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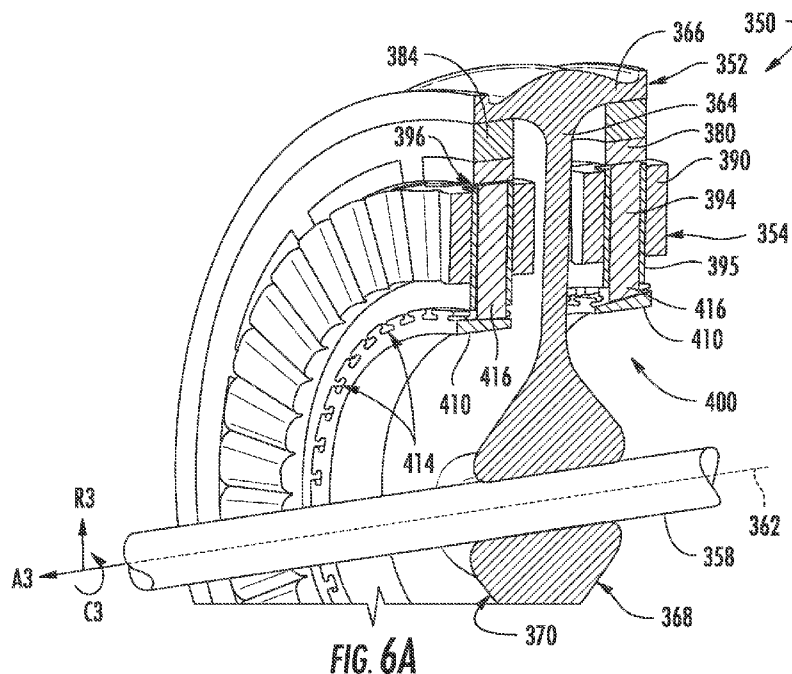
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(57) Abstract: An electric machine is provided which includes a rotor disk extending along a radial direction and having a rotor flange attached to or formed integrally with the rotor disk and extending substantially along the axial direction. A plurality of rotor magnets are mounted on the rotor disk and positioned against the rotor flange. The electric machine includes a stator assembly including a tracking tooth in magnetic flux communication with the rotor magnets across an air gap. The stator assembly further includes an actuator operable with the tracking tooth to move the tracking tooth along the radial direction to adjust a height of the air gap.



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**Declarations under Rule 4.17:**

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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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## HIGH SPEED ELECTRIC MACHINE

## FIELD

[0001] The present subject matter relates generally to an electric machine, and more particularly, to a high speed electric machine.

## BACKGROUND

[0002] Electric machines, e.g., electric motors and generators, are used in a variety of industries to convert electrical energy to mechanical energy, and vice versa, for useful purposes. For example electric machines are used in the automotive, aviation, maritime, and other industries to operate aircrafts, helicopters, automobiles, boats, submarines, trains, and/or any other suitable vehicles.

[0003] To reduce fuel consumption and improve propulsive efficiency, it is generally desirable to use electric machines with large power densities, referred to herein as the electric machine's specific power or power-to-weight ratio. Electric machines having a high specific power may be smaller and more lightweight while generating equivalent or greater power than heavier electric machines.

[0004] Increasing the rotation speeds of electric machines is known to increase power-to-weight ratios. However, as the rotational speeds increase, the stresses on the various rotating components of the electric machine also increase. For example, certain electric machines use a disk retaining structure which allows for much higher tip speeds and power densities than conventional machines. However, as the rotor disk experiences large centrifugal forces during high speed operation, the rotor disk may creep or stretch slightly, which may affect the specific power of the electric machine.

[0005] More specifically, electric machines have an air gap between the rotor and the stator assemblies. The size of the air gap has an effect on the interaction of magnetic fields generated by the rotor assembly and the stator assembly, and thus on the performance and efficiency of the motor in general. During high speed operation, the rotor disk might stretch slightly, thus increasing the size of the airgap between a rotor and a stator, and affecting the specific power of the electric machine.

[0006] Accordingly, an electric machine with features for improving specific power and efficiency is desirable. More specifically, an electric machine with features for adjusting an air gap between a stator assembly and a rotor assembly to improve performance of the electric machine would be particularly beneficial.

## BRIEF DESCRIPTION

[0007] Aspects and advantages of the invention will be set forth in part in the following description, or may be obvious from the description, or may be learned through practice of the invention.

[0008] In one exemplary embodiment of the present disclosure, an electric machine defining an axial direction, a radial direction, and a circumferential direction is provided. The electric machine includes a rotor disk rotatable about the axial direction and a rotor flange attached to or formed integrally with the rotor disk and extending from the rotor disk substantially along the axial direction. A plurality of rotor magnets is mounted to the rotor flange. A stator assembly includes a tracking tooth operable with the rotor magnets to produce a torque, the tracking tooth being spaced apart from the rotor magnets along the radial direction to define an air gap. An actuator assembly is operable with the tracking tooth for moving the tracking tooth along the radial direction to adjust a height of the air gap.

[0009] In another exemplary embodiment of the present disclosure, a method for operating an electric machine is provided. The electric machine defines an axial direction and a radial direction. The electric machine includes a rotor disk rotatable about the axial direction, a rotor flange extending from the rotor disk generally along the radial direction, a rotor magnet mounted to the rotor flange, and a stator assembly including a tracking tooth operable with the rotor magnet to drive the electric machine. The method includes moving the tracking tooth of the stator assembly along the radial direction during operation of the electric machine to adjust an air gap height defined along the radial direction between the tracking tooth and the rotor magnet.

[0010] According to yet another exemplary embodiment of the present subject matter, an electric machine configured for driving a boundary layer ingestion fan mounted to an aft end of a fuselage of an aircraft is provided. The electric machine includes a drive shaft that is mechanically coupled to the boundary layer ingestion fan and defining an axial direction and a radial direction. A rotor disk is mounted to the drive shaft and being rotatable about the axial direction, the rotor disk extending from the drive shaft to a rotor tip substantially along the radial direction. A rotor flange is attached to or formed integrally with the rotor disk and extending from the rotor disk substantially along the axial direction and a plurality of rotor magnets are mounted to the rotor flange. A stator assembly includes a plurality of tracking teeth spaced apart from the rotor magnets along the radial direction to define an air gap and an actuator assembly configured for moving the tracking teeth along the radial direction to adjust a height of the air gap.

[0011] These and other features, aspects and advantages of the present invention will become better understood with reference to the following description and appended claims. The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0012] A full and enabling disclosure of the present invention, including the best mode thereof, directed to one of ordinary skill in the art, is set forth in the specification, which makes reference to the appended figures, in which:

[0013] FIG. 1 is a top view of an aircraft according to various exemplary embodiments of the present disclosure.

[0014] FIG. 2 is a port side view of the exemplary aircraft of FIG. 1

[0015] FIG. 3 is a schematic, cross-sectional view of a gas turbine engine mounted to the exemplary aircraft of FIG. 1.

[0016] FIG. 4 is a schematic, cross-sectional view of an aft engine in accordance with an exemplary embodiment of the present disclosure.

[0017] FIG. 5 is a schematic view of an electric machine and an actuator assembly for the exemplary aft engine of FIG. 4 in accordance with an exemplary embodiment of the present disclosure.

[0018] FIG. 6A is a perspective, cross-sectional view of an electric machine and an actuator assembly according to an exemplary embodiment of the present subject matter.

[0019] FIG. 6B is a perspective, cross-sectional view of the exemplary actuator assembly of FIG. 6A according to an exemplary embodiment of the present subject matter.

[0020] FIG. 6C is a cross-sectional view of the exemplary actuator assembly of FIG. 6A according to an exemplary embodiment of the present subject matter.

[0021] FIG. 7 is a schematic cross-sectional view of an electric machine and an actuator assembly according to another exemplary embodiment of the present subject matter.

[0022] FIG. 8 is a schematic cross-sectional view of an electric machine and an actuator assembly according to still another exemplary embodiment of the present subject matter.

[0023] FIG. 9 illustrates a method for operating the exemplary electric machine and actuator assembly of FIG. 5 according to an exemplary embodiment of the present subject matter.

## DETAILED DESCRIPTION

[0024] Reference will now be made in detail to present embodiments of the invention, one or more examples of which are illustrated in the accompanying drawings. The detailed description uses numerical and letter designations to refer to features in the drawings. Like or similar designations in the drawings and description have been used to refer to like or similar parts of the invention.

[0025] As used herein, the terms “first”, “second”, and “third” may be used interchangeably to distinguish one component from another and are not intended to signify location or importance of the individual components. The terms “forward” and “aft” refer to the relative positions of a component based on an actual or anticipated direction of travel. For example, “forward” may refer to a front of an aircraft based on an anticipated direction of travel of the aircraft, and “aft” may refer to a back of the aircraft based on an anticipated direction of travel of the aircraft. The terms “upstream” and “downstream” refer to the relative direction with respect to fluid flow in a fluid pathway. For example, “upstream” refers to the direction from which the fluid flows, and “downstream” refers to the direction to which the fluid flows.

[0026] Referring now to the drawings, wherein identical numerals indicate the same elements throughout the figures, FIG. 1 provides a top view of an exemplary aircraft 10 as may incorporate various embodiments of the present invention. FIG. 2 provides a port side view of the aircraft 10 as illustrated in FIG. 1. As shown in FIGS. 1 and 2 collectively, the aircraft 10 defines a longitudinal centerline 14 that extends therethrough, a vertical direction V, a lateral direction L, a forward end 16, and an aft end 18. Moreover, the aircraft 10 defines a mean line 15 extending between the forward end 16 and aft end 18 of the aircraft 10. As used herein, the “mean line” refers to a midpoint line extending along a length of the aircraft 10, not taking into account the appendages of the aircraft 10 (such as the wings 20 and stabilizers discussed below).

[0027] Moreover, the aircraft 10 includes a fuselage 12, extending longitudinally from the forward end 16 of the aircraft 10 towards the aft end 18 of the aircraft 10, and a pair of wings 20. As used herein, the term “fuselage” generally includes all of the body of the aircraft 10, such as an empennage of the aircraft 10. The first of such wings 20 extends laterally outwardly with respect to the longitudinal centerline 14 from a port side 22 of the fuselage 12 and the second of such wings 20 extends laterally outwardly with respect to the longitudinal centerline 14 from a starboard side 24 of the fuselage 12. Each of the wings 20 for the exemplary embodiment depicted includes one or more leading edge flaps 26 and one or more trailing edge flaps 28. The aircraft 10 further includes a vertical stabilizer 30 having a rudder flap 32 for yaw control, and a pair of horizontal stabilizers 34, each having an elevator flap 36 for pitch control. The fuselage 12 additionally includes an outer surface or skin 38. It should be appreciated however, that in

other exemplary embodiments of the present disclosure, the aircraft 10 may additionally or alternatively include any other suitable configuration of stabilizer that may or may not extend directly along the vertical direction V or horizontal/ lateral direction L.

