EUROPEAN PATENT SPECIFICATION

ROTOR-STATOR STRUCTURE FOR ELECTRODYNAMIC MACHINES

ROTOR-STATOR-STRUKTUR FÜR ELEKTRODYNAMISCHE MASCHINEN

STRUCTURE DE ROTOR-STATOR POUR MACHINES ELECTRODYNAMIQUES

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Description

BRIEF DESCRIPTION OF THE INVENTION

[0001] This invention relates generally to electric motors, alternators, generators and the like, and more particularly, to a rotor-stator structure for motors that, for example, increases output torque per unit size (or per unit weight) either by minimizing the length of magnetic flux paths or by straightening those paths through field pole members, or both. Further, the rotor-stator structure conserves resources, such as reducing manufacturing costs, such as by minimizing wastage and by eliminating “back-iron” material.

BACKGROUND OF THE INVENTION

[0002] In traditional stator and rotor structures for fractional and sub-fractional horsepower motors, permanent magnets are often integrated into a rotor assembly that typically rotates in the same plane as a ferromagnetic stator structure that provides magnetic return paths for magnet and current-generated flux. Current-generated flux, which is also referred to as Ampere Turn (“AT”)-generated flux, is generated by passing a current through a coil winding that is wrapped about a pole region of a stator member structure. While functional, conventional stator and rotor structures of these and other electric motors have several drawbacks, as are discussed next.


[0004] FIG. 1 illustrates a traditional electric motor exemplifying commonly-used stator and rotor structures. Electric motor 100 is a cylindrical motor composed of a stator structure 104, a magnetic hub 106 and a shaft 102. The rotor structure of motor 100 includes one or more permanent magnets 110, all of which are attached via magnetic hub 106 to shaft 102 for rotation within stator structure 104. Stator structure 104 typically includes field poles 118, each having a coil winding 114 (only one is shown) that is wound about each field pole 118. Stator structure 104 includes slots 108 used in part to provide a wire passage for winding coil wire about stator field poles 118 during manufacturing. Slots 108 also provide magnetic separation between adjacent field poles 118. Stator structure 104 includes a peripheral flux-carrying segment 119 as part of magnetic return path 116. In many cases, stator structure 104 is composed of laminations 114, which are formed from isotropic (e.g., non-grain oriented), magnetically permeable material. Magnetic return path 116, which is one of a number of magnetic return paths in which permanent magnet-generated flux and AT-generated flux is present, is shown as being somewhat arcane in nature at peripheral flux-carrying segment 119 but includes relatively sharp turns into the field pole regions 118.

[0005] One drawback of traditional electric motors, including electric motor 100, is that magnetic return path 116 requires a relatively long length for completing a magnetic circuit for flux emanating from one rotor magnet pole 110 and traversing via magnetic return path 116 to another rotor magnet pole 110. Furthermore, magnetic return path 116 is not a straight line, which is preferred for carrying magnetic flux. As shown, magnetic return path 116 has two ninety-degree turns in the stator path. Magnetic return path 116 turns once from field pole region 118 to peripheral flux-carrying segment 119, and then again from peripheral flux-carrying segment 119 to another field pole region 118. Both of these turns are sub-optimal for carrying flux efficiently. As implemented, magnetic return path 116 requires more material, or “back-iron,” than otherwise is necessary for carrying such flux between field poles. Consequently, magnetic return paths 116 add weight and size to traditional electric motors, thereby increasing the motor form factor as well as cost of materials to manufacture such motors.

[0006] Another drawback of conventional electric motors is that laminations 114 do not effectively use anisotropic materials to optimize the flux density and reduce hysteresis losses in flux-carrying poles, such as through field poles 118, and stator regions at peripheral flux-carrying segment 119. In particular, peripheral flux-carrying segment 119 includes a non-straight flux path, which limits the use of such anisotropic materials in minimizing hysteresis losses (or “iron losses”). Hysteresis is the tendency of a magnetic material to retain its magnetization.

[Hysteresis loss] is the energy required to magnetize and demagnetize the magnetic material constituting the stator regions, wherein hysteresis losses increase as the amount of magnetic material increases. As magnetic return path 116 has one or more turns of ninety-degrees or greater, the use of anisotropic materials, such as grain-oriented materials, cannot effectively reduce hysteresis losses because the magnetic return path 116 in peripheral flux-carrying segment 119 would cut across the directional orientation of laminations 114. For example, if direction 120 represents the orientation of grains for laminations 114, then at least two portions of magnetic return path 116 traverse across direction 120 of the grain, thereby reducing the flux density capacity of those portions of stator peripheral flux-carrying segment 119. Consequently, anisotropic materials generally have not been implemented in structures similar to stator structure 104 since the flux paths are usually curvilinear rather than straight, which limits the benefits provided by using such materials.

[0007] Yet another drawback of conventional electric motors is the relatively long lengths of magnetic return path 116. Changing magnetic fields, such as those developed at motor commutation frequencies, can cause eddy currents to develop in laminations 114 in an orientation opposing the magnetic field inducing it. Eddy currents result in power losses that are roughly proportional
to a power function of the rate at which the magnetic flux changes and roughly proportional to the volume of affected lamination material.

