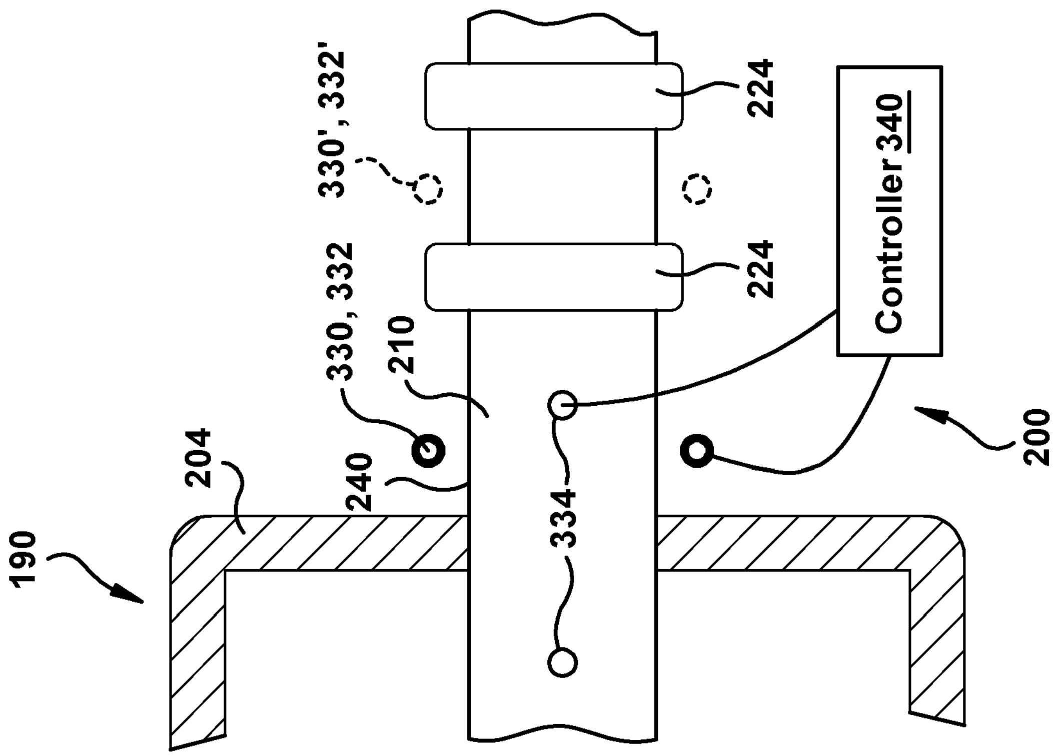
Controller 340

FIG. 5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334
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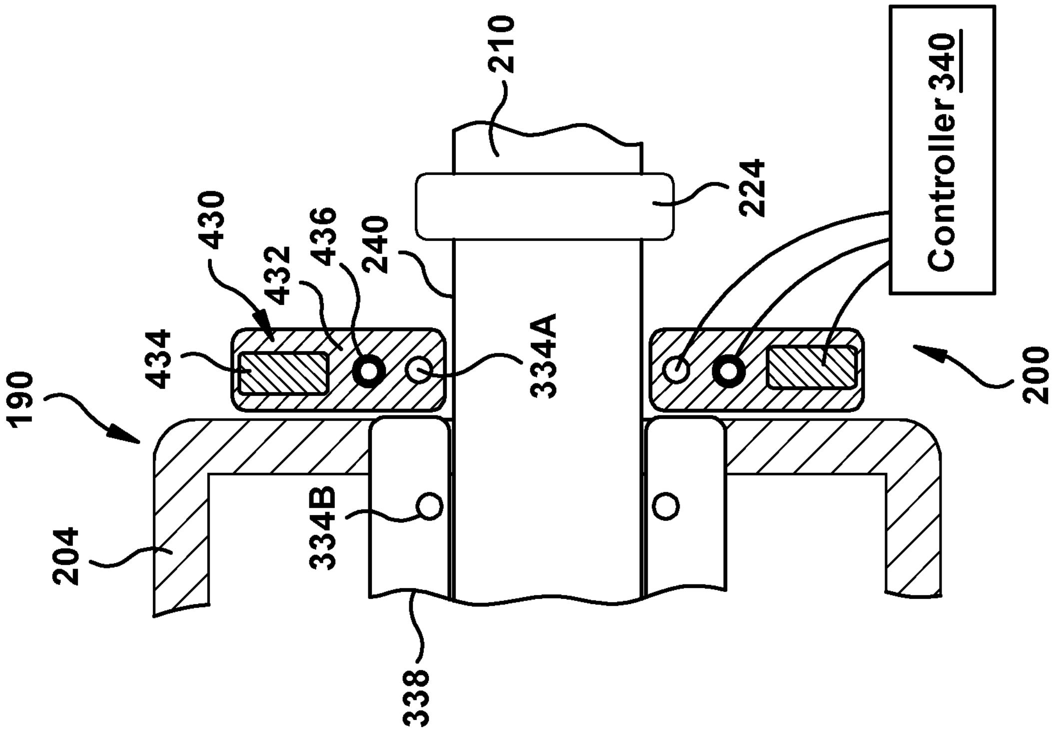
224
224
200
Controller 340