[0028] The exemplary aircraft 10 of FIGS. 1 and 2 includes a propulsion system 100, herein referred to as “system 100”. The exemplary system 100 includes one or more aircraft engines and one or more electric propulsion engines. For example, the embodiment depicted includes a plurality of aircraft engines, each configured to be mounted to the aircraft 10, such as to one of the pair of wings 20, and an electric propulsion engine. More specifically, for the embodiment depicted, the aircraft engines are configured as gas turbine engines, or rather as turbofan jet engines 102, 104 attached to and suspended beneath the wings 20 in an under-wing configuration. Additionally, the electric propulsion engine is configured to be mounted at the aft end of the aircraft 10, and hence the electric propulsion engine depicted may be referred to as an “aft engine.” Further, the electric propulsion engine depicted is configured to ingest and consume air forming a boundary layer over the fuselage 12 of the aircraft 10. Accordingly, the exemplary aft engine depicted may be referred to as a boundary layer ingestion (BLI) fan 106. The BLI fan 106 is mounted to the aircraft 10 at a location aft of the wings 20 and/or the jet engines 102, 104. Specifically, for the embodiment depicted, the BLI fan 106 is fixedly connected to the fuselage 12 at the aft end 18, such that the BLI fan 106 is incorporated into or blended with a tail section at the aft end 18, and such that the mean line 15 extends therethrough. It should be appreciated, however, that in other embodiments the electric propulsion engine may be configured in any other suitable manner, and may not necessarily be configured as an aft fan or as a BLI fan.

[0029] Referring still to the embodiment of FIGS. 1 and 2, in certain embodiments the propulsion system further includes one or more electric generators 108 operable with the jet engines 102, 104. For example, one or both of the jet engines 102, 104 may be configured to provide mechanical power from a rotating shaft (such as an LP shaft or HP shaft) to the electric generators 108. Although depicted schematically outside the respective jet engines 102, 104, in certain embodiments, the electric generators 108 may be positioned within a respective jet engine 102, 104. Additionally, the electric generators 108 may be configured to convert the mechanical power to electrical power. For the embodiment depicted, the propulsion system 100 includes an electric generator 108 for each jet engine 102, 104, and also includes a power conditioner 109 and an energy storage device 110. The electric generators 108 may send electrical power to the power conditioner 109, which may transform the electrical energy to a proper form and either store the energy in the energy storage device 110 or send the electrical energy to the BLI fan 106. For the embodiment depicted, the electric generators 108, power

conditioner 109, energy storage device 110, and BLI fan 106 are all are connected to an electric communication bus 111, such that the electric generator 108 may be in electrical communication with the BLI fan 106 and/or the energy storage device 110, and such that the electric generator 108 may provide electrical power to one or both of the energy storage device 110 or the BLI fan 106. Accordingly, in such an embodiment, the propulsion system 100 may be referred to as a gas-electric propulsion system.

[0030] It should be appreciated, however, that the aircraft 10 and propulsion system 100 depicted in FIGS. 1 and 2 is provided by way of example only and that in other exemplary embodiments of the present disclosure, any other suitable aircraft 10 may be provided having a propulsion system 100 configured in any other suitable manner. For example, it should be appreciated that in various other embodiments, the BLI fan 106 may alternatively be positioned at any suitable location proximate the aft end 18 of the aircraft 10. Further, in still other embodiments the electric propulsion engine may not be positioned at the aft end of the aircraft 10, and thus may not be configured as an “aft engine.” For example, in other embodiments, the electric propulsion engine may be incorporated into the fuselage of the aircraft 10, and thus configured as a “podded engine,” or pod-installation engine. Further, in still other embodiments, the electric propulsion engine may be incorporated into a wing of the aircraft 10, and thus may be configured as a “blended wing engine.” Moreover, in other embodiments, the electric propulsion engine may not be a boundary layer ingestion fan, and instead may be mounted at any suitable location on the aircraft 10 as a freestream injection fan. Furthermore, in still other embodiments, the propulsion system 100 may not include, e.g., the power conditioner 109 and/or the energy storage device 110, and instead the generator(s) 108 may be directly connected to the BLI fan 106.

[0031] Referring now to FIG. 3, a schematic cross-sectional view of a propulsion engine in accordance with an exemplary embodiment of the present disclosure is provided. In certain exemplary embodiments, the propulsion engine may be configured a high-bypass turbofan jet engine 200, herein referred to as “turbofan 200.” Notably, in at least certain embodiments, the jet engines 102, 104 may be also configured as high-bypass turbofan jet engines. In various embodiments, the turbofan 200 may be representative of jet engines 102, 104. Alternatively, however, in other embodiments, the turbofan 200 may be incorporated into any other suitable aircraft 10 or propulsion system 100.

[0032] As shown in FIG. 3, the turbofan 200 defines an axial direction A1 (extending parallel to a longitudinal centerline 201 provided for reference) and a radial direction R1. In general, the turbofan 200 includes a fan section 202 and a core turbine engine 204 disposed downstream from the fan section 202.

[0033] The exemplary core turbine engine 204 depicted generally includes a substantially tubular outer casing 206 that defines an annular inlet 208. The outer casing 206 encases, in serial flow relationship, a compressor section including a booster or low pressure (LP) compressor 210 and a high pressure (HP) compressor 212; a combustion section 214; a turbine section including a high pressure (HP) turbine 216 and a low pressure (LP) turbine 218; and a jet exhaust nozzle section 220. A high pressure (HP) shaft or spool 222 drivingly connects the HP turbine 216 to the HP compressor 212. A low pressure (LP) shaft or spool 224 drivingly connects the LP turbine 218 to the LP compressor 210.

[0034] For the embodiment depicted, the fan section 202 includes a variable pitch fan 226 having a plurality of fan blades 228 coupled to a disk 230 in a spaced apart manner. As depicted, the fan blades 228 extend outwardly from disk 230 generally along the radial direction R1. Each fan blade 228 is rotatable relative to the disk 230 about a pitch axis P by virtue of the fan blades 228 being operatively coupled to a suitable actuation member 232 configured to collectively vary the pitch of the fan blades 228 in unison. The fan blades 228, disk 230, and actuation member 232 are together rotatable about the longitudinal axis 12 by LP shaft 224 across a power gear box 234. The power gear box 234 includes a plurality of gears for stepping down the rotational speed of the LP shaft 224 to a more efficient rotational fan speed.

[0035] Referring still to the exemplary embodiment of FIG. 3, the disk 230 is covered by rotatable front hub 236 aerodynamically contoured to promote an airflow through the plurality of fan blades 228. Additionally, the exemplary fan section 202 includes an annular fan casing or outer nacelle 238 that circumferentially surrounds the fan 226 and/or at least a portion of the core turbine engine 204. It should be appreciated that the nacelle 238 may be configured to be supported relative to the core turbine engine 204 by a plurality of circumferentially-spaced outlet guide vanes 240. Moreover, a downstream section 242 of the nacelle 238 may extend over an outer portion of the core turbine engine 204 so as to define a bypass airflow passage 244 therebetween.

[0036] Additionally, the exemplary turbofan 200 depicted includes an electric machine 246 rotatable with the fan 226. Specifically, for the embodiment depicted, the electric machine 246 is configured as an electric generator co-axially mounted to and rotatable by the LP shaft 224 (the LP shaft 224 also rotating the fan 226 through, for the embodiment depicted, the power gearbox 234). The electric machine 246 includes a rotor 248 and a stator 250. In certain exemplary embodiments, the rotor 248 and stator 250 of the electric machine 246 are configured in substantially the same manner as the exemplary rotor and stator of the electric motor 336 described below with reference to FIG. 4 or the electric machine 350 described below with reference to FIGS. 5 through 8. Additionally, as will be appreciated, the rotor 248 may be

attached to the LP shaft 224 and the stator 250 may remain static within the core turbine engine 204. During operation, the electric machine may define an electric machine tip speed (i.e., a linear speed of the rotor 248 at an airgap radius of electric machine 246, as described below). Notably, when the turbofan engine 200 is integrated into the propulsion system 100 described above with reference to FIGS. 1 and 2, the electric generators 108 may be configured in substantially the same manner as the electric machine 246 of FIG. 3.

[0037] It should also be appreciated, however, that the exemplary turbofan engine 200 depicted in FIG. 3 is by way of example only, and that in other exemplary embodiments, the turbofan engine 200 may have any other suitable configuration. For example, although rotor 248 is illustrated as being attached to the LP shaft 224, it should be appreciated that rotor 248 could alternatively be attached to the HP shaft 222 or any other suitable shaft. Further, it should be appreciated, that in other exemplary embodiments, the jet engines 102, 104 may instead be configured as any other suitable aeronautical engine, such as a turboprop engine, turbojet engine, internal combustion engine, etc.

[0038] Referring now to FIG. 4, a schematic, cross-sectional side view of an electric propulsion engine in accordance with various embodiments of the present disclosure is provided. The electric propulsion engine depicted is mounted to an aircraft 10 at an aft end 18 of the aircraft 10 and is configured to ingest a boundary layer air. Accordingly, for the embodiment depicted, the electric propulsion engine is configured as a boundary layer ingestion (BLI), aft fan (referred to hereinafter as “BLI fan 300”). The BLI fan 300 may be configured in substantially the same manner as the BLI fan 106 described above with reference to FIGS. 1 and 2 and the aircraft 10 may be configured in substantially the same manner as the exemplary aircraft 10 described above with reference to FIGS. 1 and 2.

[0039] As shown in FIG. 4, the BLI fan 300 defines an axial direction A2 extending along a longitudinal centerline axis 302 (or center axis) that extends therethrough for reference, as well as a radial direction R2 and a circumferential direction C2 (a direction extending about the axial direction A2, see, e.g., FIG. 6A). Additionally, the aircraft 10 defines a mean line 15 extending therethrough.

[0040] In general, the BLI fan 300 includes a fan 304 rotatable about the centerline axis 302 and a structural support system 308. The structural support system 308 is configured for mounting the BLI fan 300 to the aircraft 10, and for the embodiment depicted generally includes an inner frame support 310, a plurality of forward support members 312, an outer nacelle 314, a plurality of aft support members 316, and a tail cone 318. As is depicted, the inner frame support 310 is attached to a bulkhead 320 of the fuselage 12. The plurality of forward support members 312 are attached to the inner frame support 310 and extend outward generally along the radial

direction R2 to the nacelle 314. The nacelle 314 defines an airflow passage 322 with an inner casing 324 of the BLI fan 300, and at least partially surrounds the fan 304. Further, for the embodiment depicted, the nacelle 314 extends substantially three hundred and sixty degrees (360°) around the mean line 15 of the aircraft 10. The plurality of aft support members 316 also extend generally along the radial direction R2 from, and structurally connect, the nacelle 314 to the tail cone 318.