[0008] Other drawbacks of commonly-used electric motors include the implementation of specialized techniques for reducing "cogging," or detent torque, that are not well-suited for application with various types of electric motor designs. Cogging is a non-uniform angular torque resulting in "jerking" motions rather than a smooth rotational motion. This effect usually is most apparent at low speeds and applies additive and subtractive torque to the load when field poles 118 are at different angular positions relative to magnet poles. Further, the inherent rotational accelerations and decelerations cause audible vibrations.

[0009] In another type of electric motor, magnetic poles are positioned at relatively large diameters about (or radial distances from) a rotor shaft. These magnetic poles, as well as the permanent magnets giving rise to those magnetic poles, are typically arranged coaxially about the shaft, with adjacent magnetic poles alternating in polarity. An armature disk usually supports the permanent magnets as separate, non-monolithic magnets in a plane perpendicular to the rotor shaft. Structures such as this are designed based on a certain tenet of electric motor design. According to this tenet, an increase in output torque is achieved by increasing the radial distance between the magnetic poles and the rotor shaft. Consequently, the magnetic poles of this type of electric motor are increasingly being positioned at larger distances from the rotor shaft to increase the torque arm distance from the axis of rotation to the air gaps, thereby increasing the output torque. A drawback to this approach is that additional materials are consumed in forming larger motor structures to accommodate the larger torque arm distance, such as those structures that are used to form magnetic flux return paths. These magnetic flux return paths are typically formed using "back-iron" to complete a larger flux path, which is generally circuitous in nature. By adding back-iron to complete a magnetic circuit, the magnetic material volume through which the magnetic flux passes increases, which detrimentally tends to increase the hysteresis and eddy current losses, both of which can be collectively referred to as "core losses." Further, the addition of back-iron to complete a magnetic circuit increases the length of the magnetic flux path, thereby exacerbating core losses. Another drawback to motors of this type is that the motor volume increases as the magnetic poles are positioned farther from the shaft, which, in turn, limits the available applications and uses for this type of motor.

[0010] "Back-iron" is a term commonly used to describe a physical structure (as well as the materials giving rise to that physical structure) that is often used to complete an otherwise open magnetic circuit. Back-iron structures are generally used only to transfer magnetic flux from one magnetic circuit element to another, such as either from one magnetically permeable field pole to another, or from a magnet pole of a permanent magnet to a magnet pole of another permanent magnet, or both. Further, "back-iron" structures are not generally formed to accept an associated ampere-turn generating element, such as one or more coils.

[0011] In view of the foregoing, it would be desirable to provide a rotor-stator structure that minimizes the above-mentioned drawbacks in electric motors and generators, and to increase output torque and efficiency either on a per unit size or per unit weight basis, or both, as well as to conserve resources during manufacturing and/or operation.

SUMMARY OF THE INVENTION

[0012] A system according to claim 1 is disclosed for implementing an exemplary rotor-stator structure for use in electrodynamic machines, such as electric motors, generators, alternators, and the like. According to one embodiment of the present invention, a rotor-stator structure for electrodynamic machines comprises conical magnets having conical surfaces arranged axially on an axis of rotation such that the conical surfaces face each other. The conical magnets include at least two conical magnets being positioned so that the directions of polarization of the two conical magnets are in substantially opposite directions. Further, the rotor-stator structure can also include field pole members arranged coaxially to the axis. The field pole members have flux interaction surfaces formed at the ends of the field pole members and adjacent to portions of the conical surfaces that confront the flux interaction surfaces. The flux interaction surfaces define air gaps with the portions of the conical surfaces and are configured to magnetically couple the field pole members to the conical magnets. Preferably, each of the field pole members is spaced from another of the field pole members by a field pole gap. Advantageously, each of the conical magnets establishes an air gap with each of the field pole members. Conveniently, the air gaps, the conical magnets and the field pole members are sufficient to form a closed flux path that passes through at least two of the field pole members in different directions and through the at least two conical magnets in substantially opposite directions. In some cases, the rotor-stator structure includes a shaft on which the conical magnets are affixed, the shaft defining the axis of rotation. The conical surfaces each can have an angle of inclination from about 10 degrees to about 80 degrees with respect to the axis of rotation. In one embodiment, each of the field pole members further comprises a magnetically permeable material that is continuous from one end of each field pole member to the other end, where at least a portion of each field pole member is configured to accept an element, such as one or more coils, for generating ampere-turn ("AT") flux. In an alternative embodiment, the rotor-stator structure further comprises one or more coils, at least one of which is wound about each of the field pole members to form active field pole members.
In some cases, the rotor-stator structure excludes back-iron, thereby decreasing hysteresis losses as well as materials for manufacturing an electrodynamic machine. In another embodiment, at least one of the field pole members of a rotor-stator structure is substantially straight. Substantially straight field pole members can provide a relatively short magnetic flux path between magnets, which may be accompanied by a reduction in the volume of the magnetically permeable material as compared to the use of back-iron in some traditional stator structures. By reducing the volume of magnetically permeable material through which magnetic flux is conducted, hysteresis losses can be decreased.

