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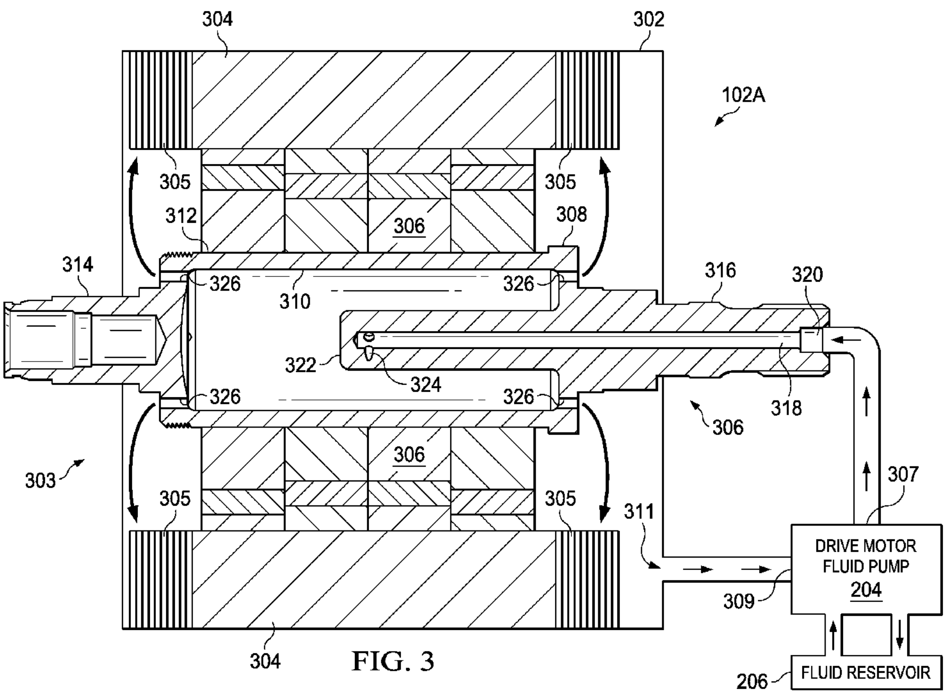

FIG. 3

(57) Abstract: An electric motor includes a case, a stator that includes end-windings, a rotor coupled to the case via rotor bearings, a drive motor fluid pump, and drive motor electronics. The rotor includes a hollow cylindrical body, a first shaft portion, and a second shaft portion, a fluid feed tube having a fluid receive end and a fluid feed end, the fluid feed end extending into the hollow cylindrical body, and a plurality of fluid exit ports. The drive motor electronics power the stator without causing rotation of the rotor. The drive motor fluid pump pumps fluid into the hollow cylindrical body via the fluid feed tube, pumps the fluid out of the plurality of fluid ports, and onto the stator end-windings to collect heat from the rotor and the stator. The drive motor fluid pump then circulates the fluid to a heat exchanger for heating a battery.

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— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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TITLE

ELECTRIC MOTOR WASTE HEAT MODE TO HEAT BATTERY

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims priority pursuant to 35 U.S.C. § 119(e) to U.S. Provisional Patent Application No. 62/346,741, entitled "ELECTRIC MOTOR COOLING SYSTEM AND ROTOR DISCHARGE PROTECTION', filed 7 June 2016, which is incorporated herein by reference in its entirety and made part of the present application for all purposes.

BACKGROUND

TECHNICAL FIELD

[0002] The present invention relates to electric motors; and more particularly to using an electric motor to heat a servicing battery.

DESCRIPTION OF RELATED ART

[0003] Electric motors can generate considerable heat, especially by the traction motor of a vehicle where size and weight constraints are coupled with the need for high power output. Electric motor overheating causes the motor winding insulation to deteriorate quickly. For every 10-degree Celsius rise in electric motor temperature, insulation life is cut in half. Another issue caused by overheating is that permanent magnets in the rotor lose their magnetic properties as they overheat, resulting in a loss of efficiency. For induction motors, an increase in temperature of their copper windings reduces efficiency of the induction motor—copper electrical resistivity increases 4% for every 10-degree Celsius temperature increase. Thus, it is important to cool the internal motor components (e.g., rotor) as well as the outer motor components (e.g., case, stator). The electric motor cooling system must operate efficiently over large variations in ambient operating environment as the electric motor may be subjected to a wide range of ambient temperatures, humidity levels, and/or dust/dirt levels.

[0004] A number of different approaches have been taken to meeting the cooling demands placed on a vehicle's electric motor. For example, U.S. Pat. No. 6,191,511 discloses using a closed loop, liquid cooling circuit in an attempt to achieve a temperature balance within the motor, the cooling circuit passing the coolant (typically a fluid such as oil, e.g., automatic transmission oil or similar type oil) through both the stator and a hollow rotor shaft. Within the hollow rotor shaft is a stationary injection tube, the injection tube fixed to a stator flange.

The fluid is pumped through the injection tube to the end of the rotor shaft where it is passed between the cavity of injection tube and the hollow rotor shaft. The fluid then passes through a cylindrical cooling chamber extending over the length and periphery of the stator before cooling the stator structure and being returned to the injection tube.

[0005] U.S. Pat. No. 6,329,731 discloses a liquid cooled electric motor in which one of the main elements of the planetary gear drives the displacement pump of a cooling circuit. Fluid is pumped through a stationary tube about which the hollow rotor shaft rotates. The fluid then passes between the stationary tube and the hollow rotor shaft before passing through a radiator incorporated into the motor and planetary gear casing.

[0006] U.S. Pat. No. 7,156,195 discloses an electric motor in which fluid is collected within the reduction gear case, not the motor case, thus avoiding deterioration and alteration of the motor magnets. The fluid from the reservoir is pumped through the end of a passage in the drive shaft where it flows toward the motor. Some of the fluid is sprayed onto the reduction gears while the rest of the fluid is pumped between the drive shaft and the reduction gear shaft and the motor output shaft.

[0007] These prior solutions had a number of shortcomings. They failed to address the differing heat production locations along the length of the rotor. More heat tends to be generated in the central portion of the rotor, as compared the end or distal portions of the rotor. The prior art solutions tended to cool using a fluid that flowed from one distal portion of the rotor to another distal portion of the rotor, causing a heat gradient from end to end and end to rotor center. Further, the prior art solutions included a number of relatively complex parts, resulting in relatively high production costs and a relatively high failure rate.

[0008] Another problem with the operation of battery powered electric vehicles is that the powering batteries do not operate efficiently at low temperatures. As the deployment of electric vehicles proliferates, many are used in environments having cold winters and/or in locations that are cold at all times. In order to keep the electric vehicles operating at a reasonable efficiency level, the electric vehicles must be stored inside or use externally powered battery heaters to keep the batteries at an acceptable operating temperature. This solution, of course, does not work when a heated storage location is unavailable or when external power is not available.

SUMMARY

[0009] According to a first embodiment of the present disclosure, an electric motor includes a case, a stator having end-windings, a rotor coupled to the case via rotor bearings, a drive motor fluid pump, and drive motor electronics. The rotor includes a hollow cylindrical body, a first shaft portion, a second shaft portion, a fluid feed tube, and a plurality of fluid exit ports. The hollow cylindrical body includes an inner wall, an outer wall, a first distal end, and a second distal end. The first shaft portion couples to the first distal end of the hollow cylindrical body. The second shaft portion couples to the second distal end of the hollow cylindrical body. A fluid feed tube has a fluid receive end and a fluid feed end, the fluid feed end extending into the hollow cylindrical body.

[0010] In a waste heat mode, the drive motor electronics power the stator without causing rotation of the rotor. Further, in the waste heat mode, the drive motor fluid pump at least partially fills the hollow cylindrical body with the fluid to force the fluid from the hollow cylindrical body via the fluid exit ports to spray upon the stator end-windings and to collect heat from the stator end-windings. Still further, the drive motor fluid pump circulates the fluid to a heat exchanger for heating a battery.

[0011] With the electric motor of the present disclosure, a fluid is heated by the end-windings of the stator while the rotor is stationary and the captured heat is used to heat the battery. Thus, a separate battery heating structure is not needed, reducing complexity and expense of a machine serviced by the electric motor and battery.