FIG. 4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436
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434
334A
190
200
Controller 340
204
334B
338

FIG. 6

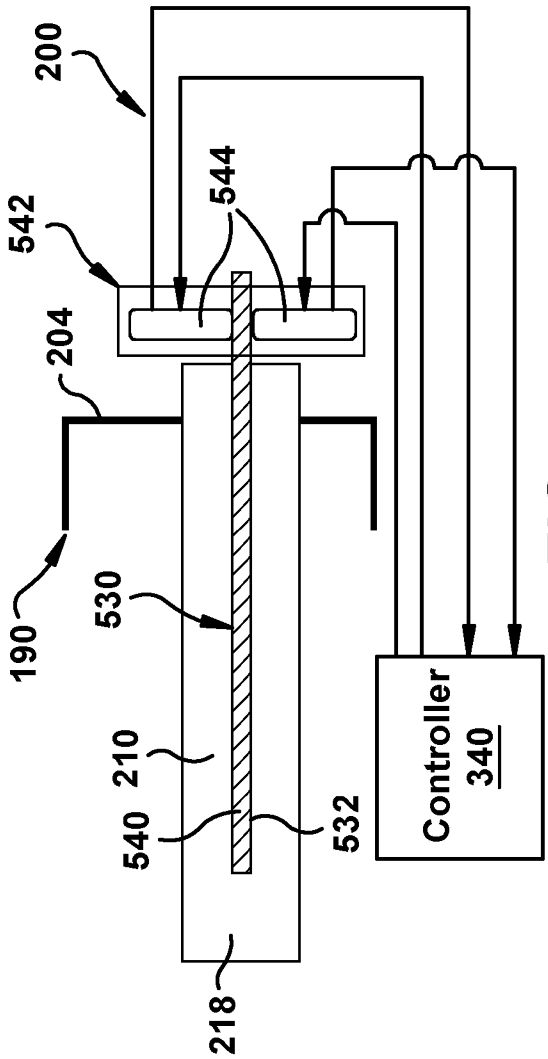

200
542
544
204
190
530
210
540
532
218
Controller
340

FIG. 7

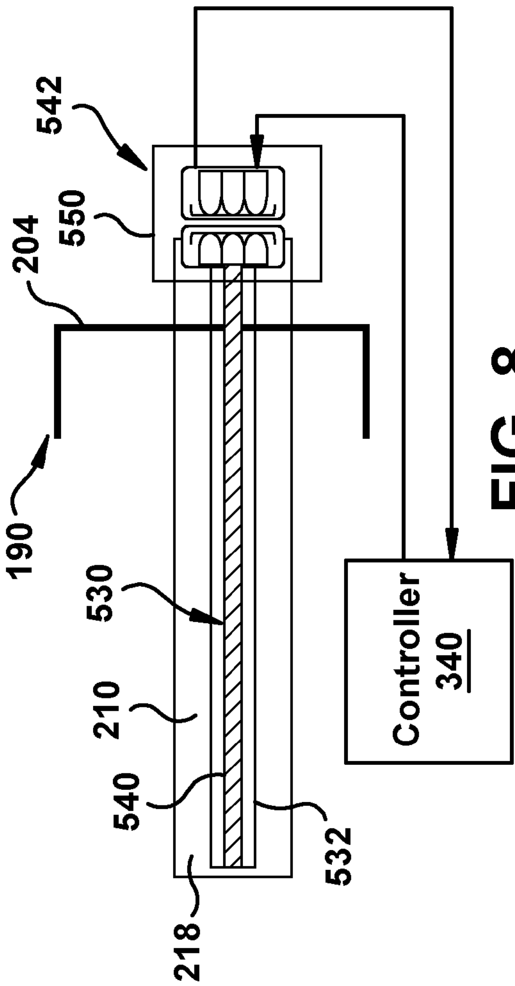