[0013] The field pole members and the conical magnets of an exemplary rotor-stator structure can be arranged to minimize linear deviations in a path portion of a magnetic flux path coincident with a substantially straight line extending from a surface portion of a first conical magnet to a surface portion of a second conical magnet, the path portion terminating at the surface portions. In a specific embodiment, the rotor-stator structure is configured to generate magnetic flux paths consisting essentially of the first conical magnet, the second conical magnet, at least one of the field pole members, and two or more air gaps. The field pole members, in some instances, can comprise laminations to minimize eddy currents, thereby reducing power losses. The laminations can be formed from a substrate composed of a magnetically permeable material in a manner that reduces wastage of the magnetically permeable material. Notably, in certain instances, at least one of the laminations is anisotropic, which can include grain-oriented materials. In one embodiment, the rotor-stator structure further comprises a coil wound about at least one of the field pole members to form at least one active field pole member, where at least the one field pole member is shaped to minimize manufacturing complexity associated with winding the coil on traditional field poles by obviating the need to wind the coil via a slot. In still another embodiment, each of the flux interaction surfaces further comprises a skewed flux interaction surface to reduce field poles gaps between adjacent field pole members, thereby minimizing detent torque. The skewed flux interaction surface may include a first edge defining a first side of a field pole gap and a second edge defining a second side of another field pole gap, whereby the first edge and the second edge maintain angles that do not align with a direction of polarization of at least one of the conical magnets, where one first edge of a first field pole member and one second edge of a second field pole member form the field pole gap. Detent torque can also be reduced by offsetting the directions of polarization of the two conical magnets by about 150 to about 180 degrees. The field pole members, in at least one example of a rotor-stator structure, are stationary while the conical magnets can rotate relative to the field pole members, whereas in other examples, the conical magnets remain stationary and the field pole members rotate relative to the conical magnets.

Advantageously, each of the field pole members may be an elongated field pole member having a length dimension in an axial direction greater than a width dimension. Preferably, said flux path passes through at least two of said field pole members in different directions. Conventionally, the directions of polarization are configured to form a flux path portion of the closed flux path within the interior of each of the conical magnets, the flux path portion extending through a plane that includes the axis of rotation. Advantageously, the flux path portion extends from a first point to a second point, the first point and the second point lying on conical surface portions associated with the same conical surface. Preferably, the directions of polarization are each substantially perpendicular to the axis of rotation. More preferably, the directions of polarization are each perpendicular to the axis of rotation.

[0014] According to another embodiment of the present invention, a rotor-stator structure for electrodynamic machines having an axis comprises a rotor having at least two magnets arranged axially about the axis. The two magnets can be spaced apart from each other and can have regions of predetermined magnetic polarization. The magnets can each have confronting magnetic surfaces of principal dimension that is substantially at an acute angle to the axis. The confronting magnetic surfaces face each other generally, with the magnetic polarizations being in substantially opposite directions. The magnetic polarizations can be described as lying within planes passing through the magnet surfaces while being substantially perpendicular to the axis. In one embodiment, the magnets are substantially conical magnets and the magnetic surfaces are conical magnetic surfaces. The rotor-stator structure can also include field poles arranged coaxial to the axis and having flux interaction surfaces formed at the ends of the field poles. The flux interaction surfaces are typically located adjacent the confronting magnetic surfaces, which are generally coextensive with the principal dimension thereof, defining functioning air gaps therebetween. Each of the field pole members can be magnetically permeable, wherein the flux interaction surfaces are configured to magnetically couple the field pole members to the conical magnets. In at least one instance, one or more field pole members each further comprises a coil about the one or more field pole members, thereby forming one or more active field pole members. In one embodiment, the rotor-stator structure is configured to limit magnetic flux paths to traverse only through two of the conical magnets, the field pole members, the flux interaction surfaces, and the air gaps. As such, back-iron is excluded. In a specific embodiment, the field pole members comprise one or more of silicon-iron alloys, nickel-iron alloys, cobalt-nickel alloys, magnetic-powdered alloys, and soft magnetic composite, whereas the conical magnets can be permanent magnets composed of a magnet material having a recoil permeability less than 1.3. As an example, the conical magnets can be composed of neodymium iron ("NdFe"), in whole
or in part. As other example, the magnets can be composed of ceramic, Samarium Cobalt ("SmCo"), or any other rare earth magnet material.

[0015] According to yet another embodiment of the present invention, an exemplary rotor-stator structure for electrodynamic machines comprises a shaft defining an axis of rotation and having a first end portion, a central portion and a second end portion. The rotor-stator structure includes at least a first magnet having a surface contoured as at least a portion of a cone to form a first conical surface, the first magnet having a first direction of polarization and being disposed axially on the shaft at the first end portion. Also, the rotor-stator structure can include a second magnet having a surface contoured as at least a portion of a cone to form a second conical surface, the second magnet having a second direction of polarization and being disposed axially on the shaft at the second end portion such that the first direction of polarization is substantially opposite to the second direction of polarization. Generally, the second conical surface faces, or confronts, the first conical surface. The rotor-stator structure is further composed of a number of field pole members arranged substantially coaxial to the shaft. Each of the field pole members comprises a number of substantially straight laminations, at least one of which is composed of anisotropic material and arranged in parallel with other laminations and in parallel with the axis of rotation. Each of the field pole members has a first pole shoe at its first field pole member end and a second pole shoe at its second field pole member end, the first pole shoe being positioned adjacent to a portion of the first conical surface to form a first flux interaction region and the second pole shoe being positioned adjacent to a portion of the second conical surface to form a second flux interaction region. Further, the rotor-stator structure includes at least one coil wound about at least one of the number of field pole members to form an active field pole member. As such, at least in some cases, the rotor-stator structure is configured to generate at least one magnetic flux path limited to traverse only through the first magnet, the second magnet, the active field pole member and the first and second flux interaction regions. In a specific embodiment, the at least one coil extends substantially the length of the active field pole member in an axial direction for reducing flux leakage from the peripheries of the active field pole member.