[0012] The electric motor may include a number of additional features and structures. These features and structures may be included in various combinations that include some of these features and structures, all of these features and structures, or one of these features and structures. The electric motor may further include fluid circulation piping having an output portion coupled between the drive motor fluid pump output and the fluid receive end of the second shaft portion and an input portion coupled between a fluid collection point on the case and the drive motor fluid pump input. The electric motor may further include a radiator configured to cool the fluid and/or a heat exchanger coupled between the drive motor fluid pump and the radiator.

[0013] The fluid feed end of the fluid feed tube may include a plurality of fluid spray ports configured to spray fluid onto the inner wall of the hollow cylindrical body electric motor. The

electric motor may include an oil distribution ring coupled to the rotor and configured to deflect fluid from the plurality of fluid exit ports to the stator end-windings.

[0014] The electric motor may include a drive motor fluid pump having a drive motor fluid pump outlet and a drive motor fluid pump inlet. The electric motor may further include fluid circulation piping having an output portion coupled between the drive motor fluid pump outlet and the fluid receive end of the second shaft portion, an input portion coupled between a fluid collection point on the case and the drive motor fluid pump inlet and drive motor fluid pump electronics. The electric motor may further include a heat exchanger coupled between the drive motor fluid pump and the radiator.

[0015] According to a second embodiment of the present disclosure, a method for operating an electric motor includes powering a stator of the electric motor to heat end-windings of the stator without causing a rotor of the electric motor to rotate. The method further includes pumping fluid into a hollow cylindrical body of the rotor via a fluid feed tube, out of the hollow cylindrical body of the rotor via a plurality of fluid exit ports, and the end-windings of the stator to collect heat from at least the end-windings of the stator to produce heated fluid. The method then includes pumping the heated fluid to a heat exchanger for heating a battery.

[0016] The method serves to heat fluid by the stator end-windings and using the heated fluid to heat a battery. With the fluid flow of this method, a single operation supports battery heating. Thus, a separate battery heating method is not needed.

[0017] The method of operating the electric motor may include a number of additional operations and/or features. These operations and/or features may be included in various combinations that include some of these operations and/or features, all of these operations and/or features, or one of these operations and/or features.

[0018] The method may further include pumping the fluid into the hollow cylindrical body and spraying the fluid from the fluid feed tube onto an inner wall of the hollow cylindrical body of the rotor. Spraying the fluid from the fluid feed tube may include spraying the fluid onto a central portion of the inner wall of the hollow cylindrical body. The method may also include circulating coolant between the heat exchanger and the battery, wherein the coolant is heated by the heated fluid in the heat exchanger.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0019] FIG. 1 illustrates the basic components of a battery powered electric vehicle.

[0020] FIG. 2 illustrates components of a drive motor cooling system and a battery heating system, both constructed and operating according to a disclosed embodiment.

[0021] FIG. 3 illustrates components of a drive motor and a portion of the components of a drive motor cooling system according to a disclosed embodiment.

[0022] FIG. 4 illustrates components of a drive motor and a portion of the components of a drive motor cooling system according to a disclosed embodiment, particularly showing the manner in which fluid flows.

[0023] FIGs. 5A and 5B illustrate a rotor according to a representative embodiment, detailing the construct of fluid exit ports within a hollow central portion of the rotor.

[0024] FIGs. 6A, 6B, 6C, and 6D illustrate operation of a drive motor according to one or more embodiments of the present disclosure.

[0025] FIG. 7 is a flow diagram illustrating electric motor cooling and battery heating operations according to a disclosed embodiment.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0026] FIG. 1 illustrates the basic components of a battery powered electric vehicle (electric vehicle) 100. The electric vehicle 100 includes at least one drive motor (traction motor) 102A and/or 102B, at least one gear box 104A and/or 104B coupled to a corresponding drive motor 102A and/or 102B, a battery 106 and electronics 108 (including drive motor electronics). Generally, the battery 106 provides electricity to the electronics 108 of the electric vehicle 100 and to propel the electric vehicle 100 using the drive motor 102A and/or 102B. The electric vehicle 100 includes a large number of other components that are not described herein but known to one or ordinary skill. While the construct of the electric vehicle 100 of FIG. 1 is shown to have four wheels, differing electric vehicles may have fewer or more than four wheels. Further, differing types of electric vehicles 100 may incorporate the inventive concepts described herein, including motor cycles, aircraft, trucks, boats, train engines, among other types of vehicles.

[0027] Various operational issues with the electric vehicle 100 are described herein in conjunction with various embodiments. One of these operational issues relates to the cooling of the drive motor 102A or 102B. Another of these operational issues relates to control of operating temperature of the battery 106. Subsequent description herein may relate back to the components of this FIG. 1. Common numbering may be used to refer to components identified in further FIGs. described herein.

[0028] FIG. 2 illustrates components of a drive motor cooling system and a battery heating system 200, both constructed and operating according to a disclosed embodiment. The drive motor cooling system and battery heating system 200 includes a drive motor cooling system 202 having a drive motor fluid pump 204, a fluid reservoir 206 and electronics 208. In the illustrated embodiment, the fluid is oil, e.g., automatic transmission oil, lubricating oil, or similar oil. In other embodiments, other types of fluid may be used. The drive motor fluid pump 204 pumps fluid between the drive motor 102A and/or 102B, the fluid reservoir 206, and a heat exchanger 210. In one embodiment, the heat exchanger 210 exchanges heat from the fluid with water or alcohol based coolant and routes the water or alcohol based coolant to a radiator 212 for cooling. The heat exchanger 210 may include another pump to circulate the water or alcohol based coolant to battery 106 via coolant tubes 214. In other embodiments, the drive motor fluid pump 204 may couple directly to the coolant tubes 214 of the battery 106 and/or to the radiator 212 when a common fluid is used. The drive motor fluid pump 204 is controlled by electronics 208, which may include a digital computer, memory, and/or data processing and controlling components. The drive motor fluid pump 204 may include control valves to control flow of fluid between the drive motor 102A and/or 102B, the reservoir 206, and the heat exchanger 210 (and battery 106 coolant tubes 214 in other embodiments). The heat exchanger 210 may also include valves to direct the flow of coolant to the battery 106 coolant tubes 214 and to the radiator 212, under control of electronics 208 in some embodiments.

[0029] Further illustrated in FIG. 2 are drive motor electronics 216 that receive electrical power from the battery 106 and power the drive motor 102A and/or 102B. The drive motor electronics 216 include power electronics and control electronics. The power electronics may include an inverter to drive a stator of the drive motor 102A and/or 102B. The control electronics may include processing circuitry and memory. The processing circuitry may be a central processing unit, customized control circuitry, or other circuitry that is configured to execute software instructions and process data. The memory may include RAM, ROM, DRAM, static RAM, flash RAM, flash ROM, or another type of memory capable of storing software instructions and/or data.

[0030] FIG. 3 illustrates components of a drive motor 102A (or 102B) and a portion of the components of a drive motor cooling system 200 according to a disclosed embodiment. The drive motor 102A includes a case 302, a stator 304 coupled to the case 302 that includes end-windings 305, stator drive electronics (not shown), at least one rotor bearing coupled to the case (not shown in FIG. 3), and a rotor 303 coupled to the case 302 via at least one rotor bearing. The rotor 303 includes a hollow cylindrical body 308 having an inner wall 310, an outer wall 312, a first distal end, and a second distal end. The rotor 303 also includes a first shaft portion 314 coupled to a first distal end of the hollow cylindrical body 308 and a second shaft portion 316 coupled to a second distal end of the hollow cylindrical body 308. The second shaft portion 316 includes a fluid feed tube 318 formed therewith having a fluid receive end 320 and a fluid feed end 322. The fluid feed end 322 extends to a central inner portion of the hollow cylindrical body 308. The fluid feed end 322 of the second shaft portion 316 includes a plurality of fluid spray ports 324 configured to spray fluid onto the inner wall 310 of the hollow cylindrical body 308. The rotor 303 also includes a plurality of fluid exit ports 326 formed adjacent the first distal end and second distal end of the hollow cylindrical body 308.

[0031] A distance from the inner wall 310 of the hollow cylindrical body 308 to the plurality of fluid exit ports 326 is based upon a specified fluid thickness to support rotor cooling while the rotor 303 rotates, e.g., when the motor 102A is causing movement of a serviced vehicle 100. Such specified fluid thickness is based upon viscosity of the fluid, rotational velocity of the rotor 303, and temperature of the fluid. The relationship between the inner wall 310, the plurality of fluid exit ports 326, and the specified fluid thickness will be described further with reference to FIGs. 4 and 5.