542
550
204
190
530
210
540
532
218
Controller
340

FIG. 8

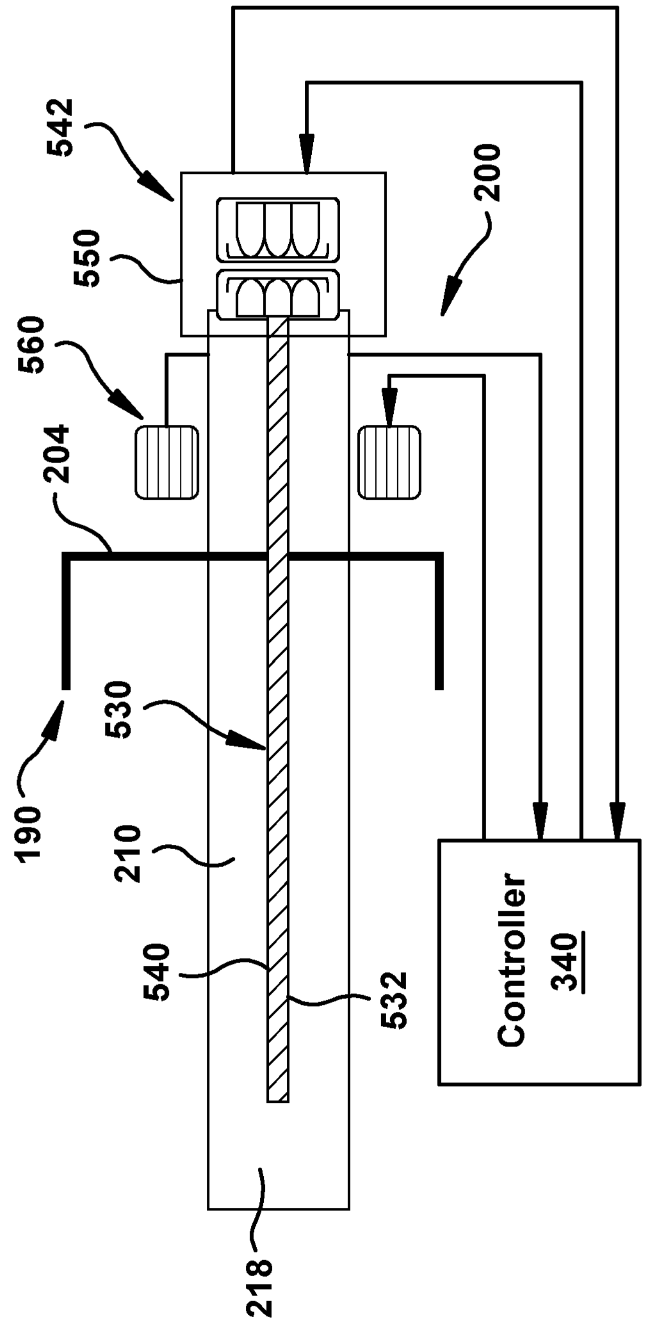
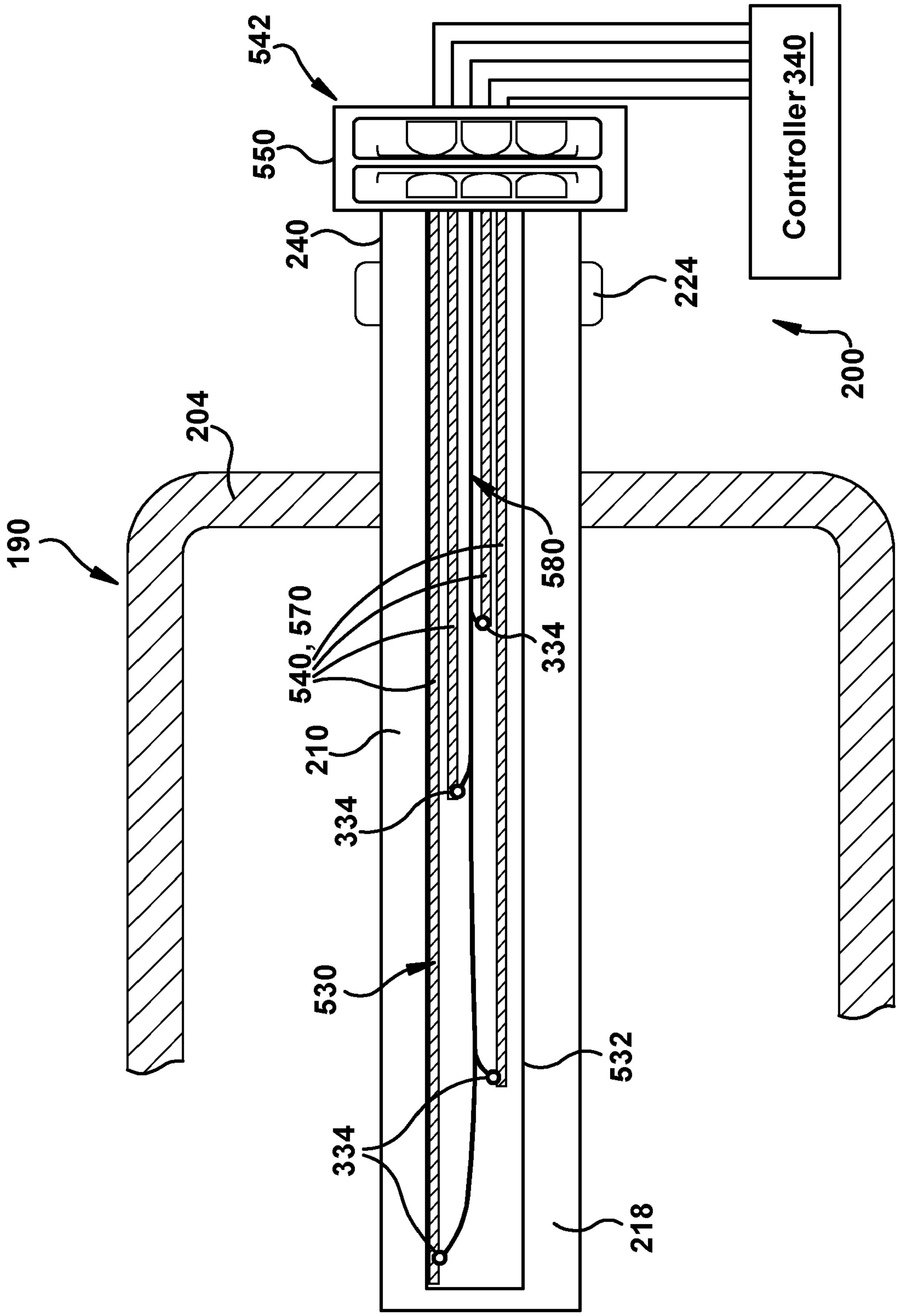