[0016] In an alternate embodiment, the first pole shoe and the second pole shoe further comprise a first pole face and a second pole face, respectively, wherein at least a portion of the first pole face is contoured to form a first air gap having a gap thickness principally defined by the distance between the portion of the first conical surface and the first pole face, and at least a portion of the second pole face is contoured to form a second air gap having a gap thickness principally defined by the distance between the portion of the second conical surface and the second pole face. The gap thickness is generally no greater than 40% of an average diameter of either the first magnet or the second magnet. In another embodiment, the first magnet and the second magnet each are dipole magnets oriented in a manner so their polarizations differ by an angle between 150 to 180 degrees, wherein each of the dipole magnets is monolithic. In some embodiments, the first magnet and the second magnet each are multipole magnets. An exemplary configuration for a rotor-stator includes three or four field poles and dipole magnets. Another configuration includes six or eight field poles configured to operate with four-pole conical magnets. The rotor-stator structure, in some instances, can be configured to receive mechanical power as rotational motion about the shaft for implementing an electric generator.

[0017] According to still yet another embodiment of the present invention, an exemplary rotor-stator structure for electrodynamic machines comprises a shaft defining an axis of rotation, at least two permanent magnets each having at least one conical surface and an outer surface, each of the at least two permanent magnets being affixed coaxially on the shaft such that one of the at least one conical surface faces another, a plurality of sets of coils, and a plurality of ferromagnetic field pole members. The plurality of ferromagnetic field pole members are disposed substantially parallel to the axis, each of the ferromagnetic field pole members having a length along an axial direction, the length substantially extending at least between both of the at least one conical surface of the at least two permanent magnets. Each of the ferromagnetic field pole members also has at least a central portion around which a set of coils of the plurality of sets of coils is wound. Each of the ferromagnetic field pole members has a pole shoe having at least a pole face formed at each end of the ferromagnetic field pole members. Each pole face is generally configured to form a flux interaction region with or via a portion of the at least one conical surface of either one of the at least two permanent magnets.

[0018] According to at least one embodiment, an exemplary rotor-stator structure can be disposed within an electric motor to provide more output torque deliverable by such a motor relative to conventional electric motors of the same size and/or weight. In one embodiment, a rotor-stator structure provides a relatively shorter and straighter magnetic path, and a more efficient use of materials than traditional stator-rotor structures for electrodynamic machines. In cases where anisotropic (e.g., grain-oriented materials) magnetically permeable materials are used to form field pole members of specific embodiments of the present invention, the inherent magnetic properties of such materials contribute to an increase of flux density in flux-carrying regions. Note that these materials may or may not be used to form laminations. The elimination or at least reduction of exterior return paths, such as those return paths traditionally implement-
ed using back-iron, therefore saves weight and reduces the overall size of electrodynamic machines implementing various embodiments of the rotor-stator structure of the present invention. In another embodiment, a stator-rotor structure provides a greater motor efficiency than a similarly-sized conventional motor with the same output torque. This efficiency increase is due, at least in part, to lower resistance windings, which translates to lower current-squared-times-resistance (i.e., I² * R) power losses while producing the same ampere turn-generated flux created in similarly-sized packages or motor housings of traditional motors. Further, the rotor-stator structure of the present invention is less complex (e.g., in the coil winding process) and less costly (e.g., due to conservation of materials) to manufacture than conventional motors.

BRIEF DESCRIPTION OF THE FIGURES

[0019] The invention is more fully appreciated in conjunction with the following detailed description taken in conjunction with the accompanying drawings, in which:

[0020] FIG. 1 exemplifies commonly-used stator and rotor structures implemented in a traditional electric motor;

[0021] FIG. 2 is an exploded view of an exemplary rotor-stator structure in which the magnets are conical in shape, according to one embodiment of the present invention;

[0022] FIG. 3 depicts an end view for the rotor-stator structure of FIG. 2 without a magnet to illustrate the orientation of the pole faces that are configured to interact via an air gap with a confronting magnetic surface of a conical magnet, according to one embodiment of the present invention;

[0023] FIG. 4 depicts another end view for the rotor-stator structure of FIG. 2 illustrating a conical magnet positioned adjacent to pole faces in accordance with an embodiment of the present invention;

[0024] FIGs. 5A and 5B depict sectional views illustrating an exemplary magnetic flux path, according to at least one embodiment of the present invention;