[0032] The rotor 303 also includes a cylindrical laminated stack 306 coupled to the outer wall 312 of the hollow cylindrical body 308. The cylindrical laminated stack 306 includes a plurality of permanent magnets and insulating material. The stator 304 includes a plurality of stator windings (not shown) that are intercoupled by the stator end-windings 305. In one embodiment, the electric motor is a three phase 4-pole electric motor. In such embodiment, the stator 304 includes three different phase windings in a 4-pole configuration and the cylindrical laminated stack 306 includes magnets placed to correspond to the three phase 4-pole configuration.

[0033] The drive motor fluid pump 204 has a drive motor fluid pump output 307 and a drive motor fluid pump input 309. The drive motor cooling system 200 includes fluid circulation piping having an output portion coupled between the drive motor fluid pump output

307 and the fluid receive end 320 of the rotor second shaft portion 316. Further, the fluid circulation piping includes an input portion coupled between a fluid collection opening 311 in the case 302 and the drive motor fluid pump input 309. The drive motor fluid pump electronics 208 direct the drive motor fluid pump 204 (and associated valves) to pump fluid from the reservoir 206 into the fluid receive end 320 of the fluid feed tube 318. The fluid is recirculated to the drive motor fluid pump 204 via the fluid collection opening 311 in the case 302. The stator drive electronics and the drive motor fluid pump electronics are designed to operate in an inactive mode, a waste heat mode, and a rotor/stator cooling mode.

[0034] In the waste heat mode, the stator drive electronics provide electrical power to the stator 304 without causing rotation of the rotor 303. Further, in the waste heat mode, the drive motor fluid pump 204 at least substantially fills the hollow cylindrical body 308 with fluid. This waste heat mode operation causes the drive motor fluid pump 204 to circulate fluid on end-windings 305 of the stator 304 to heat the fluid. The waste heat generated from the end-windings 305 of the stator 304 is collected by the fluid and circulated to the heat exchanger 210. The heated fluid may then be routed to the coolant tubes 214 of the battery to heat the battery 106. These operations are described further herein with reference to FIG. 7.

[0035] In the rotor/stator cooling mode, the stator drive electronics provide electrical power to the stator 304 to cause rotation of the rotor 303 based upon the power requirements of the driving situation of the electric vehicle 100. Further, the drive motor fluid pump 204 circulates fluid to manage the operating temperature of the rotor 303 and the stator 304 of the electric motor. The drive motor fluid pump 204 circulates the fluid to the heat exchanger 210. The heat exchanger 210 may cool the fluid or use heat from the fluid for battery 106 warming.

[0036] FIG. 4 illustrates components of a drive motor 102A and a portion of the components of a drive motor cooling system according to a disclosed embodiment, particularly showing the manner in which fluid flows. Numbering between FIGs. 3 and 4 is consistent with arrows included in FIG. 4 to illustrate fluid flow and heat flow. At box reference 1 of FIG. 4, fluid (oil in the embodiment of FIG. 4) enters the fluid feed tube 318 at the fluid receive end 320. The fluid feed tube 318, which may be a forged internal extension of the second shaft portion 316, transports the fluid towards the fluid feed end 322 of the second shaft portion 316. At box reference number 2 of FIG. 4, fluid exits the fluid feed tube 318 via fluid spray ports 324. The pressure of pumping of the fluid and centrifugal force when the rotor 303 is spinning causes the fluid to be received upon the inner wall 310 of the hollow cylindrical body 308. When the rotor 303 is spinning, as indicated at box reference number 3 of FIG. 4, the oil builds up a 0.5mm thick layer (or other thickness in other embodiments) on a central portion of the inner wall 310 and runs along the inner wall 310 towards the fluid exit ports 326. As indicated at box reference number 4 of FIG. 4, the fluid exits the rotor 303 via the fluid exit ports 326 providing constant flow and heat transport.

[0037] Note that in FIGs. 3 and 4, drive motor fluid pump 204 is not a regular coolant pump. The fluid that the drive motor fluid pump 204 pumps through the rotor 303 cannot be water/glycol fluid, which is not dielectric liquid, but is oil and, thus, the drive motor fluid pump 204 is an oil pump in embodiments described herein. Further, the rotor cooling structure and method described herein may be used with any other stator cooling method. The rotor cooling described herein may be in series or in parallel with one or more stator cooling branches.

[0038] FIGs. 5A and 5B illustrate a rotor 303 according to a representative embodiment, detailing the construct of fluid exit ports within a hollow central portion of the rotor 303. As shown, fluid exits the fluid exit ports 326 from the interior of the rotor 303. In the waste heat mode, the drive motor drive motor fluid pump fills the hollow cylindrical body 308 with fluid and the fluid is forced out of the fluid exit ports 326 by pumping pressure.

[0039] Referring to all of FIGs. 4, 5A and 5B, during the rotor/stator cooling mode, the centrifugal force caused by the rotor's 303 rotation causes the fluid to form a film on the inner wall 310 of the hollow cylindrical body 308. Thickness of the film as it moves along the inner wall is based upon a distance from the outermost portion of the fluid exit ports 326 and the inner wall 310 as well as fluid properties such as viscosity and temperature, angular velocity of the rotor 303, and other factors. In one embodiment, this dimension is 0.5 mm. The fluid flows from a central portion of the inner wall 310 to distal portions of the hollow cylindrical body 308 in which the plurality of fluid exit ports 326 are formed. The fluid is at a first temperature when it exits the fluid spray ports 324 and is collected on the inner wall 310 at the central portion. As the fluid flows along the inner wall 310 towards the distal ends of the hollow cylindrical body 308 it collects heat from the rotor 303 and the fluid is at a second temperature, which is higher than the first temperature. Thus, with the structure of the rotor cooling system, more cooling is provided to a central portion of the rotor 303, at which more heat is generated. This benefit results in more uniform temperature control of the rotor 303.

[0040] FIGs. 6A, 6B, 6C, and 6D illustrate operation of a drive motor according to one or more embodiments of the present disclosure. The rotor 303 includes at least one oil distribution ring 602 fixed to the rotor 303. The oil distribution ring 602 deflects fluid (oil) exiting the hollow cylindrical body 308 via the fluid exit ports 326 towards the stator end-windings 305. Deflection of the fluid is performed both during the waste heat mode and the rotor/stator cooling mode. FIG. 6A details the oil distribution ring 602 located on a proximal end of the rotor 303. FIG. 6B shows fluid flow (direction of arrow) from the inside of the hollow cylindrical body 308, out of fluid exit port 326, against the oil distribution ring 602, and towards the stator end-windings 305. FIG. 6C illustrates fluid flow from the oil distribution ring 602 towards the stator end-windings 305. FIG. 6D illustrates fluid flow from fluid exit port 326 past the laminated stack 306 towards the stator end-windings 305.

[0041] FIG. 7 is a flow diagram illustrating electric motor cooling and battery heating operations 700 according to a disclosed embodiment. As shown, the electric motor cooling and battery heating operations include an inactive mode (step 702), a waste heat mode (step 704) and a rotor/stator cooling mode (step 718). The inactive mode (step 702) is used when the electric car is not being used, when the battery 106 is in an acceptable operating temperature range, and/or when the rotor/stator do not require cooling. The waste heat mode (step 704) is enacted when the thermal management of the battery 106 (or another component of the electric vehicle 100) requires warming of the battery 106. In cold locations, the temperature of the battery 106 may be as low as -30 degrees Fahrenheit due to ambient temperature. In order for the battery 106 to be sufficiently functional to drive the electrical vehicle 100, the temperature of the battery 106 must be raised to at least – 10 degrees Fahrenheit. The waste heat mode (step 704) serves this purpose.