[0041] In certain embodiments, the forward support members 312 and the aft support members 316 may each be generally spaced along the circumferential direction C2 of the BLI fan 300. Additionally, in certain embodiments the forward support members 312 may be generally configured as inlet guide vanes and the aft support members 316 may generally be configured as outlet guide vanes. If configured in such a manner, the forward and aft support members 312, 316 may direct and/or condition an airflow through the airflow passage 322 of the BLI fan 300. Notably, one or both of the forward support members 312 or aft support members 316 may additionally be configured as variable guide vanes. For example, the support member may include a flap (not shown) positioned at an aft end of the support member for directing a flow of air across the support member.

[0042] It should be appreciated, however, that in other exemplary embodiments, the structural support system 308 may instead include any other suitable configuration and, e.g., may not include each of the components depicted and described above. Alternatively, the structural support system 308 may include any other suitable components not depicted or described above.

[0043] The BLI fan 300 additionally defines a nozzle 326 between the nacelle 314 and the tail cone 318. The nozzle 326 may be configured to generate an amount of thrust from the air flowing therethrough, and the tail cone 318 may be shaped to minimize an amount of drag on the BLI fan 300. However, in other embodiments, the tail cone 318 may have any other shape and may, e.g., end forward of an aft end of the nacelle 314 such that the tail cone 318 is enclosed by the nacelle 314 at an aft end. Additionally, in other embodiments, the BLI fan 300 may not be configured to generate any measureable amount of thrust, and instead may be configured to ingest air from a boundary layer of air of the fuselage 12 of the aircraft 10 and add energy/ speed up such air to reduce an overall drag on the aircraft 10 (and thus increase a net thrust of the aircraft 10).

[0044] Referring still to FIG. 4, the fan 304 includes a plurality of fan blades 328 and a fan shaft 330. The plurality of fan blades 328 are attached to the fan shaft 330 and spaced generally along the circumferential direction C2 of the BLI fan 300. As depicted, the plurality fan blades 328 are, for the embodiment depicted, at least partially enclosed by the nacelle 314.

[0045] Moreover, for the embodiment depicted, the fan 304 is rotatable about the centerline axis 302 of the BLI fan 300 by an electric machine. More particularly, for the embodiment depicted, the electric machine is configured as an electric motor 336 and the BLI fan 300 additionally includes a power gearbox 338 mechanically coupled to the electric motor 336. Additionally, the fan 304 is mechanically coupled to the power gearbox 338. For example, for the embodiment depicted, the fan shaft 330 extends to and is coupled to the power gearbox 338, and a driveshaft 340 of the electric motor 336 extends to and is also coupled to the power gearbox 338. Accordingly, for the embodiment depicted, the fan 304 is rotatable about the central axis 302 of the BLI fan 300 by the electric motor 336 through the power gearbox 338.

[0046] The power gearbox 338 may include any type of gearing system for altering a rotational speed between the driveshaft 340 and the fan shaft 330. For example, the power gearbox 338 may be configured as a star gear train, a planetary gear train, or any other suitable gear train configuration. Additionally, the power gearbox 338 may define a gear ratio, which as used herein, refers to a ratio of a rotational speed of the driveshaft 340 to a rotational speed of the fan shaft 330. In certain exemplary embodiments, the gear ratio of the power gearbox 338 may be greater than about 1:1 and less than about 1:5. For example, in certain embodiments, the gear ratio of the power gearbox 338 may be between about 1:1.5 and about 1:3.5, such as between about 1:1.2 and about 1:2.75. It should be appreciated, that as used herein, terms of approximation, such as “about” or “approximately,” refer to being within a 10% margin of error.

[0047] Referring still to the exemplary embodiment of FIG. 4, the electric motor 336 is located at least partially within the fuselage 12 of the aircraft 10. More specifically, the fan 304 is positioned forward of the power gearbox 338 along the central axis 302 of the BLI fan 300, and the electric motor 336 is positioned forward of the fan 304 along the central axis 302 of the BLI fan 300. However, according to alternative embodiments, power gearbox 338 could be positioned at a forward location or at any other suitable location within aircraft 10.

[0048] Further, in certain exemplary embodiments, the BLI fan 300 may be configured with a gas-electric propulsion system, such as the gas-electric propulsion system 100 described above with reference to FIGS. 1 and 2. In such an embodiment, the electric motor 336 may receive power from one or both of an energy storage device or an electric generator—such as the energy storage device 110 or electric generator 108 of FIGS. 1 and 2.

[0049] Referring now to FIG. 5, an electric machine 350 according to an exemplary embodiment of the present subject matter will be described. Although described below as being configured for driving a boundary layer ingestion fan for an aircraft, it should be appreciated that in other exemplary embodiments, electric machine 350 may be used as a motor or generator for any suitable application or in any other suitable device. For example, electric machine 350 may

be used as a primary or secondary power plant in a land-based vehicle (such as an automobile), in an under-wing mounted propulsion device for an aircraft, for nautical vehicles, etc.

[0050] As illustrated, electric machine 350 includes a rotor assembly 352 and a stator assembly 354, each of which will be described in detail below. Electric machine 350 defines an axial direction A3, a radial direction R3, and a circumferential direction C3 (a direction extending about the axial direction A3, not shown). According to one embodiment, electric machine 350 may be configured as electric motor 336 for driving BLI fan 300 (see FIG. 4). According to another exemplary embodiment, electric machine 350 may be configured as electric machine 246, e.g., acting as a generator mechanically coupled to fan 226 (see FIG. 3).

[0051] As illustrated in FIG. 5, electric machine 350 includes a drive shaft 358 defining a longitudinal axis 362 of electric machine 350. According to one exemplary embodiment, when electric machine 350 is installed in the BLI fan 300, longitudinal axis 362 may align with the centerline axis 302 of the BLI fan 300. Rotor assembly 352 may optionally include a plurality of bearings (not shown) on axial ends of drive shaft 358. Notably, the portion of rotor assembly 352 depicted in FIG. 5 may simply be one module of the rotor assembly 352. In other embodiments, a plurality of modules may be included to provide a desired power output for the electric machine 350, with the more rotor modules included, the higher the power output.

[0052] Rotor assembly 352 includes a rotor disk 364 that is mounted to and extends from drive shaft 358 substantially along the radial direction R3. In this regard, rotor disk 364 is rotatable about the axial direction A3. In an embodiment, drive shaft 358 and rotor disk 364 may be keyed so as to be in cooperative engagement. In an embodiment, drive shaft 358 may include one or more features, such as protrusions (not shown), in cooperative engagement with one or more features, such as recesses (not shown), in rotor disk 364, or vice versa. However, it should be appreciated that any suitable method of coupling drive shaft 358 to rotor disk 364 may be used to transmit torque. In an embodiment, drive shaft 358 may include additional features configured to provide passages for a cooling fluid (not shown) within rotor assembly 352. In a non-limiting example, the cooling fluid may be airflow or a coolant for reducing mechanical stresses and eddy current losses in the rotor assembly 352.

[0053] According to the illustrated exemplary embodiment, a rotor flange 366 is attached to or formed integrally with rotor disk 364 and extends from rotor disk 364 substantially along the axial direction A3. According to the illustrated embodiment, rotor disk defines a first side 368 and an opposite second side 370. Rotor flange 366 extends from both first side 368 and second side 370 along the axial direction A3 (only half of rotor assembly 352 is illustrated in FIG. 5 for clarity, but see FIGS. 6A through 6C). In addition, according to the illustrated embodiment, rotor flange 366 extends from a rotor tip 372 defined at an outermost location of rotor disk 364 along

the radial direction R3. However, it should be appreciated that other configurations are possible. For example, rotor flange 366 may extend from only a single side of rotor disk 364, may extend from a different radial location of rotor disk 364, and/or may extend at an angle relative to the axial direction A3.

[0054] Rotor flange 366 may be any size suitable for supporting high speed operation of electric machine 350, e.g., by absorbing centrifugal forces of motor components such as radial stresses and hoop stresses. For example, according to an exemplary embodiment, rotor flange 366 may define a length L1 measured from rotor disk 364 to a distal end of rotor flange 366 along the axial direction A3. Rotor disk 364 may also define a height H1 measured from the center of drive shaft 358 (i.e., from longitudinal axis 362) to an airgap (as described below) along the radial direction R3. In certain exemplary embodiments, electric machine 350 may define a length to height (L1:H1) aspect ratio greater than about 1:20 and less than about 1:1. For example, in certain embodiments, the aspect ratio may be between about 3:20 and about 17:20, such as between about 1:4 and about 3:4, or about 1:2. It should be appreciated, that as used herein, terms of approximation, such as “about” or “approximately,” refer to being within a 10% margin.

[0055] In addition, rotor disk 364 and rotor flange 366 may be constructed from any suitably rigid material. More specifically, rotor disk 364 and rotor flange 366 may be constructed of a material sufficient for withstanding the large centrifugal forces generated during high speed operation (e.g., tip speeds of 1000 feet per second or higher) of electric machine 350. For example, according to one exemplary embodiment, rotor disk 364 and rotor flange 366 are integrally formed from a single piece of titanium, or another suitably rigid and lightweight steel alloy. In addition, rotor disk 364 may be constructed of a non-magnetic material or a magnetically permeable material. According to alternative embodiments, rotor flange 366 may be mounted to rotor disk 364 using any suitable method of attachment, e.g., welding, gluing, mechanical fasteners, etc.

[0056] Still referring to FIG. 5, according to the illustrated exemplary embodiment, rotor assembly 352 includes a plurality of rotor magnets 380. Rotor magnets 380 are configured to generate a rotor magnetic field and stator assembly 354 is configured to generate a stator magnetic field. The rotor magnetic field and the stator magnetic field interact to generate a torque that rotates rotor disk 364 and drive shaft 358. Although rotor magnets 380 and stator assembly 354 may be referred to generally herein as “magnets,” it should be appreciated that these magnets may be any suitable magnetic material, and may be permanent magnets, electromagnets, etc. For example, according to the illustrated embodiment, rotor magnets 380 are permanent magnets and stator assembly 354 includes electromagnets, but alternative

embodiments may use any suitable combination of rotor magnets 380 and stator assemblies 354 to generate a torque on rotor disk 364 and drive shaft 358. In addition, although stator assembly 354 is illustrated as having concentrated windings, it should be appreciated that stator assembly 354 may alternatively have distributed windings or any other suitable stator winding configuration. Furthermore, rotor magnets 380 and stator assembly 354 may include any suitable coating or covering, such as a metallic or non-metallic magnetic shielding material or retaining structure.