FIG. 9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Controller 340
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334
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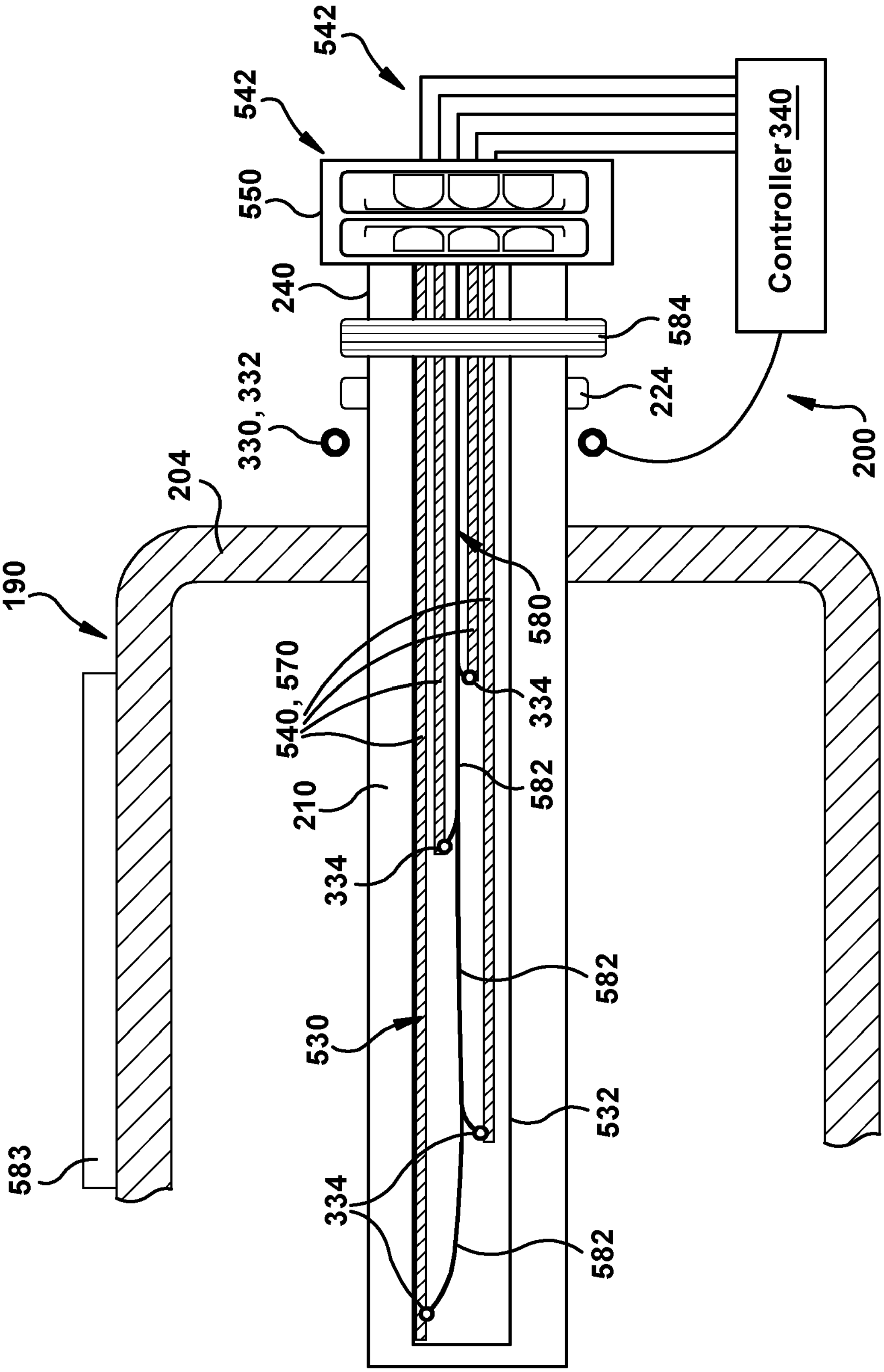
FIG. 10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204
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530
532
583
334
582

FIG. 11

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EUROPEAN SEARCH REPORT

Application Number
EP 16 19 2100

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F01D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	14 February 2017	Mielimonka, Ingo

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