[0042] In waste heat mode, the stator of the electric motor is powered to heat end-windings of the stator (and other portions of the stator 304 as well as the rotor 303) without causing the rotor 303 of the electric motor to rotate (step 706). Such stator 304 powering without rotor 303 rotation may be accomplished by applying DC voltage/current to the stator windings by the stator drive electronics. Alternately, stator 304 powering without rotor 303 rotation may be accomplished by applying the same AC drive signal to each of the phases of the stator windings. The drive motor fluid pump 204 is then operated to pump fluid into the hollow cylindrical body 308 of the rotor 303 (step 708). Such pumping continues until the hollow cylindrical body 308 is at least substantially filled. By continuing pumping until the hollow cylindrical body 308 is filled, fluid exits the hollow cylindrical body 308 via the fluid exit ports 326 and flows onto the stator end-windings 305 where the fluid gathers heat from the stator end-windings 305 (step 710). The oil distribution ring 602 may assist in directing the fluid onto the stator end-windings 305. The operation of step 710 may result in the case 302 of the electric motor being at least substantially filled with fluid. The heated fluid is then pumped to heat exchanger 210 to heat coolant circulating therethrough (step 712). The heated coolant is then circulated via the coolant tubes 214 to heat the battery 106 (step 714). The fluid heating and circulation operations are continued until the battery is heated to an acceptable operating temperature (as determined at step 716). Once the battery is heated to the acceptable operating temperature, operation returns to the inactive mode (step 702).

[0043] The waste heat mode may commence with first warming the drive motor fluid pump 204 and fluid to an acceptable operating temperature. In one embodiment, the drive motor fluid pump 204 is submerged in the fluid reservoir 206 and acts as a small heater for the fluid. In such case, the drive motor fluid pump 204 is operated very inefficiently to produce only heat and to produce little to no torque. Once the drive motor fluid pump 204 and fluid are warmed, the waste heat mode may continue to warm the battery 106. Local hot spots allow to drive motor fluid pump 204 to suck in fluid and around the drive motor fluid pump 204 into the downstream cooling and lubrication system by sucking cold oil in at the same time. This cold oil will be heated up subsequently, which will raise the fluid temperature even faster to continue with the waste heat mode.

[0044] The waste heat mode operations 704 of FIG. 7 may be performed using differing rotor and stator structures than those described previously herein. For example, a differing fluid feed tube structure may be used to feed the fluid into the hollow cylindrical body 308 of the rotor. In such example, the fluid feed tube may be separate from the shaft of the rotor. Further, differing structure may be employed for the fluid to exit the hollow cylindrical body 308 of the rotor and/or to be directed onto the end-windings 305 of the stator.

[0045] In the rotor/stator cooling mode (step 718), the stator is enabled to rotate the rotor as required to propel the electric vehicle 100 (step 720). Fluid is pumped into the hollow cylindrical body 308 by the drive motor fluid pump 204 at a selected flow rate (step 722). The fluid flows along the inner wall 310 of the hollow cylindrical body 308 towards the distal ends of the hollow cylindrical body 308, collecting heat from the rotor 303 along the way, and then exits the hollow cylindrical body 308 via the fluid exit ports 326 towards the end-windings 305 of the stator (step 724). The fluid is then optionally routed to the heat exchanger 210 for cooling of the fluid (step 726). If a flow rate adjustment is necessary to alter the cooling rate (as determined at step 728), the fluid flow rate is modified (step 730). If not, operation returns to step 722. The rotor/stator cooling mode is ceased when the car ceases operations or if the rotor/stator no longer needs cooling.

[0046] In the foregoing specification, the disclosure has been described with reference to specific embodiments. However, as one skilled in the art will appreciate, various embodiments disclosed herein can be modified or otherwise implemented in various other ways without departing from the spirit and scope of the disclosure. Accordingly, this description is to be considered as illustrative and is for the purpose of teaching those skilled in the art the manner of making and using various embodiments of the disclosed system, method, and computer program product. It is to be understood that the forms of disclosure herein shown and described are to be taken as representative embodiments. Equivalent elements, materials, processes or steps may be substituted for those representatively illustrated and described herein. Moreover, certain features of the disclosure may be utilized independently of the use of other features, all as would be apparent to one skilled in the art after having the benefit of this description of the disclosure.

[0047] Routines, methods, steps, operations, or portions thereof described herein may be implemented through electronics, e.g., one or more processors, using software and firmware instructions. A “processor” includes any hardware system, hardware mechanism or hardware component that processes data, signals or other information. A processor can include a system with a central processing unit, multiple processing units, dedicated circuitry for achieving functionality, or other systems. Some embodiments may be implemented by using software programming or code in one or more digital computers or processors, by using application specific integrated circuits (ASICs), programmable logic devices, field programmable gate arrays (FPGAs), optical, chemical, biological, quantum or nano-engineered systems, components and mechanisms. Based on the disclosure and teachings representatively provided herein, a person skilled in the art will appreciate other ways or methods to implement the invention.

[0048] As used herein, the terms “comprises,” “comprising,” "includes," "including," "has," "having" or any contextual variants thereof, are intended to cover a non-exclusive inclusion. For example, a process, product, article, or apparatus that comprises a list of elements is not necessarily limited to only those elements, but may include other elements not expressly listed or inherent to such process, product, article, or apparatus. Further, unless expressly stated to the contrary, "or" refers to an inclusive or and not to an exclusive or. For example, a condition “A or B” is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B is true (or present).

[0049] Although the steps, operations, or computations may be presented in a specific order, this order may be changed in different embodiments. In some embodiments, to the extent multiple steps are shown as sequential in this specification, some combination of such steps in alternative embodiments may be performed at the same time. The sequence of operations described herein can be interrupted, suspended, reversed, or otherwise controlled by another process.

[0050] It will also be appreciated that one or more of the elements depicted in the drawings/figures can also be implemented in a more separated or integrated manner, or even removed or rendered as inoperable in certain cases, as is useful in accordance with a particular application.

CLAIMS:

1. An electric motor comprising:

a case;

a stator that includes end-windings; and

a rotor coupled to the case via rotor bearings, the rotor comprising:

a hollow cylindrical body having an inner wall, an outer wall, a first distal end, and a second distal end;

a first shaft portion coupled to the first distal end of the hollow cylindrical body;

a second shaft portion coupled to the second distal end of the hollow cylindrical body;

a fluid feed tube having a fluid receive end and a fluid feed end, the fluid feed end extending into the hollow cylindrical body; and

a plurality of fluid exit ports;

a drive motor fluid pump to pump fluid into the fluid receive end of the fluid feed tube; and

drive motor electronics, wherein in a waste heat mode:

the drive motor electronics power the stator without causing rotation of the rotor;

the drive motor fluid pump at least partially fills the hollow cylindrical body with the fluid to force the fluid from the hollow cylindrical body to collect heat from the stator end-windings; and

the drive motor fluid pump circulates the fluid to a heat exchanger for heating a battery.

2. The electric motor of claim 1, wherein the second shaft portion includes the fluid feed tube formed therein.

3. The electric motor of claim 1, further comprising fluid circulation piping having:

an output portion coupled between the drive motor fluid pump output and the fluid receive end of the second shaft portion; and

an input portion coupled between a fluid collection point on the case and the drive motor fluid pump input.

4. The electric motor of claim 1, further comprising a radiator configured to cool the fluid.

5. The electric motor of claim 4, further comprising a heat exchanger coupled between the drive motor fluid pump and the radiator.

6. The electric motor of claim 1, wherein the fluid feed end of the fluid feed tube comprises a plurality of fluid spray ports configured to spray fluid onto the inner wall of the hollow cylindrical body.

7. The electric motor of claim 1, further comprising an oil distribution ring coupled to the rotor and configured to deflect fluid from the plurality of fluid exit ports to the stator end-windings.

8. An electric motor comprising:

a case;

a stator that includes end-windings; and

a rotor coupled to the case via rotor bearings, the rotor comprising:

a hollow cylindrical body, a first shaft portion, and a second shaft portion;

a fluid feed tube having a fluid receive end and a fluid feed end, the fluid feed end extending into the hollow cylindrical body; and

a plurality of fluid exit ports forming corresponding passages between an interior of the hollow cylindrical body and an exterior of the hollow cylindrical body;

a drive motor fluid pump to pump fluid into the fluid receive end of the fluid feed tube; and

drive motor electronics, wherein in a waste heat mode:

the drive motor electronics power the stator without causing rotation of the rotor;

the drive motor fluid pump circulates fluid into the hollow cylindrical body via the fluid feed tube, out of the plurality of fluid ports, and onto the stator end-windings to collect heat from the rotor and the stator; and

the drive motor fluid pump circulates the fluid to a heat exchanger for heating a battery.