[0057] In an embodiment, rotor magnets 380 are permanent magnets. Rotor magnets 380 may define a magnetization direction (i.e., a north-south pole orientation) that extends along the radial direction R3, e.g., when operating as a “radial flux” machine. For example, in the illustrated embodiment, rotor magnets 380 are configured having a magnetization or pole direction that is oriented substantially radially within the electric machine 350. More specifically, stator assembly 354 is located inward of rotor flange 366 along the radial direction R3, e.g., such that electric machine 350 is in an outrunner configuration. In this regard, rotor magnets 380 generate a magnetic field to be radially directed between rotor assembly 352 and stator assembly 354. According to some exemplary embodiments, rotor assembly 352 may further include a rotor back iron 384, e.g., for providing a return path for magnetic flux. As described herein, the magnetic field generated by rotor magnets 380 further interacts with a stator magnetic field produced by its armature currents to produce a torque. It should be appreciated, however, that according to alternative embodiments, electric machine 350 may be configured as an “axial flux” machine. In an axial flux machine, rotor magnets 380 may be configured to generate a magnetic field that extends substantially along the axial direction A3 between rotor assembly 352 and stator assembly 354. Additionally, in still other exemplary embodiments, electric machine 350 may be configured as an “inrunner” electric machine, such that rotor flange 366 is located inward of stator assembly 354.

[0058] Rotor magnets 380 may be mounted to rotor disk assembly 352 in any suitable manner and at any suitable location. For example, rotor magnets 380 may be mounted to rotor disk 364 or directly to rotor flange 366. According to the illustrated embodiment, rotor magnets 380 are mounted to a radially interior surface of rotor flange 366. In this manner, rotor flange 366 is designed to absorb centrifugal loads exerted on rotor magnets 380 at high speeds of operation. As such, rotor assembly 352 and thus electric machine 350 are designed to withstand high speeds and centrifugal loading.

[0059] According to the illustrated embodiment, stator assembly 354 includes a stationary core 390 that has a fixed position along the radial direction R3. Stationary core 390 may be a magnetically permeable material, e.g., metal, and may include multiple stator-slots (not shown)

for receiving conductive armature windings 392. The armature windings 392 may include copper windings in a variety of topologies and forms. As such, stator assembly 354 may be configured as an electromagnet. In an embodiment, stator assembly 354 is configured to carry a magnetic flux optimally to and from rotor magnets 380. In addition, stationary core 390 may be laminated directionally to reduce eddy current heating in the stationary core 390 and thereby to improve motor efficiency.

[0060] As illustrated schematically in FIG. 5, stator assembly 354 may further include a tracking tooth 394. Tracking tooth 394 is in sliding contact with stationary core 390 such that it is in magnetic communication with stationary core 390. In this regard, according to some exemplary embodiments, tracking tooth 394 may be positioned within a low-friction, magnetically permeable sleeve 395 (see, e.g., FIGS. 6A through 6C). For example, sleeve 395 may allow tracking tooth 394 to slide freely along the radial direction R3 while maintaining magnetic flux communication with stationary core 390. Tracking tooth 394 is spaced apart from rotor magnets 380 along the radial direction R3 to define an air gap 396. However, tracking tooth 394 is slidable along the radial direction R3 to adjust a height of air gap 396. Notably, the height of air gap 396 (i.e., “gap height”) is an important aspect in the design of electric machines. Gap height has an effect on specific power (i.e., power to weight ratio) of the electric machines as well as total power and efficiency. Although the description above refers to a single tracking tooth 394, it should be appreciated that any suitable number of tracking teeth may be used to adjust a size of an airgap according to exemplary embodiments. For example, stator assembly 354 may include a plurality of tracking teeth spaced along the circumferential direction C3. Each of these tracking teeth may be moved in unison, or independently from each other, along the radial direction R3.

[0061] To facilitate control of the height of air gap 396, stator assembly 354 may further include an actuator assembly 400 operable with tracking tooth 394 for moving tracking tooth 394 along the radial direction R3 to adjust the height of air gap 396. Illustrated schematically in FIG. 5, actuator assembly 400 may be any device or assembly capable of moving tracking tooth 394 relative to stationary core 390. According to the illustrated exemplary embodiment, actuator assembly 400 may be controlled by a controller 402.

[0062] Controller 402 may be used to control the operation of actuator assembly 400, e.g., to adjust the radial position of tracking tooth 394 and the height of air gap 396. The controller may include one or more discrete processors, memory devices, and power storage units (not pictured). The processor may also include a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination

thereof designed and programmed to perform or cause the performance of the functions described herein. The processor may also include a microprocessor, or a combination of the aforementioned devices (e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration).

[0063] Additionally, the memory device(s) may generally comprise memory element(s) including, but not limited to, computer readable medium (e.g., random access memory (RAM)), computer readable non-volatile medium (e.g., a NVRAM, flash memory, EEPROM, or FRAM), a compact disc-read only memory (CD-ROM), a magneto-optical disk (MOD), a digital versatile disc (DVD), and/or other suitable memory elements. The memory can store information accessible by the processor(s), including instructions that can be executed by the processor(s). For example, the instructions can be software or any set of instructions that, when executed by the processor(s), cause the processor(s) to perform operations. Optionally, the instructions may include a software package configured to operate actuator assembly 400.

[0064] In addition, electric machine 350 may include one or more sensors for providing feedback regarding the operation of electric machine 350. For example, according to the illustrated embodiment, a speed sensor 404 may be configured to, e.g., measure the rotational speed of drive shaft 358. According to another embodiment, a gap size sensor 406 may be configured to, e.g., measure the height of air gap 396. Controller 402 may be in operative communication with sensors 404 and/or 406 and may make real-time adjustments to the radial position of tracking tooth 394 to selectively control the operation of electric machine 350 to achieve various goals.

[0065] Referring now to FIGS. 6A through 6C, views of one exemplary embodiment of electric machine 350, and more particularly of actuator assembly 400, are provided. Specifically, FIGS. 6A and 6B provide perspective, cross-sectional views of electric machine 350 and actuator assembly 400 and FIG. 6C provides a cross-sectional view of electric machine 350 and actuator assembly 400. The exemplary rotor assembly and stator assembly may be configured in substantially the same manner as electric machine 350 depicted in FIG. 5 and described above. Accordingly, the same or similar numbering may refer to the same or similar parts. Notably, however, windings 392 are depicted as being integrated into stationary core 390 for clarity in FIGS. 6A through 6C.

[0066] According to the exemplary embodiment illustrated in FIGS. 6A through 6C, actuator assembly 400 includes a unison ring 410. Unison ring 410 is operably coupled with tracking tooth 394 such that moving unison ring 410 along the axial direction A3 moves tracking tooth 394 along the radial direction R3. More specifically, unison ring 410 includes a slanted profile or

surface 412 relative to the axial direction A3. Tracking tooth 394 is slidably coupled to unison ring 410, but also is fixed along the axial direction A3, such that moving unison ring 410 along the axial direction A3 moves tracking tooth 394 along the radial direction R3 toward or away from rotor magnets 380.

[0067] As best illustrated in FIGS. 6A and 6B, unison ring 410 defines a receiving slot 414 that is slanted similar to slanted surface 412. Tracking tooth 394 defines a complementary mounting member 416 on a radially inner end of tracking tooth 394. Receiving slot 414 is configured for slidably receiving mounting member 416 such that the relative positioning of tracking tooth 394 and unison ring 410 along the radial direction R3 is substantially fixed. It should be appreciated that the configuration described above for operably coupling tracking tooth 394 to unison ring 410 is only exemplary and that any other suitable configuration could be used to transfer movement of unison ring 410 into movement of tracking tooth 394. For example, unison ring 410 could alternatively define circumferentially extending slots that cause tracking tooth 394 to move when unison ring 410 is rotated about the axial direction A3.

[0068] Referring now to FIG. 7, a side, cross-sectional view of an actuator assembly 400 in accordance with another exemplary embodiment of the present disclosure is depicted. The exemplary rotor assembly and stator assembly may be configured in substantially the same manner as electric machine 350 depicted in FIG. 5 and described above. Accordingly, the same or similar numbering may refer to the same or similar parts.

[0069] As illustrated schematically in FIG. 7, actuator assembly 400 includes a tracking member 420. Tracking member 420 is mounted to tracking tooth 394 and extends to rotor disk 364 to slidably mechanically couple tracking tooth 394 to rotor disk 364 and support tracking tooth 394 along the radial direction R3. In this manner, as rotor disk 364 stretches slightly due to the centrifugal forces experienced during high speed operation, tracking member 420 automatically adjusts the radial position of tracking tooth 394 to more precisely control the height of air gap 396. Notably, according to the illustrated embodiment, tracking member 420 is coupled to rotor disk 364 by a low friction interface 422. The low friction interface 422 could include some form of bearing or other friction reducing mechanism which allows coupling of the tracking member 420 and rotor disk 364 in the radial direction R3, but freedom in the circumferential direction C3. In order to minimize variations in the size of air gap 396 due to stretching of rotor disk 364 between tracking member 420 and rotor tip 372, according to an exemplary embodiment, tracking member 420 is coupled to rotor disk 364 closer to rotor flange 366 than to a base of rotor disk 364 (e.g., where rotor disk 364 is joined with drive shaft 358).

[0070] Referring now to FIG. 8, an axial view of an actuator assembly 400 in accordance with another exemplary embodiment of the present disclosure is depicted. The exemplary rotor

assembly and stator assembly may be configured in substantially the same manner as electric machine 350 depicted in FIG. 5 and described above. Accordingly, the same or similar numbering may refer to the same or similar parts.

[0071] As illustrated in FIG. 8, stator assembly 354 includes a plurality of tracking teeth 394 and a plurality of fixed bridges 430. The tracking teeth 394 and fixed bridges 430 are alternately positioned along the circumferential direction C3 within rotor flange 366. The tracking teeth 394 are in slidable contact with the fixed bridges 430 and are thus in magnetic flux communication through the fixed bridges 430, which are constructed of a magnetically permeable material. One or more actuators 432 may be configured for moving plurality of tracking teeth 394 along the radial direction R3 relative to the fixed bridges 430 while maintaining magnetic flux communication between the two. According to the illustrated embodiment, each of the plurality of fixed bridges 430 has a trapezoidal cross section having a wide end and a short end. The wide end faces outward along the radial direction R3 (i.e., towards rotor flange 366) and the short end faces inward along the radial direction R3 (i.e., toward drive shaft 358). It will be appreciated that the shape of the fixed bridges 430 allow tracking teeth 394 to slide radially inward and radially outward during operation (by actuators 432), while still maintaining magnetic flux communication with one or more adjacent tracking teeth 394.