[0025] FIG. 5C depicts an example of a second flux path exiting a pole face of a stator member generating an ampere-turn magnetic flux, according to one embodiment of the present invention;

[0026] FIG. 5D depicts an example of a second flux path(s) entering a pole face of an active field pole member that originally generated the ampere-turn magnetic flux of FIG. 5C, according to one embodiment of the present invention;

[0027] FIGs. 6A and 6B illustrate an exemplary field pole member, according to an embodiment of the present invention;

[0028] FIGs. 6C depicts a partial sectional view of the rotor-stator structure of FIGs. 6A and 6B, according to one embodiment of the present invention;

[0029] FIGs. 7A and 7B illustrate an exemplary field pole member having skewed pole faces, according to a specific embodiment of the present invention;

[0030] FIG. 8 illustrates another exemplary field pole member having skewed pole faces, according to a specific embodiment of the present invention;

[0031] FIGs. 9A to 9M illustrate examples of other-shaped permanent magnets that can be implemented in an exemplary rotor-stator structure, according to various embodiments of the present invention;

[0032] FIG. 10 shows a multiple pole magnet, according to an embodiment of the present invention; and

[0033] FIG. 11 shows an end view for an example of another rotor-stator structure as an alternate embodiment of the present invention.

[0034] Like reference numerals refer to corresponding parts throughout the several views of the drawings. Note that most of the reference numerals include one or two left-most digits that generally identify the figure that first introduces that reference number.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

Definitions

[0035] The following definitions apply to some of the elements described with respect to some embodiments of the invention. These definitions may likewise be expanded upon herein.

[0036] As used herein, the term "air gap" refers to a space, or a gap, between a magnet surface and a confronting pole face. Such a space can be physically described as a volume bounded at least by the areas of the magnet surface and the pole face. An air gap functions to enable relative rotation between a rotor and a stator, and to define a flux interaction region. Although an air gap is typically filled with air, it need not be so limiting.

[0037] As used herein, the term "back-iron" commonly describes a physical structure (as well as the materials giving rise to that physical structure) that is often used to complete an otherwise open magnetic circuit. In particular, back-iron structures are generally used only to transfer magnetic flux from one magnetic circuit element to another, such as either from one magnetically permeable field pole member to another, or from a magnet pole of a first magnet to a magnet pole of a second magnet, or both, without an intervening ampere-turn generating element, such as coil, between the field pole members or the magnet poles. Furthermore, back-iron structures are not generally formed to accept an associated ampere-turn generating element, such as one or more coils.

[0038] As used herein, the term "coil" refers to an assemblage of successive convolutions of a conductor arranged to inductively couple to a magnetically permeable material to produce magnetic flux. In some embodiments, the term "coil" can be described as a "winding" or a "coil winding."

[0039] As used herein, the term "coil region" refers
generally to a portion of a field pole member around which a coil is wound.

As used herein, the term "core" refers to a portion of a field pole member where a coil is normally disposed between pole shoes and is generally composed of a magnetically permeable material for providing a part of a magnetic flux path.

As used herein, the term "field pole member" refers generally to an element composed of a magnetically permeable material and being configured to provide a structure around which a coil can be wound (i.e., the element is configured to receive a coil for purposes of generating magnetic flux). In some embodiments, a field pole member includes a core (i.e., core region) and at least two pole shoes, each of which is generally located at or near a respective end of the core. But note that in other embodiments, a field pole member includes a core and only one pole shoe. Without more, a field pole member is not configured to generate ampere-turn flux. In some embodiments, the term "field pole member" can be described generally as a "stator-core." In some embodiments, a field pole member generally has an elongated shape such that the length of the field pole member (e.g., the distance between the ends of the field pole member) is generally greater than its width (e.g., the width of the core).

As used herein, the term "active field pole member" refers to an assemblage of a core, one or more coils, and at least one pole shoe. In particular, an active field pole member can be described as a field pole member assembled with one or more coils for selectively generating ampere-turn flux. In some embodiments, the term "active field pole member" can be described generally as a "stator-core member."

As used herein, the term "ferromagnetic material" refers to a material that generally exhibits hysteresis phenomena and whose permeability is dependent on the magnetizing force. Also, the term "ferromagnetic material" can also refer to a magnetically permeable material whose relative permeability is greater than unity and depends upon the magnetizing force.

As used herein, the term "field interaction region" refers to a region where the magnetic flux developed from two or more sources interact vectorially in a manner that can produce mechanical force and/or torque relative to those sources. Generally, the term "flux interaction region" can be used interchangeably with the term "field interaction region." Examples of such sources include field pole members, active field pole members, and/or magnets, or portions thereof. Although a field interaction region is often referred to in rotating machinery parlance as an "air gap," a field interaction region is a broader term that describes a region in which magnetic flux from two or more sources interact vectorially to produce mechanical force and/or torque relative to those sources, and therefore is not limited to the definition of an air gap (i.e., not confined to a volume defined by the areas of the magnet surface and the pole face and planes extending from the peripheries between the two areas). For example, a field interaction region (or at least a portion thereof) can be located internal to a magnet.

As used herein, the term "generator" generally refers to an electrodynamic machine that is configured to convert mechanical energy into electrical energy regardless of, for example, its output voltage waveform. As an "alternator" can be defined similarly, the term generator includes alternators in its definition.