9. The electric motor of claim 8, wherein the second shaft portion includes the fluid feed tube formed therein.

10. The electric motor of claim 9, wherein the fluid feed tube is oriented along an axis of rotation of the rotor.

11. The electric motor of claim 8, further comprising fluid circulation piping having:

an output portion coupled between the drive motor fluid pump output and the fluid receive end of the second shaft portion; and

an input portion coupled between a fluid collection point on the case and the drive motor fluid pump input.

12. The electric motor of claim 8, further comprising a radiator configured to cool the fluid.

13. The electric motor of claim 12, further comprising a heat exchanger coupled between the drive motor fluid pump and the radiator.

14. The electric motor of claim 8, wherein the fluid feed end of the fluid feed tube comprises a plurality of fluid spray ports configured to spray fluid into the hollow cylindrical body.

15. The electric motor of claim 8, further comprising an oil distribution ring coupled to the rotor and configured to deflect fluid from the plurality of fluid exit ports to the stator end-windings.

16. A method for operating an electric motor comprising:

powering a stator of the electric motor to heat end-windings of the stator without causing a rotor of the electric motor to rotate;

pumping fluid into a hollow cylindrical body of the rotor via a fluid feed tube, out of the hollow cylindrical body of the rotor via a plurality of fluid exit ports, and the end-windings of the stator to collect heat from at least the end-windings of the stator to produce heated fluid; and

pumping the heated fluid to a heat exchanger for heating a battery.

17. The method of claim 16, wherein the fluid feed tube that is oriented along an axis of rotation of the rotor.

18. The method of claim 16, wherein pumping the fluid into the hollow cylindrical body includes spraying the fluid from the fluid feed tube onto an inner wall of the hollow cylindrical body of the rotor.

19. The method of claim 18, wherein spraying the fluid from the fluid feed tube includes spraying the fluid onto a central portion of the inner wall of the hollow cylindrical body.

20. The method of claim 16, further comprising circulating coolant between the heat exchanger and the battery, wherein the coolant is heated by the heated fluid in the heat exchanger.