[0072] As an illustrative aspect of the present disclosure, FIG. 9 provides a method 500 for operating an electric machine. The electric machine may be configured in accordance with one or more of the embodiments described above with reference to FIGS. 5 through 8. Accordingly, the exemplary electric machine may include a rotor assembly, a stator assembly, and an actuator assembly configured for moving a tracking tooth to adjust an air gap within the exemplary electric machine. Method 500 could alternatively be used to operate any other suitable electric machine, e.g., to improve its specific power or efficiency.

[0073] Method 500 includes, at step 510, determining a rotational speed of a rotor flange or determining a gap height between the rotor assembly and the stator assembly. Method 500 further includes, at step 520, moving a tracking tooth of the stator assembly along the radial direction during operation of the electric machine to adjust an air gap height defined along the radial direction between the tracking tooth and the rotor assembly. Step 520 can include moving the tracking tooth of the stator assembly based at least in part on the measured rotational speed of the rotor flange or the determined gap height.

[0074] Although the method above describes adjusting the height of the tracking tooth based on gap height or rotational speed, it should be appreciated that tracking tooth may be adjusted based on any other operating parameter of the electric machine. In this regard, step 510 may include measuring or determining any other operating parameter of the electric machine. For

example, method 500 could instead be used to adjust a height of an airgap based on the demanded torque input/output of the electric machine. In this regard, by adjusting the height of the airgap the electric machine may be loaded or unloaded to add or remove torque from the system.

[0075] The rotor assembly 352, stator assembly 354, the various associated components, and the method 500 of operation described herein are primarily configured to maximize power density and electrical performance of an electric machine. For example, electric machine 350 is configured to operate at relatively high speeds while maintaining a relatively tight clearance between the rotor and the stator, despite a growth of the rotor disk as a result of the high centrifugal loads on the rotor. Such a configuration allows for increased power density and improved electrical performance. Therefore, an electric machine in accordance with one or more embodiments of the present disclosure may provide for an electric machine having a desired efficiency and power density. Furthermore, the present disclosure provides additional advantages in terms of low volume, mass, and cost. These techniques and systems thus allow for an electric machine having a higher power-to-weight ratio that is more robust than prior designs. More particularly, the provided electric machine 350 as disclosed herein is capable of running at higher speeds and loads, effectively permitting a smaller machine to handle higher loads.

[0076] The rotor assembly 352, stator assembly 354, and the various associated components described herein are primarily configured to maximize power density and electrical performance of an electric machine. For example, electric machine 350 includes a rotor assembly 352 capable of operating at relatively high speeds, despite the high centrifugal forces and stresses exerted on rotor assembly 352 and other components of electric machine 350. For example, electric machine 350 may operate at high speeds as determined by the electric machine average airgap speed (described below). For example, electric machine 350 defines an electric machine average airgap speed during operation of electric machine 350. The electric machine average airgap speed refers to a general measure of the speed of the rotor disk 364 at airgap 396 (e.g., a surface speed or linear speed of rotor disk 364). As will be appreciated, such an average airgap speed may be calculated by multiplying a rotational speed of rotor disk 364 of electric machine 350 by an average radial centerline of airgap 396. For example, on an axial flux machine, the average radial centerline is the average radius of stator assembly 354 along the radial direction R3. For a radial flux machine, the average radial centerline is the radial center of airgap 396 along the radial direction R3. As an example, electric machine 350 may be configured to operate at electric machine tip speeds above about 750 feet per second (ft/s). More particularly, an electric machine in accordance with one or more exemplary embodiments of the present disclosure may operate during standard day, maximum speed conditions with an electric machine tip speed

above about 850 feet per second (ft/s), such as above about 900 ft/s, such as above about 1,000 ft/s.

[0077] It should be appreciated, however, that the exemplary electric machine 350 described above with reference to FIGS. 5 through 8 may alternatively be configured in any other suitable manner. For example, in other exemplary embodiments, electric machine 350 may be configured in accordance with one or more of the exemplary embodiments described in United States Patent Application Serial Number 14/317,294 (published at the time of filing as United States Patent Publication Number 2015/0380999), which is incorporated herein fully by reference for all purposes. For example, although electric machine 350 illustrated herein is configured as an “outrunner” motor, it should be appreciated that electric machine 350 could also be configured as an “inrunner” electric machine while remaining within the scope of the present subject matter.

[0078] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they include structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

## WHAT IS CLAIMED IS:

1. An electric machine defining an axial direction, a radial direction, and a circumferential direction, the electric machine comprising:
  - a rotor disk rotatable about the axial direction;
  - a rotor flange attached to or formed integrally with the rotor disk and extending from the rotor disk substantially along the axial direction;
  - a plurality of rotor magnets mounted to the rotor flange; and
  - a stator assembly comprising:
    - a tracking tooth operable with the rotor magnets to produce a torque, the tracking tooth being spaced apart from the rotor magnets along the radial direction to define an air gap; and
    - an actuator assembly operable with the tracking tooth for moving the tracking tooth along the radial direction to adjust a height of the air gap.
2. The electric machine of claim 1, wherein the actuator assembly comprises a unison ring, and wherein the tracking tooth is slidably coupled to the unison ring such that moving the unison ring moves the tracking tooth along the radial direction.
3. The electric machine of claim 1, wherein the actuator assembly comprises a unison ring having a slanted profile relative to the axial direction, wherein the tracking tooth is slidably coupled to the unison ring such that moving the unison ring along the axial direction moves the tracking tooth along the radial direction.
4. The electric machine of claim 3, wherein the unison ring defines a receiving slot and the tracking tooth defines a complementary mounting member, the receiving slot configured for slidably receiving the mounting member, and
  - wherein the receiving slot is slanted such that moving the unison ring along the axial direction moves the tracking tooth along the radial direction.
5. The electric machine of claim 1, wherein the actuator assembly comprises a tracking member, the tracking member being mounted to the tracking tooth and extending to the rotor disk to mechanically couple the tracking tooth to the rotor disk and support the tracking tooth along the radial direction.

6. The electric machine of claim 5, wherein the tracking member is coupled to the rotor disk by a low friction interface.
7. The electric machine of claim 5, wherein the tracking member is coupled to the rotor disk closer to the rotor flange than to a base of the rotor disk.
8. The electric machine of claim 1, wherein the electric machine defines a longitudinal axis, wherein the tracking tooth defines a top surface, and wherein the stator assembly defines a radial height extending between the longitudinal axis and the top surface of the tracking tooth, the actuator assembly being configured to adjust the radial height in response to a rotational speed of the drive shaft.
9. The electric machine of claim 1, wherein the electric machine comprises a sensor for measuring the height of the air gap and defines a longitudinal axis, wherein the tracking tooth defines a top surface, and wherein the stator assembly defines a radial height extending between the longitudinal axis and the top surface of the tracking tooth, the actuator assembly being configured to adjust the radial height in response to a measured height of the air gap.
10. The electric machine of claim 1, wherein the stator assembly comprises a plurality of tracking teeth and a plurality of fixed bridges, each of the plurality of tracking teeth being spaced apart along the circumferential direction and being in magnetic flux communication through the fixed bridges, the plurality of tracking teeth being movable along the radial direction relative to the fixed bridges while remaining in magnetic flux communication with the fixed bridges.
11. The electric machine of claim 10, wherein each of the plurality of fixed bridges has a trapezoidal cross section having a wide end and a short end, wherein the wide end faces outward along the radial direction, and wherein the short end faces inward along the radial direction.
12. The electric machine of claim 1, wherein the rotor disk defines a first side and a second side, the rotor flange extending from both the first side and the second side of the rotor disk along the axial direction.

13. The electric machine of claim 1, wherein the stator assembly further comprises a stator core, the stator core being fixed along the radial direction and being slidably coupled with the tracking tooth.

14. The electric machine of claim 1, wherein the stator assembly is located inward of the rotor flange along the radial direction.

15. The electric machine of claim 1, wherein the stator assembly comprises a plurality of tracking teeth spaced along the circumferential direction, the actuator assembly being operable for moving each of the plurality of tracking teeth along the radial direction to adjust the height of the air gap.

16. The electric machine of claim 15, wherein each of the plurality of tracking teeth defines a radial height, and wherein the actuator assembly is configured to move the plurality of tracking teeth in unison to maintain a substantially constant radial height amongst all tracking teeth.

17. A method for operating an electric machine defining an axial direction and a radial direction, the electric machine comprising a rotor disk rotatable about the axial direction, a rotor flange extending from the rotor disk generally along the radial direction, a rotor magnet mounted to the rotor flange, and a stator assembly including a tracking tooth operable with the rotor magnet to drive the electric machine, the method comprising:

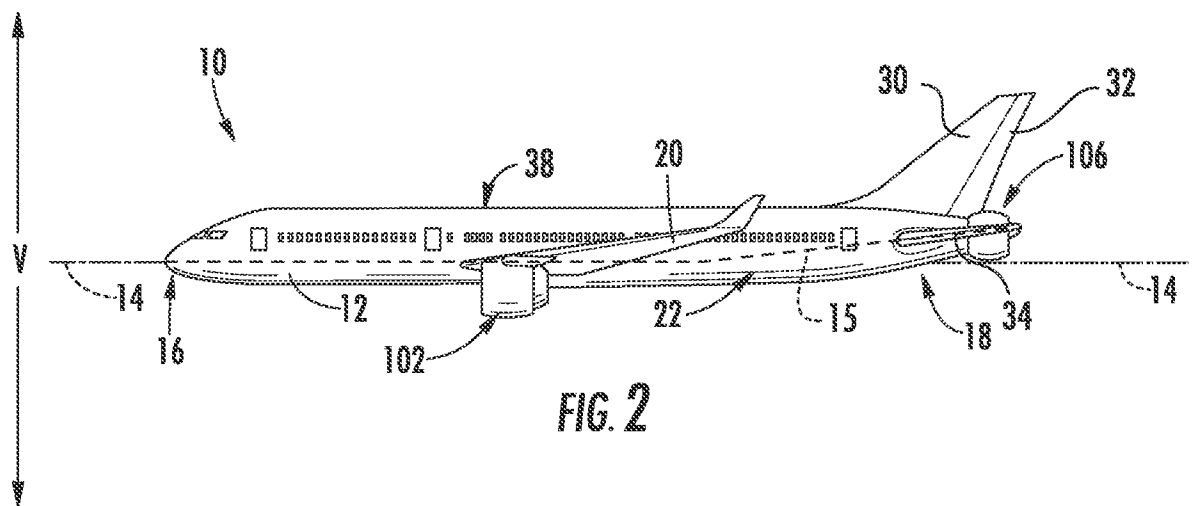
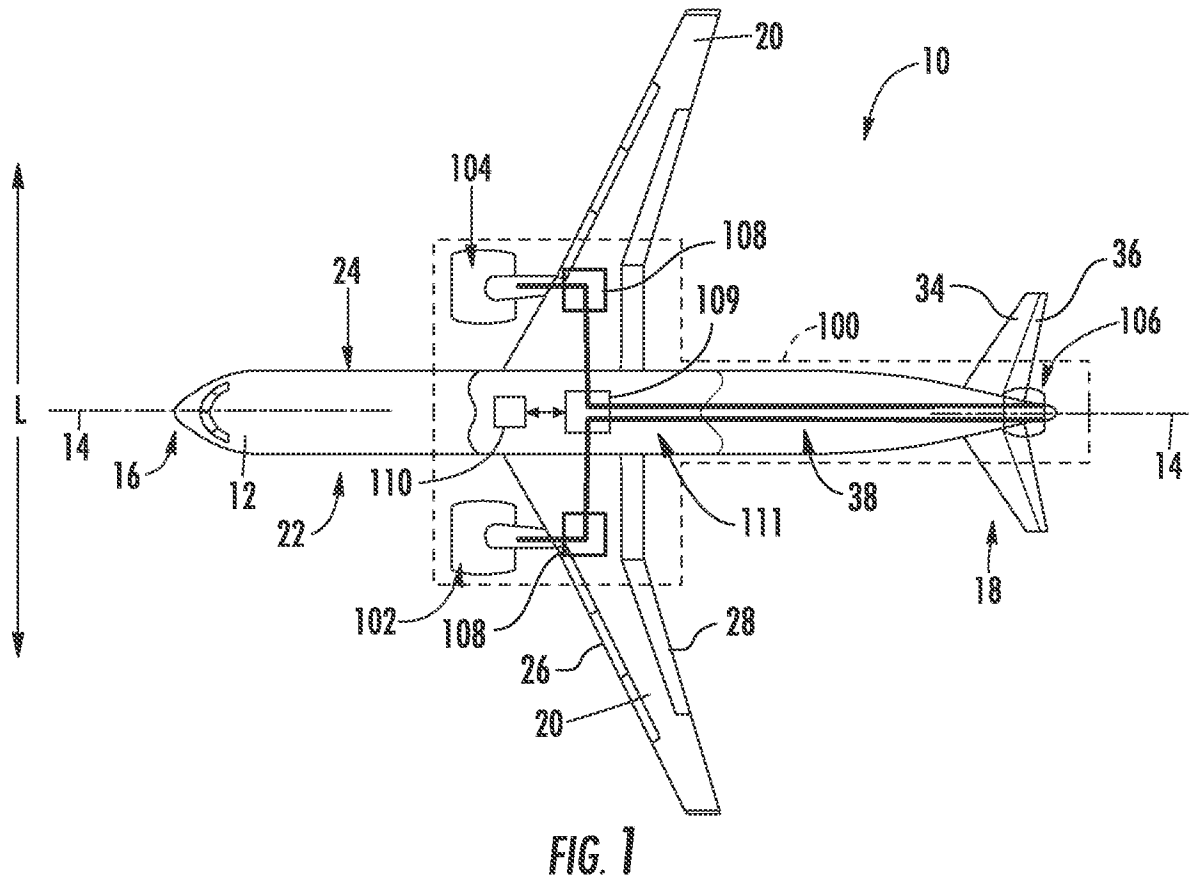
moving the tracking tooth of the stator assembly along the radial direction during operation of the electric machine to adjust an air gap height defined along the radial direction between the tracking tooth and the rotor magnet.

18. The method of claim 17, further comprising:

determining a rotational speed of the rotor flange, wherein moving the tracking tooth of the stator assembly comprises moving the tracking tooth of the stator assembly based at least in part on the determined rotational speed of the rotor flange.

19. The method of claim 17, further comprising moving the tracking tooth of the stator assembly to adjust a torque of the electric machine to a desired torque.

20. An electric machine configured for driving a boundary layer ingestion fan mounted to an aft end of a fuselage of an aircraft, the electric machine comprising:
- a drive shaft mechanically coupled to the boundary layer ingestion fan and defining an axial direction and a radial direction;
  - a rotor disk mounted to the drive shaft and being rotatable about the axial direction, the rotor disk extending from the drive shaft to a rotor tip substantially along the radial direction;
  - a rotor flange attached to or formed integrally with the rotor disk and extending from the rotor disk substantially along the axial direction;
  - a plurality of rotor magnets mounted to the rotor flange; and
  - a stator assembly comprising:
    - a plurality of tracking teeth spaced apart from the rotor magnets along the radial direction to define an air gap; and
    - an actuator assembly configured for moving the tracking teeth along the radial direction to adjust a height of the air gap.