As used herein, the term "magnet" refers to a body that produces a magnetic field external to itself. As such, the term magnet includes permanent magnets, electromagnets, and the like.

As used herein, the term "motor" generally refers to an electrodynamic machine that is configured to convert electrical energy into mechanical energy.

As used herein, the term "magnetically permeable" is a descriptive term that generally refers to those materials having a magnetically definable relationship between flux density ("B") and applied magnetic field ("H"). Further, "magnetically permeable" is intended to be a broad term that includes, without limitation, ferromagnetic materials, soft magnetic composites ("SMCs"), and the like.

As used herein, the term "pole face" refers to a surface of a pole shoe that faces at least a portion of the flux interaction region (as well as the air gap), thereby forming one boundary of the flux interaction region (as well as the air gap). In some embodiments, the term "pole face" can be described generally as a "stator surface."

As used herein, the term "pole shoe" refers to that portion of a field pole member that facilitates positioning a pole face so that it confronts a rotor (or a portion thereof), thereby serving to shape the air gap and control its reluctance. The pole shoes of a field pole member are generally located near each end of the core starting at or near a coil region and terminating at the pole face. In some embodiments, the term "pole shoe" can be described generally as a "stator region" or at least a portion of a "flux interaction surface," or both.

As used herein, the term "soft magnetic composites" ("SMCs") refers to those materials that are comprised, in part, of insulated magnetic particles, such as insulation-coated ferrous powder metal materials that can be molded to form an element of the rotor-stator structure of the present invention.

Discussion

FIG. 2 is an exploded view of an exemplary rotor-stator structure in accordance with a specific embodiment of the present invention. In this example, rotor-stator structure 200 is configured to increase torque generated per unit size (or per unit weight) for electric motor implementations by at least minimizing the length of magnetic flux paths through field pole members. In some embodiments, field pole members 204 provide straight or substantially straight flux paths (or segments thereof) to
minimize linear deviations of the magnetic flux. Typically, the path segments are generally parallel to the axis of rotation. So by implementing straight or substantially straight paths, each of those field pole members provide a relatively low reluctance flux path as compared to conventional magnetic return path designs that require magnetic flux to turn sharply about the periphery, such as at an angle of ninety-degrees (or thereabout), between field pole regions. As such, rotor-stator structures of various embodiments of the present invention can implement straight or substantially straight paths to enable electrodynamic machines to operate with reduced magnetic losses and increased efficiency. The following description is applicable to magnets with other shapes than or equivalents to conical magnet shapes.

In this example, rotor-stator structure 200 includes a rotor assembly 202 and a number of active field pole members 204 (i.e., active field pole members 204a, 204b, and 204c), whereby active field pole members 204 are configured to magnetically couple to and drive magnets of rotor assembly 202. Rotor assembly 202 includes two conical magnets 220 (i.e., conical magnets 220a and 220b) mounted on or affixed to a shaft 222 such that at least a portion of a conical magnet surface 221a on conical magnet 220a faces at least a portion of a conical magnet surface 221b on conical magnet 220b. In particular, the smaller-diameter ends (i.e., nearest the cones' vertices, if present, or nearest the cones' conceptual vertices if otherwise not present due, for example, truncation of the cone) of the conical magnets 220 face each other. Further, conical magnets 220 are each positioned adjacent to one group of ends of active field pole members 204. In various embodiments of the present invention, conical magnet surfaces 221a and 221b each have an angle of inclination with respect to the axis of rotation, where the angle is from about 5 degrees to about 85 degrees. In a specific embodiment, the angle of inclination can be from about 10 degrees to about 80 degrees. In at least one embodiment, the angle of inclination is about 30 degrees with respect to the axis of rotation. So by implementing straight or substantially straight paths, each of those field pole members provide a relatively low reluctance flux path as compared to conventional magnetic return path designs that require magnetic flux to turn sharply about the periphery, such as at an angle of ninety-degrees (or thereabout), between field pole regions. As such, rotor-stator structures of various embodiments of the present invention can implement straight or substantially straight paths to enable electrodynamic machines to operate with reduced magnetic losses and increased efficiency. The following description is applicable to magnets with other shapes than or equivalents to conical magnet shapes.

As either rotor assembly 202 or the number of active field pole members 204 can be configured to rotate in relation to the other, rotor-stator structure 200 can optionally include bearings 230 and both a front mounting plate 240a and a rear mounting plate 240b. In a specific embodiment, mounting plates 240a and 240b can be made of non-magnetic and/or non-electrically conductive materials. Cavities 244 in mounting plates 240a and 240b are designed to receive bearings 230, and grooves 242 are designed to receive at least a portion of an extended end, such as extended end 217b, of an active field pole member. In some cases, grooves 242 confine the movement of active field pole members 204 to maintain a proper position with respect to rotor assembly 202. A protective housing (not shown) can be added to protect both rotor assembly 202 and field pole members 204 and can also serve as a heat sink for one or more coils 208. While useful to implement the exemplary rotor-stator structure 200, various embodiments of the invention are not limited to including mounting plates 240a and 240b as well as bearings 230 and grooves 242, especially when generating a flux path in accordance with various embodiments of the present invention.