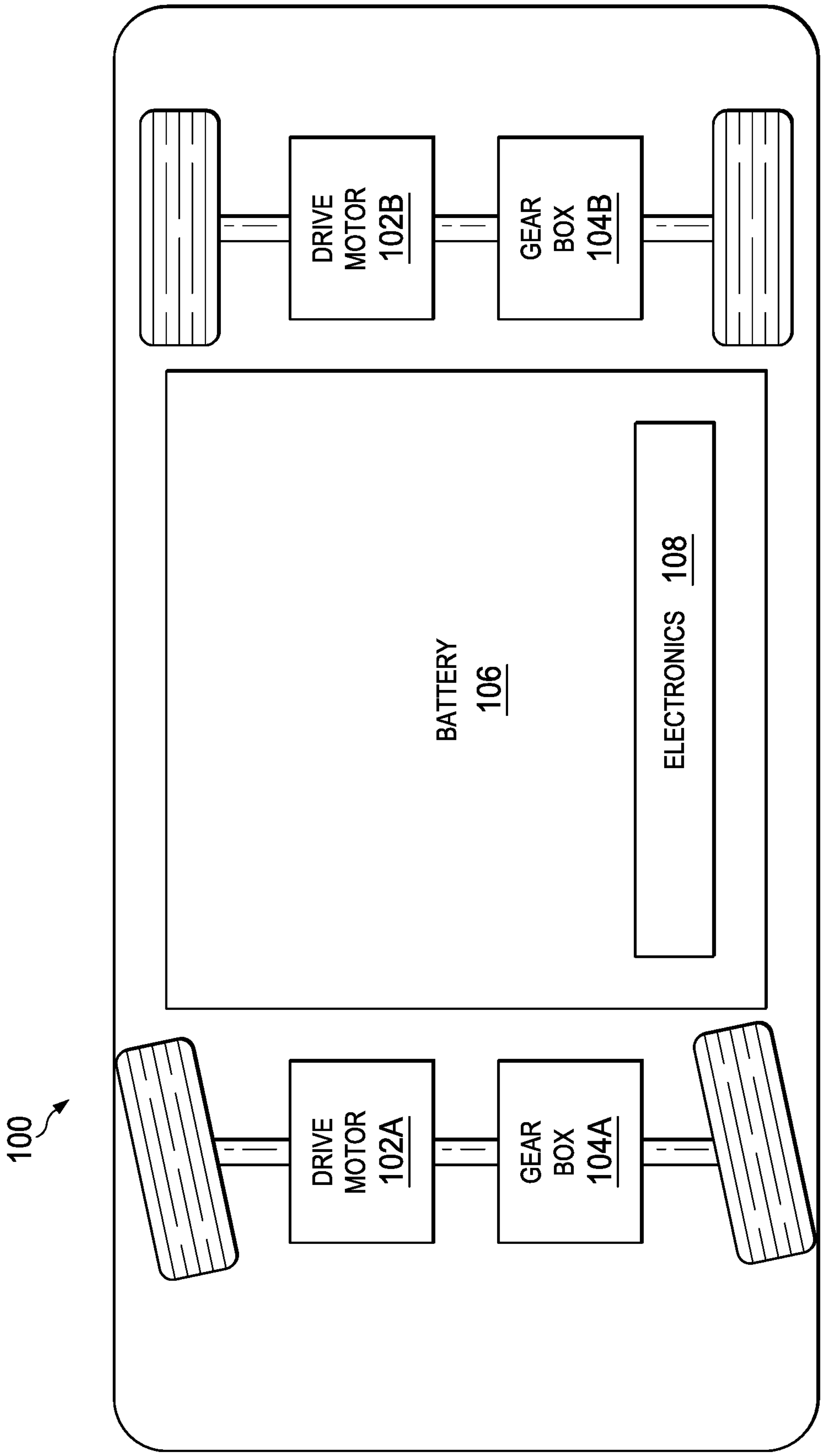

100
DRIVE MOTOR 102B
GEAR BOX 104B
BATTERY 106
ELECTRONICS 108
DRIVE MOTOR 102A
GEAR BOX 104A

FIG. 1

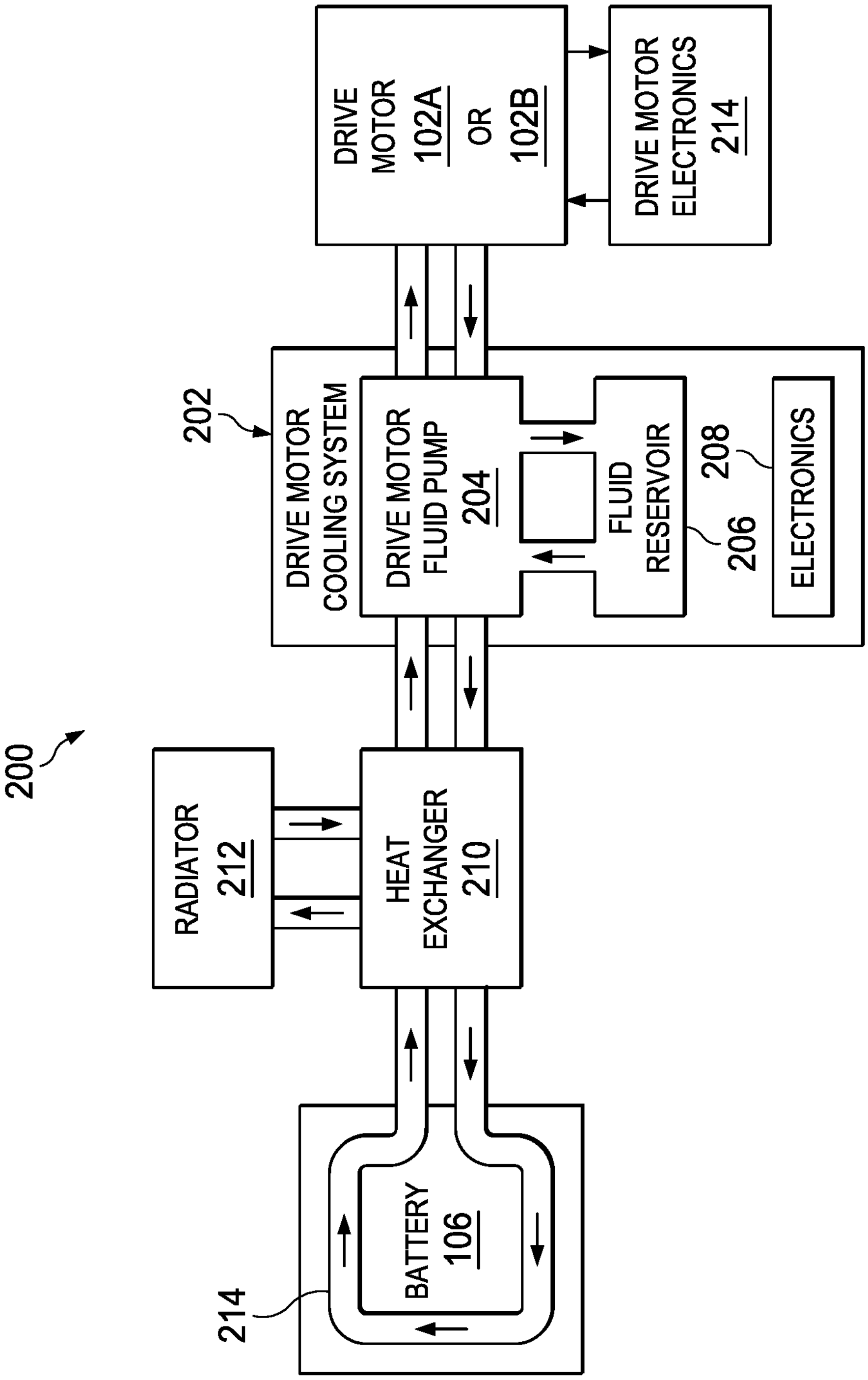

DRIVE MOTOR
102A
OR
102B
DRIVE MOTOR ELECTRONICS
214