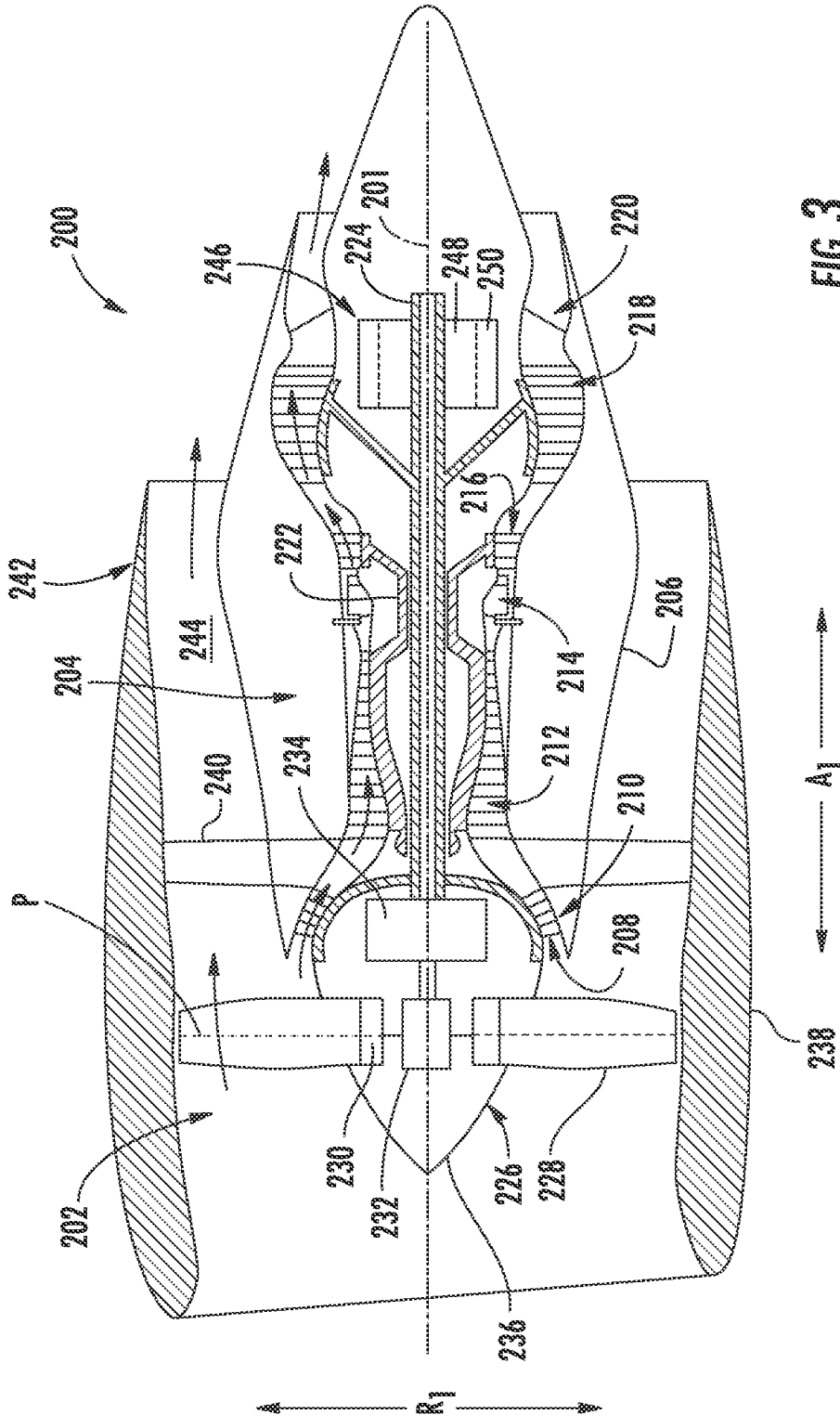


FIG. 3

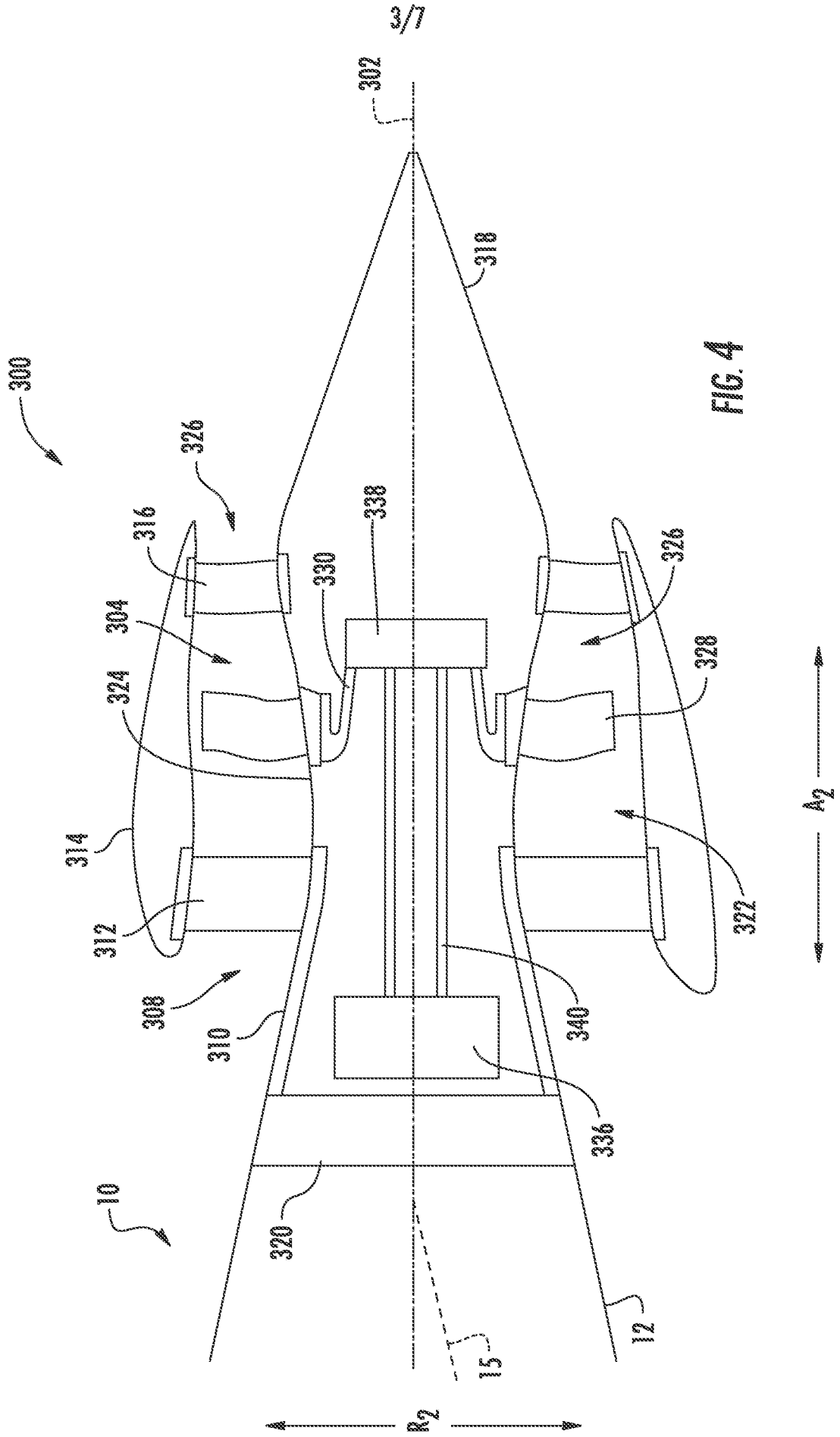
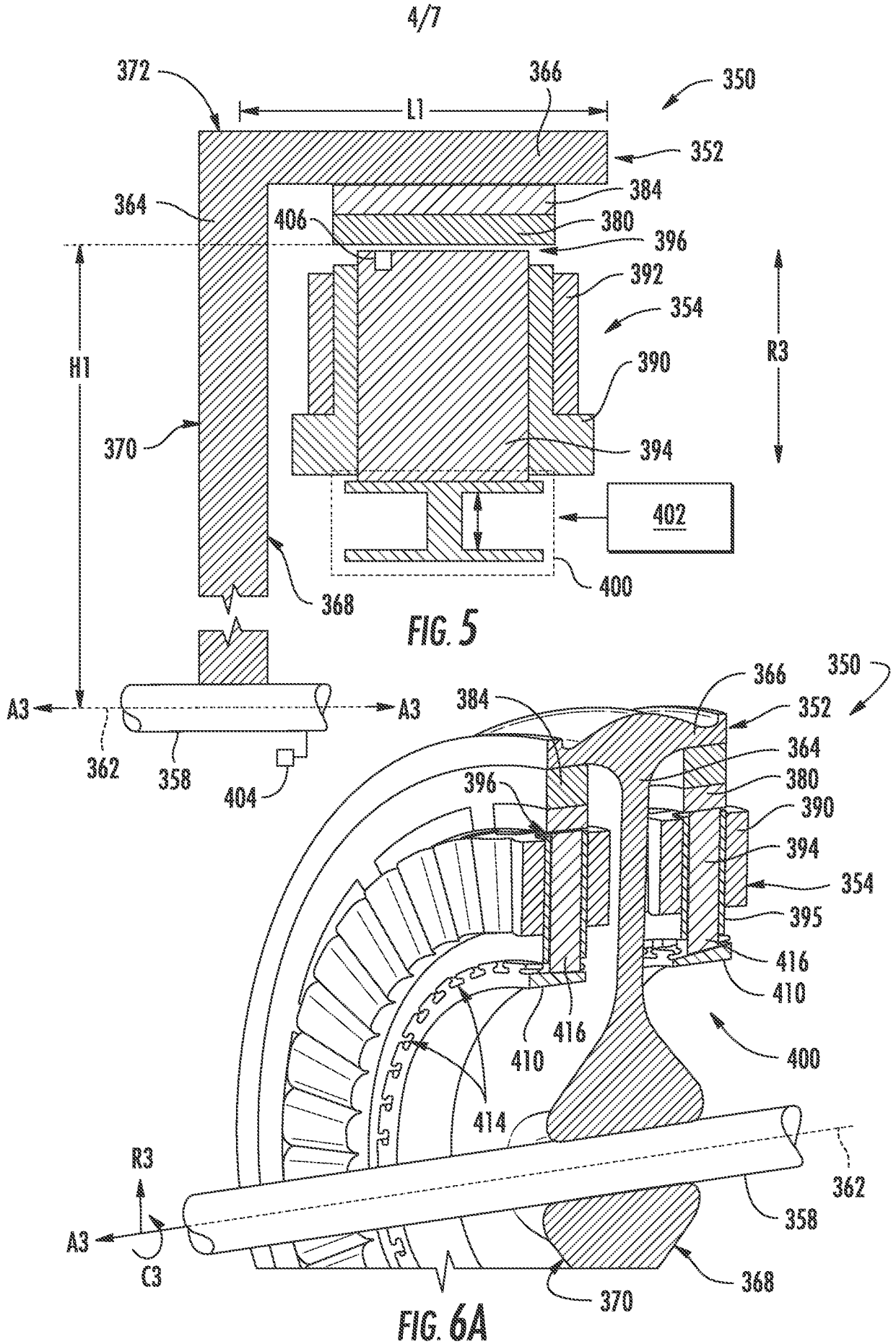
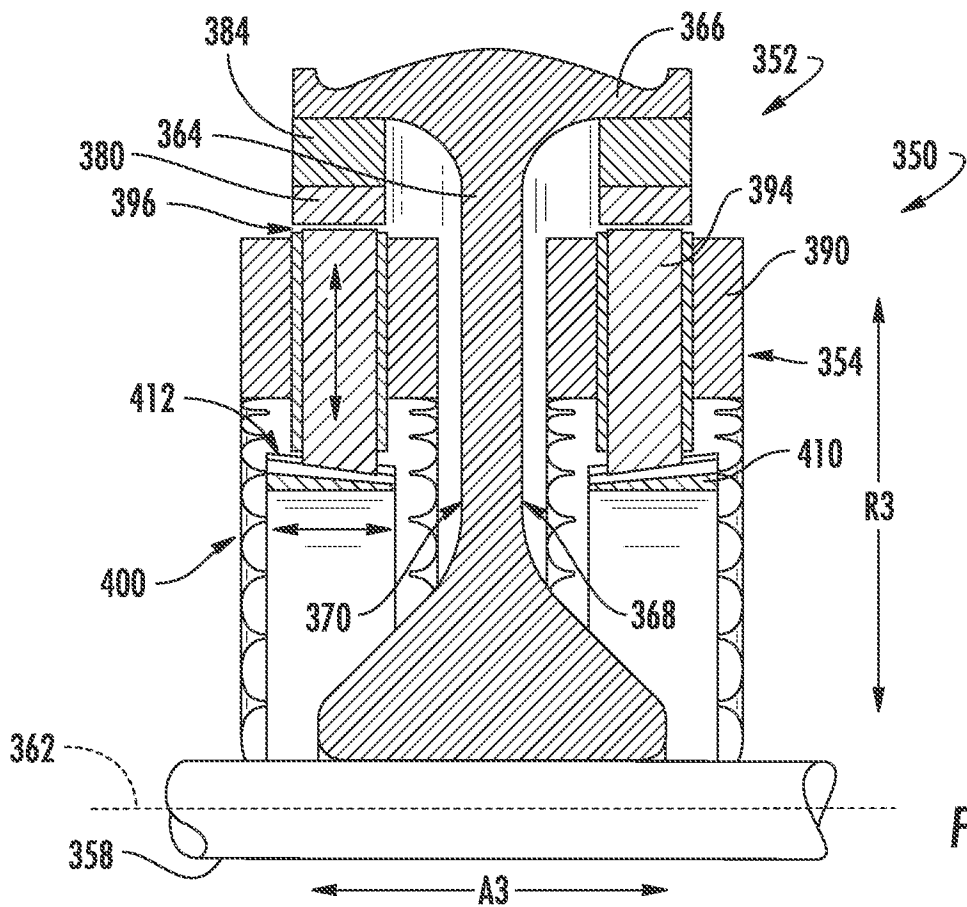
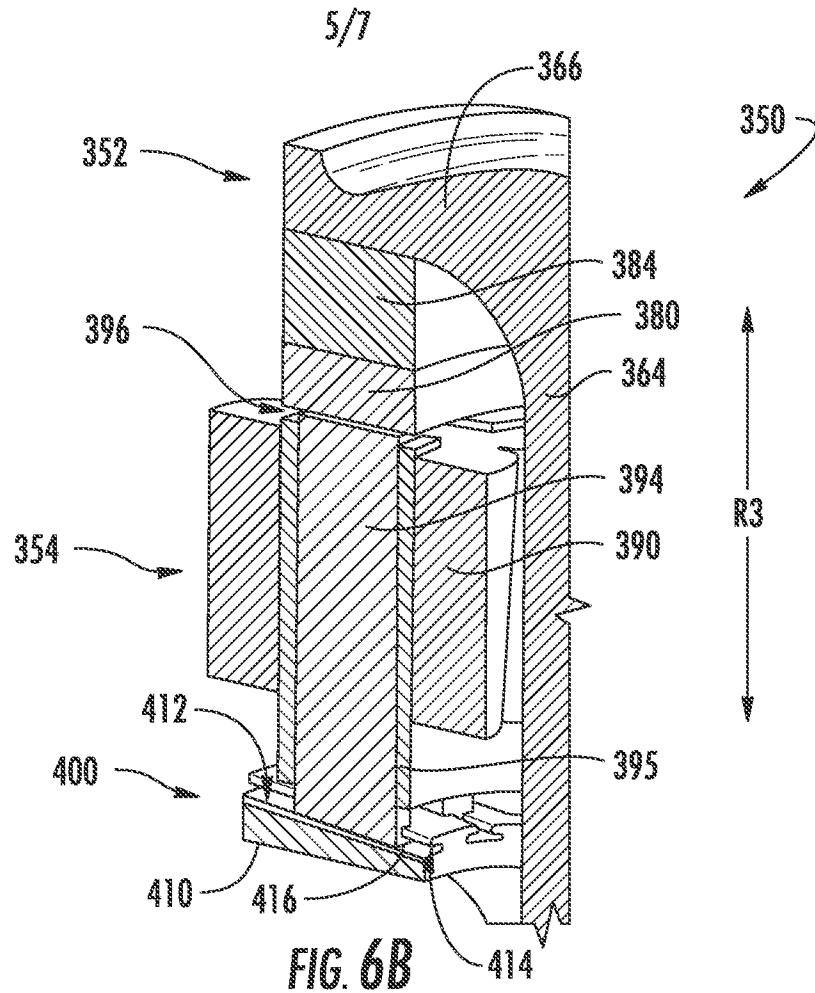