As either rotor assembly 202 or the number of active field pole members 204 can be configured to rotate in relation to the other, rotor-stator structure 200 can optionally include bearings 230 and both a front mounting plate 240a and a rear mounting plate 240b. In a specific embodiment, mounting plates 240a and 240b can be made of non-magnetic and/or non-electrically conductive materials. Cavities 244 in mounting plates 240a and 240b are designed to receive bearings 230, and grooves 242 are designed to receive at least a portion of an extended end, such as extended end 217b, of an active field pole member. In some cases, grooves 242 confine the movement of active field pole members 204 to maintain a proper position with respect to rotor assembly 202. A protective housing (not shown) can be added to protect both rotor assembly 202 and field pole members 204 and can also serve as a heat sink for one or more coils 208. While useful to implement the exemplary rotor-stator structure 200, various embodiments of the invention are not limited to including mounting plates 240a and 240b as well as bearings 230 and grooves 242, especially when generating a flux path in accordance with various embodiments of the present invention.
208b and 208c can be omitted from active field pole members 204b and 204c, respectively, to form an electrodynamic machine that, for example, costs less to manufacture than if coils 208b and 208c were included. Without coils 208b and 208c, members 204b and 204c constitute field pole members rather than active field pole members. Also note that although field pole members 206a, 206b and 206c are shown as straight field pole members, there is no requirement that field pole members 206a, 206b and 206c be straight or substantially straight. In some embodiments, one or more of field pole members 206a, 206b and 206c can be shaped to implement non-straight field pole members to convey flux in other than a straight flux path. For example, field pole members 206a, 206b and 206c can be shaped to position coils 208 closer to shaft 222, thereby decreasing the volume of an electrodynamic machine implementing rotor-stator structure 200. As used herein, a “non-straight” flux path in some embodiments can be described as a flux path having two consecutive segments and at an angle between 60 degrees and 90 degrees. In some embodiments, the term “substantially straight” can refer to a field pole member that provides straight flux paths (e.g., paths that have no deviation from a straight line between, for example, field interaction regions) as well as flux paths that include two consecutive flux path segments that are 60 degrees or less from each other in the same general direction.

In at least one specific embodiment, each of one or more active field pole members 204 include only one or more coils 208 and a field pole member, such as any of 206a, 206b and 206c. In some cases, active field pole members 204 can include tape, paper, and/or paint, or the like that do not add substantial support for coil windings that are wound about a field pole member. Generally, the windings of one or more coils 208 are wound directly on the field pole member itself. The conductors of one or more coils 208 can generally include insulation. But in this specific embodiment, each of active field pole members 204 need not include any other intermediate structure, such as a coil carrier structure, which requires additional material cost and labor during a manufacturing process.

FIG. 3 depicts an end view 300 of rotor-stator 200 illustrating orientation of the pole faces that are configured to interact via an air gap with a confronting magnetic surface of conical magnet 220a, according to one embodiment of the present invention. Absent from FIG. 3 is front mounting plate 240a, bearings 230 and conical magnet 220a, all of which are omitted to depict the end views of both the active field pole member and coil shapes, as well as the field pole gaps (“G”) between the field poles. As shown, coils 208a, 208b, and 208c respectively encompass field pole members 206a, 206b and 206c to form active field pole members 204a, 204b and 204c, all of which are compactly positioned to increase the packing density of a motor or generator implementing rotor-stator structure 200 (as compared to conventional motors using coil windings that typically are wound using slots 108 of FIG. 1). FIG. 3 also depicts edges of extended ends 311a, 311b, and 311c, and pole faces 307a, 207b, and 207c of respective active field pole members 204a, 204b and 204c. Pole faces 307a, 207b, and 207c are positioned to form magnetic air gaps between each of those pole faces, or surfaces, and at least a portion of the conical magnet surface of conical magnet 220a. Further, field pole gaps are defined by the sides (or edges) of the field pole members that constitute active field pole members 204a, 204b and 204c. For example, gap “G” represents any of the field pole gaps as defined, for example, by planes 310 and 320 extending from sides of respective field pole members 206b and 206c (FIG. 2).

FIG. 4 depicts another end view 400 of rotor-stator 200 and conical magnet 220a positioned adjacent to pole faces 307a, 207b, and 207c (FIG. 3) in accordance with an embodiment of the present invention. As shown, outer magnet surface 223a of conical magnet 220a is visible, as are the protruding edges of extended ends 311a, 311b, and 311c and coils 208. Note that in this example, conical magnet 220a is a dipole magnet (e.g., a permanent magnet) having a north pole (“N”) and a south pole (“S”). Note that in some embodiments, conical magnets 220a and 220b can be implemented using electro-magnets. Also, FIG. 4 defines three sectional views. The first sectional view, X-X, cuts through a centerline bisecting field pole member 206a and coil 208a and then passes via magnet 220a through a field pole gap between other field pole members 206b and 206c. A second section view, Y-Y, bisects field pole member 206a and coil 208a and then passes via magnet 220a through field pole member 206b and coil 208b. A third section view section view, Y’-Y’, which is similar to the second section view, Y-Y, bisects field pole member 206a and coil 208a and then passes via magnet 220a through field pole member 206c and coil 208c. Section view X-X is shown in FIG. 5A, whereas views Y-Y and Y’-Y’ produce similar drawings, both of which are depicted in FIG. 5B.