202
DRIVE MOTOR COOLING SYSTEM
DRIVE MOTOR FLUID PUMP
204
FLUID RESERVOIR
206
208
ELECTRONICS
200
RADIATOR
212
HEAT EXCHANGER
210
BATTERY
106
214

FIG. 2

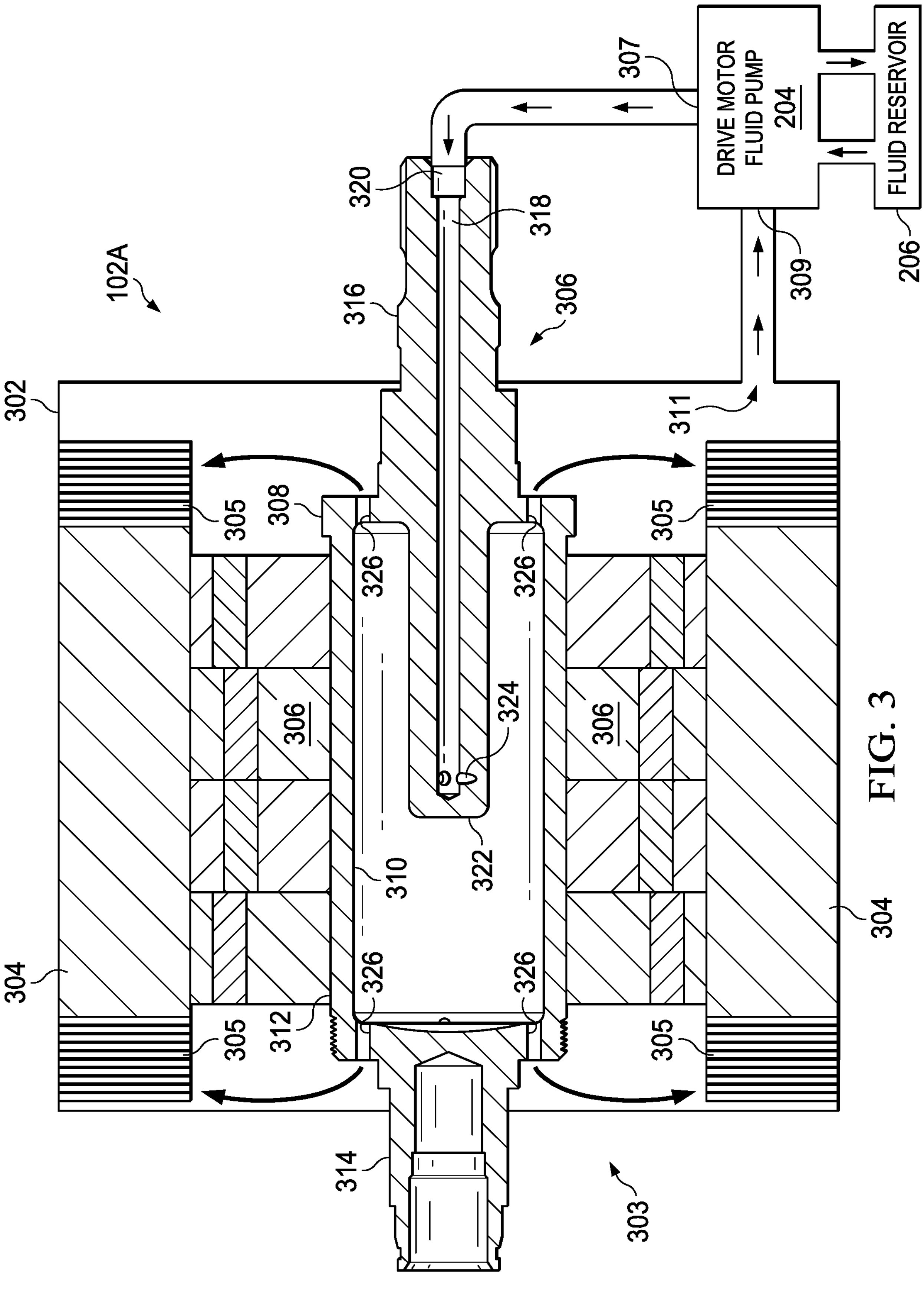
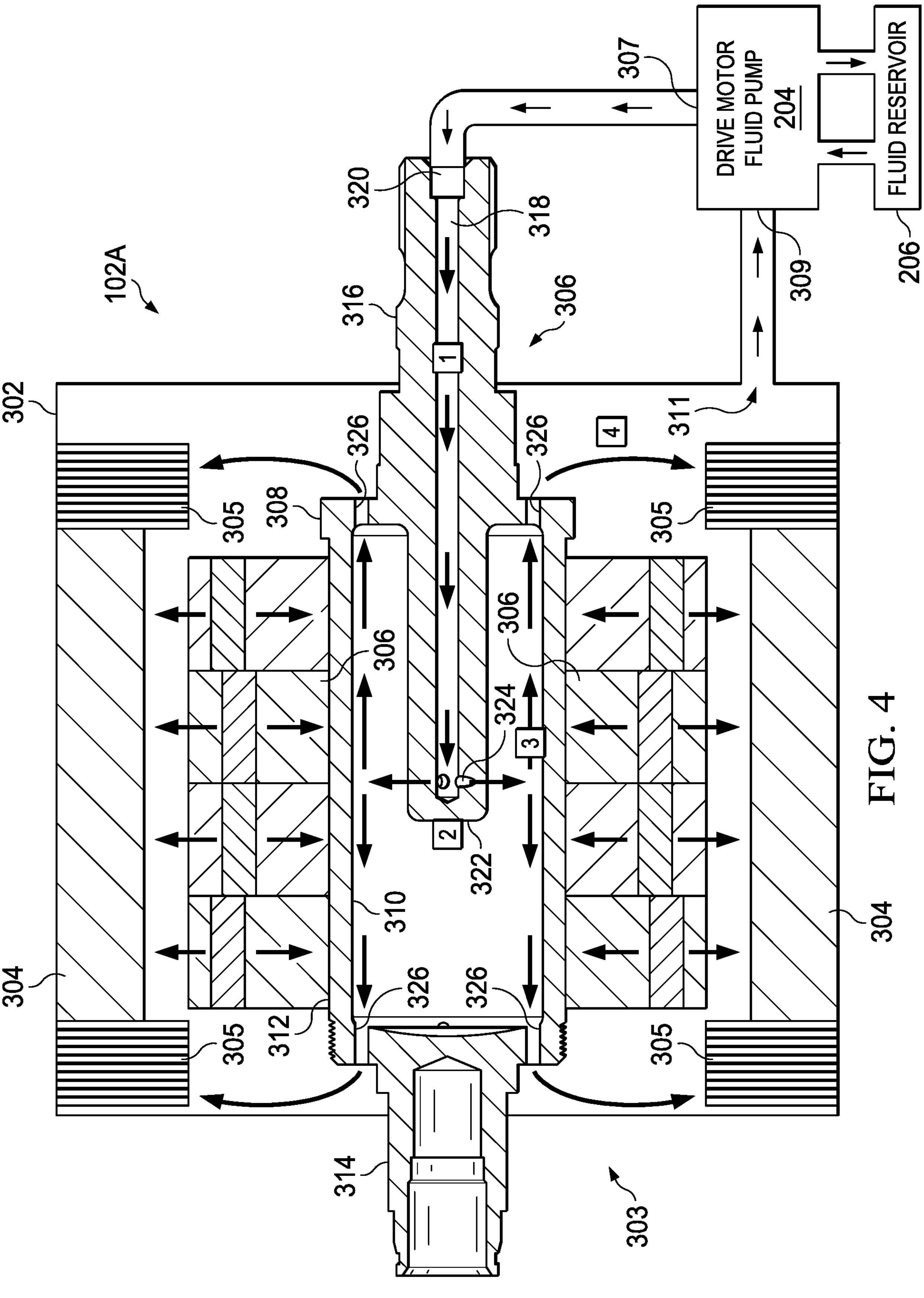