FIG. 4





6/7

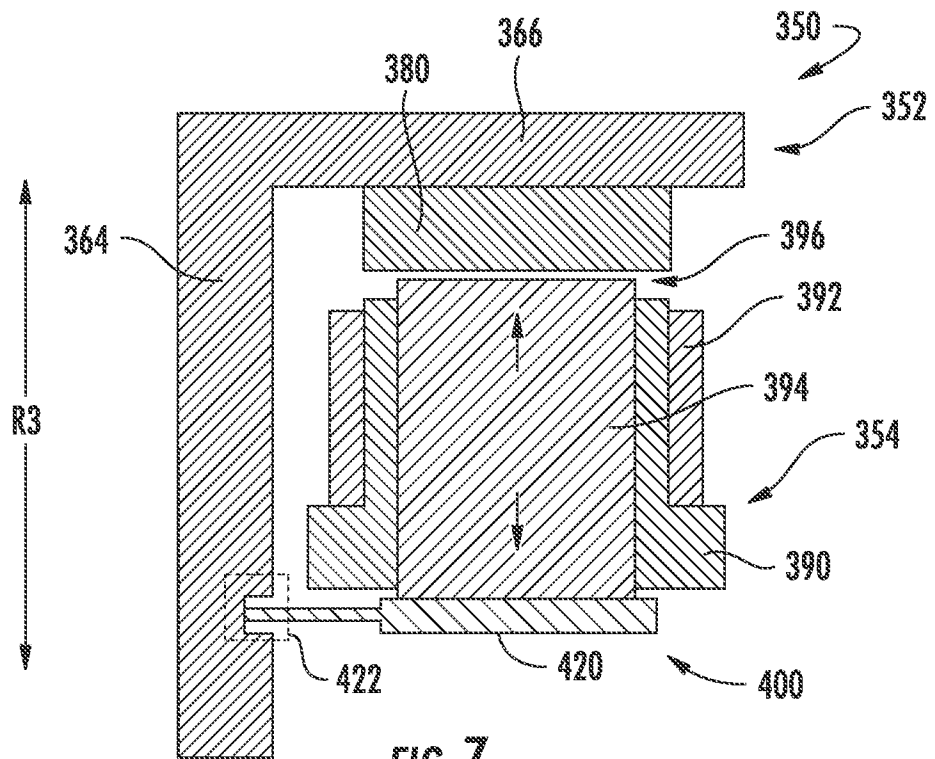


FIG. 7

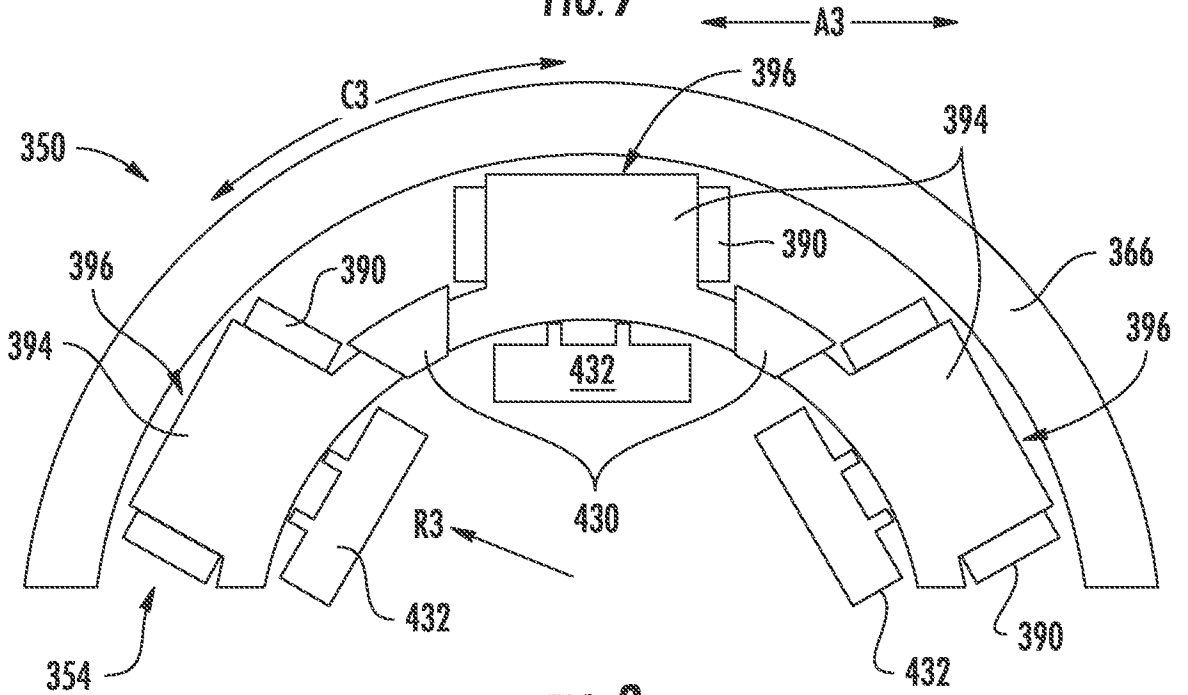


FIG. 8

7/7

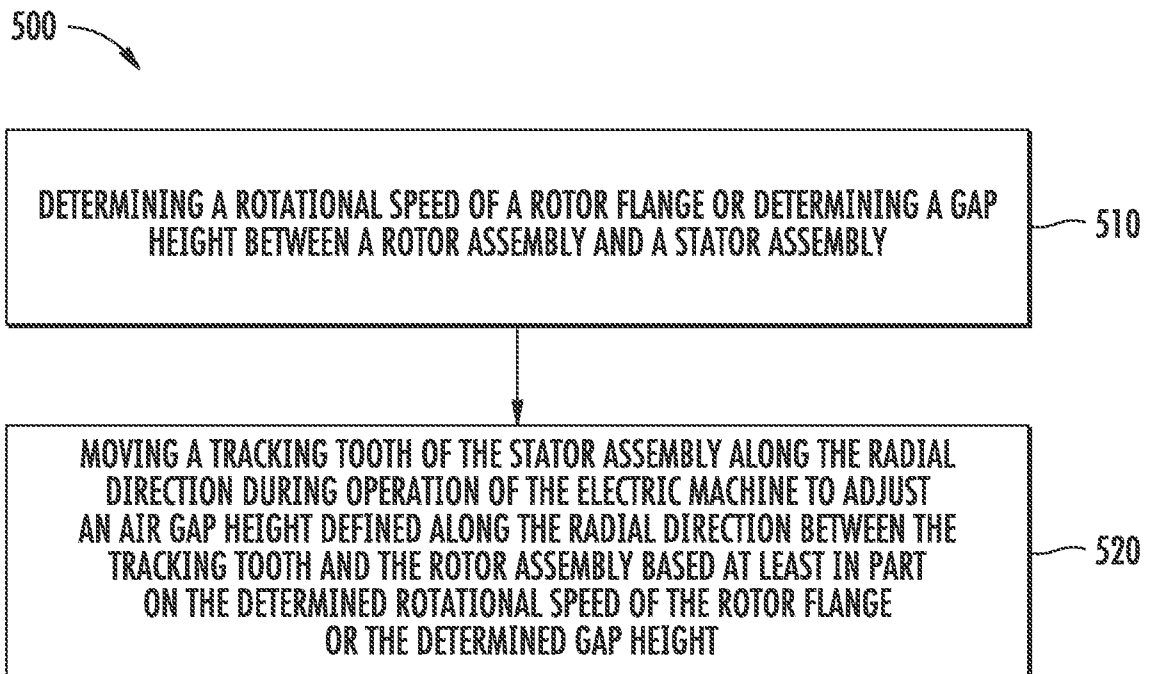


FIG. 9

## INTERNATIONAL SEARCH REPORT

International application No.  
**PCT/US2017/058884****A. CLASSIFICATION OF SUBJECT MATTER****H02K 5/22(2006.01)i, H02K 11/20(2016.01)i, H02K 1/14(2006.01)i, B64D 27/24(2006.01)i**

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 5/22; H02K 21/24; H02K 5/167; H02K 1/27; H02K 15/02; H02K 15/16; G11B 15/28; F01D 11/04; F02C 7/06; H02K 5/00; H02K 11/20; H02K 1/14; B64D 27/24

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) &amp; Keywords: electric machine, rotor, stator, gap, adjust, tracking, tooth

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2002-051494 A (VICTOR CO. OF JAPAN LTD.) 15 February 2002 See paragraphs 14-18 and figures 1-4.	1-20
A	WO 2015-023471 A1 (GENERAL ELECTRIC COMPANY) 19 February 2015 See paragraphs 23-30 and figures 1-2.	1-20
A	JP 2002-247822 A (MITSUBISHI HEAVY IND. LTD. et al.) 30 August 2002 See the entire document.	1-20
A	JP 2007-174752 A (HINO MOTORS LTD.) 05 July 2007 See the entire document.	1-20
A	KR 10-2002-0074324 A (KOREA AUTOMATIVE CORPORATION) 30 September 2002 See the entire document.	1-20

 Further documents are listed in the continuation of Box C. 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

"&amp;" document member of the same patent family

Date of the actual completion of the international search

21 February 2018 (21.02.2018)

Date of mailing of the international search report

**21 February 2018 (21.02.2018)**

Name and mailing address of the ISA/KR

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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2017/058884**

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 2002-051494 A	15/02/2002	None	
WO 2015-023471 A1	19/02/2015	CA 2920482 A1 CN 105452611 A CN 105452611 B EP 3033496 A1 JP 2016-528436 A US 2016-0201848 A1	19/02/2015 30/03/2016 21/11/2017 22/06/2016 15/09/2016 14/07/2016
JP 2002-247822 A	30/08/2002	JP 5161472 B2	21/12/2012
JP 2007-174752 A	05/07/2007	JP 4841948 B2	21/12/2011
KR 10-2002-0074324 A	30/09/2002	KR 10-0372787 B1	25/02/2003