DRIVE MOTOR FLUID PUMP
204
FLUID RESERVOIR
206
307
309
311
320
318
316
306
102A
302
305
308
326
324
322
310
312
304
314
303

FIG. 3


DRIVE MOTOR
FLUID PUMP
204
FLUID RESERVOIR
206
307
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311
320
318
316
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102A
302
304
305
308
326
310
312
314
303
324
322
1
2
3
4

FIG. 4

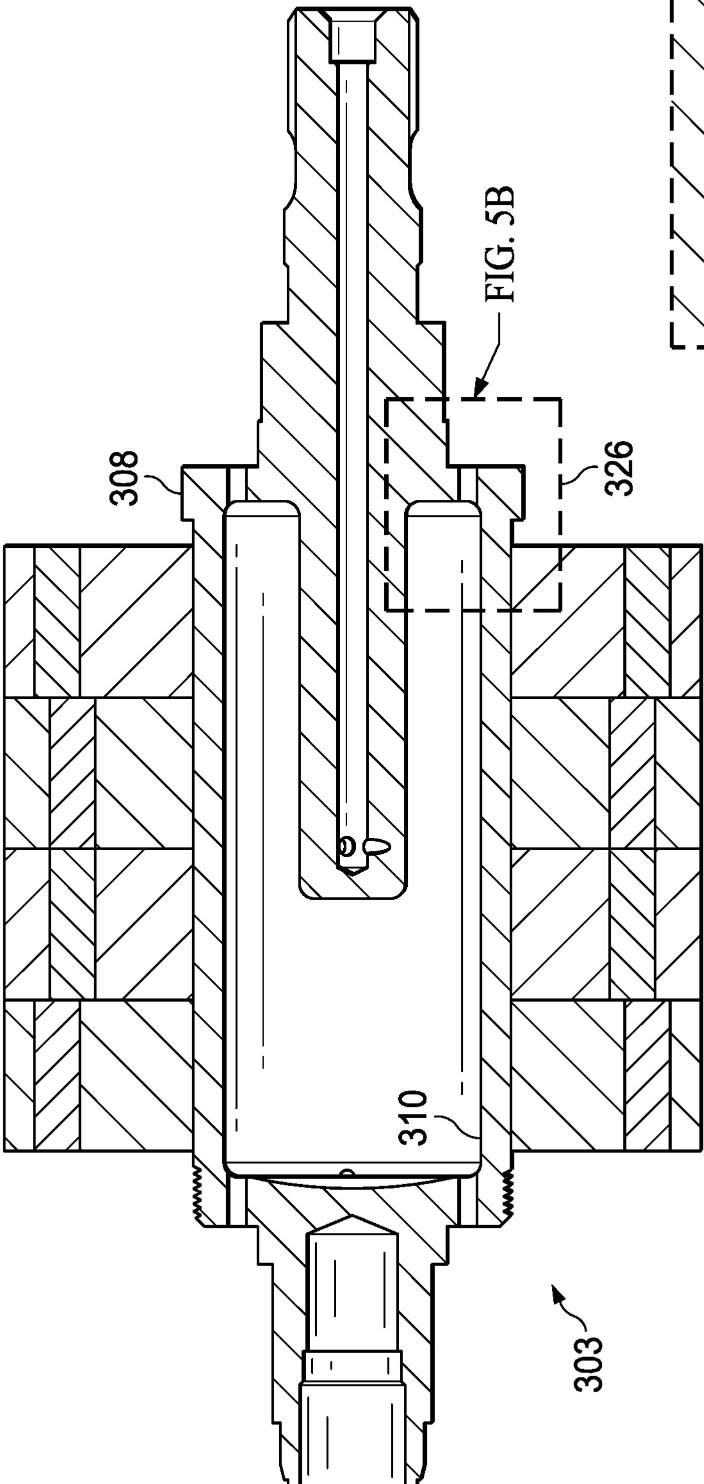

FIG. 5A

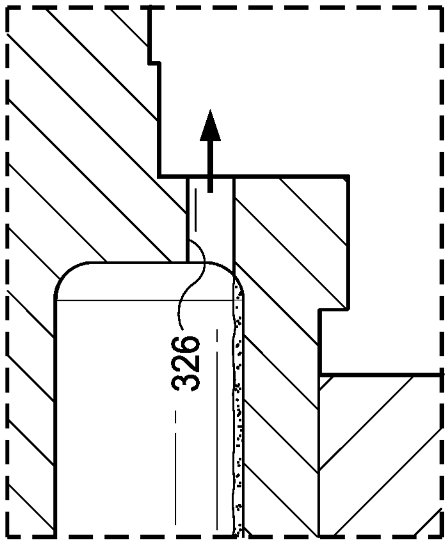

FIG. 5B

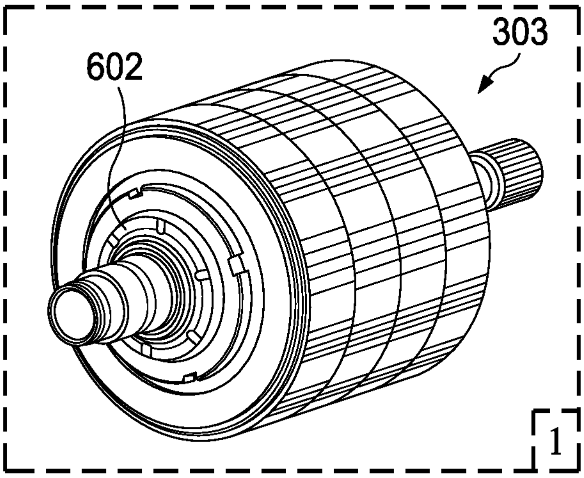

FIG. 6A

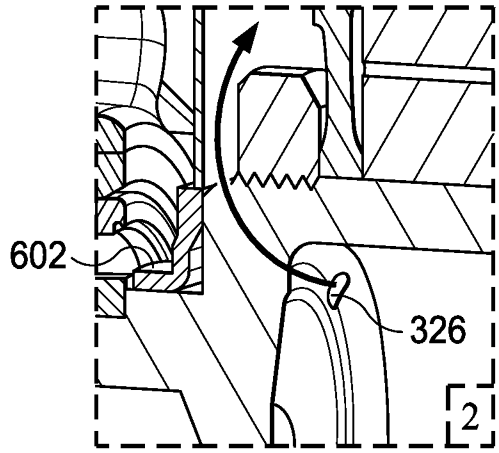

FIG. 6B

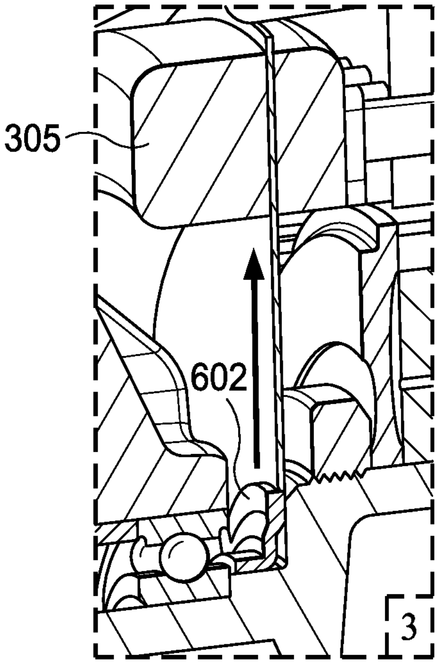

FIG. 6C

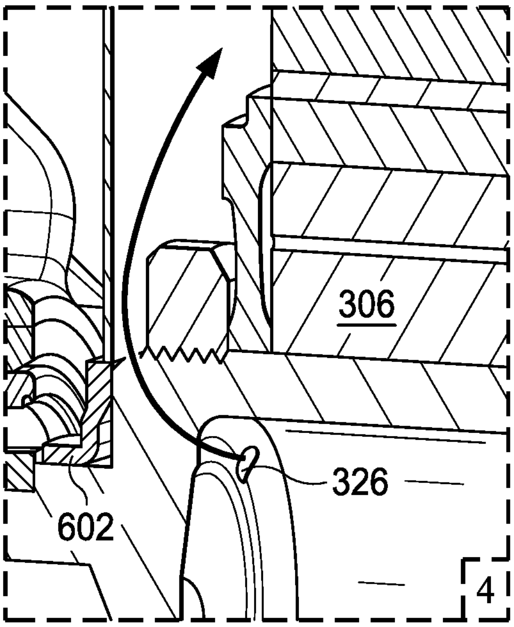

FIG. 6D

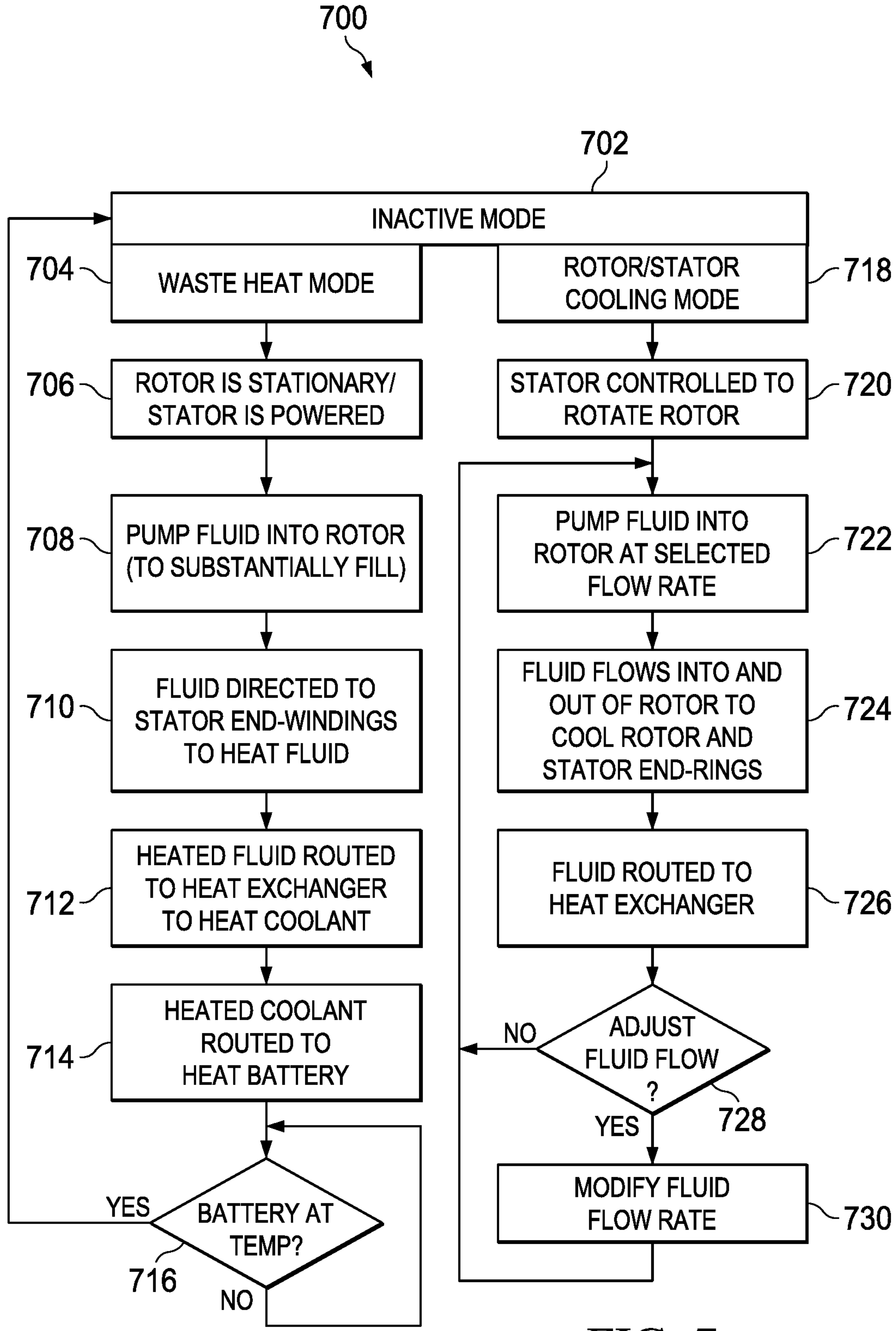
700
702
INACTIVE MODE
704
WASTE HEAT MODE
ROTOR/STATOR COOLING MODE
718
706
ROTOR IS STATIONARY/ STATOR IS POWERED
STATOR CONTROLLED TO ROTATE ROTOR
720
708
PUMP FLUID INTO ROTOR (TO SUBSTANTIALLY FILL)
PUMP FLUID INTO ROTOR AT SELECTED FLOW RATE
722
710
FLUID DIRECTED TO STATOR END-WINDINGS TO HEAT FLUID
FLUID FLOWS INTO AND OUT OF ROTOR TO COOL ROTOR AND STATOR END-RINGS
724
712
HEATED FLUID ROUTED TO HEAT EXCHANGER TO HEAT COOLANT
FLUID ROUTED TO HEAT EXCHANGER
726
714
HEATED COOLANT ROUTED TO HEAT BATTERY
NO
ADJUST FLUID FLOW ?
728
YES
YES
BATTERY AT TEMP?
716
NO
MODIFY FLUID FLOW RATE
730

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/036290

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02K9/197 H02K1/32 H02K9/193
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H02K B60H B60L

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 4 447410 B2 (HONDA MOTOR CO LTD) 7 April 2010 (2010-04-07)	1-3,6, 8-11,14, 16-20
Y	paragraph [0017] - paragraph [0034]; figures 1,2	4,5,12, 13
X	US 2011/309698 A1 (KIRKLEY JR THOMAS E [US] ET AL) 22 December 2011 (2011-12-22) paragraph [0097] - paragraph [0099] paragraph [0106] paragraph [0123] - paragraph [0129]; figures 12-14	1-20
X	US 2012/104884 A1 (WAGNER JON [US] ET AL) 3 May 2012 (2012-05-03) paragraph [0034] - paragraph [0035]; figure 5	1-3, 6-11, 14-20

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 July 2017	25/07/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Zavelcuta, Florin

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2013/136405 A1 (TOYOTA MOTOR CO LTD [JP]; HISHINUMA SHOJI [JP]; KITADA DAISUKE [JP]; M) 19 September 2013 (2013-09-19) abstract; figures 1,12	1-3, 6-11, 14-20
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X	US 2016/099633 A1 (YOSHINORI MANABU [JP] ET AL) 7 April 2016 (2016-04-07) paragraph [0029] - paragraph [0057]; figures 1-3	1-3, 6-11, 14-20
Y	EP 2 977 254 A1 (ATIEVA INC [US]) 27 January 2016 (2016-01-27) paragraph [0032] - paragraph [0033]; figure 5	4,5,12, 13
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1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2017/036290

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			WO	2011163226	A2	29-12-2011
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			US	2016013704	A1	14-01-2016
			WO	2012061439	A2	10-05-2012
WO 2013136405	A1	19-09-2013	NONE			
EP 2667486	A2	27-11-2013	BR	102013012881	A2	07-07-2015
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			EP	2667486	A2	27-11-2013
			US	2013313928	A1	28-11-2013
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			JP	5911033	B1	27-04-2016
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			EP	2977254	A1	27-01-2016
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			EP	2724450	A2	30-04-2014
			JP	5734765	B2	17-06-2015
			JP	2013009508	A	10-01-2013
			US	2014125165	A1	08-05-2014
			WO	2012176052	A2	27-12-2012