FIGS. 5A and 5B depict sectional views illustrating an exemplary magnetic flux path, according to at least one embodiment of the present invention. FIG. 5A depicts a cross section of active field pole member 204a of rotor-stator structure 500, the cross section showing a sectional view X-X of coil 208a and field pole member 206a. In this example, active field pole member 204a includes pole faces 507a and 505b, pole shoes 507a and 507b, a coil region 506 and coil 208a. In view X-X of FIG. 5A, conical magnets 220a and 220b are diametrically magnetized in opposite directions and are positioned adjacent to respective pole shoes 507a and 507b of field pole member 206a. Correspondingly, pole face 307a of pole shoe 507a forms a magnetic air gap 551a with at least a portion 521a of magnet surface 221a, with portion 521a confronting pole face 307a and shown as a cross-section. Similarly, pole face 505b of pole shoe 507b forms a magnetic air gap 551b with at least a portion 521b of magnet surface 221b, with portion 521b confronting pole face 505b and shown as a cross-section. Note that por-
tions 521a and 521b need not extend the axial length of conical magnets 220a and 220b, respectively. For example, portions 521a and 521b can be defined by regions that are bounded by the largest and smallest cross-sectional diameters of conical magnets 220a and 220b and can be of any size. Accordingly, portions 521a and 521b need only form air gaps with a pole face, with other surface portions of conical magnets 220a and 220b being configured not to form air gaps, according to at least one embodiment. Further, coil 208a encloses a coil region 506 of field pole member 206a, whereby coil region 506 is defined approximately by the axial length of coil 208a surrounding a portion of field pole member 206a. Absent in FIG. 5A is a depiction of one or more field interaction regions, which can encompass a space larger than an air gap, such as air gap 551a, and can extend into, for example, conical magnet 220a.

In at least one embodiment of the present invention, at least one of magnet portions 521a and 521b of surfaces on respective conical magnets 220a and 220b can be defined as being bounded by an angle of inclination ("θ") 501, which is an angle with respect to an axis of rotation. In the example shown, the axis of rotation is coterminous with shaft 222. In a specific embodiment, angle of inclination ("θ") 501 is 30 degrees from shaft 222. But note that angle 501 can be any angle.

With opposite polarizations, conical magnet 220a is polarized with its north pole ("N") pointing in direction 502, and conical magnet 220b is polarized with its north pole ("N") pointing in direction 504. In some embodiments, conical magnets 220a and 220b are diametrically magnetized in exactly opposite directions (i.e., 180 degrees between directions 502 and 504). But in other embodiments, directions 502 and 504 can be offset to any angle between those directions other than 180 degrees, for example, to reduce detent torque ("cogging"). In a specific embodiment, directions 502 and 504 are offset to an angle between from about 150 degrees to about 180 degrees. In various embodiments, conical magnets 220a and 220b (or other types of magnets) are each polarized to have a direction of polarization in one or more planes that are substantially perpendicular to the axis of rotation, where the term "substantially perpendicular" can in some embodiments also refer to perpendicularly angles.

FIG. 5B depicts cross sections of active field pole member 204a and either active field pole member 204b or active field pole member 204c, and depicts a magnetic flux path, according to one embodiment of the present invention. For ease of discussion, only view Y-Y will be discussed. View Y-Y is sectional view of coil 208a and field pole member 206a passing though coil 208b and field pole 206b. Magnetic flux path 560 passes through field pole members 206a and 206b and through both conical magnets 220a and 220b. For purposes of illustration, magnetic flux path 560 (or flux path) may be described as comprising two flux paths that are combined by the principle of superposition. Conical magnets 220a and 220b form the first flux path (i.e., permanent magnet-generated flux), whereas flux developed by amp-turns of the coil form the second flux path (i.e., ampere turn-generated flux). In this example, magnet flux as the first flux path exits the north pole ("N") of conical magnet 220a and crosses air gap 551a to enter pole face 307a (FIG. 3), the north pole coinciding with surface portion 521a, which confronts pole face 307a. The first flux path then traverses longitudinally through field pole member 206a and then exits pole face 505b at the end of field pole member 206a adjacent to conical magnet 220b. The first flux path continues by crossing air gap 551b and enters the south pole ("S") of conical magnet 220b, the south pole generally coinciding with a surface portion 521b of magnet surface 221b and confronts pole face 213b. Next, the first flux path crosses air gap 551c and enters pole face 213b (FIG. 2). From there, the first flux path returns through field pole member 206b to pole face 207b from which it exits, crosses air gap 551d, and then enters the south pole of conical magnet 220a, thereby completing the first flux path. Generally, the south pole of conical magnet 220a coincides with a surface portion 561a of magnet surface 221a (FIG. 2) that is confronting pole face 207b. Note that in the case shown, the flux exiting pole face 207b is equivalent to that flux exiting pole face 207c. Note that no supplemental structure or material need be required to form any portion of magnetic flux path 560. As such, rotor-stator structure 550 does not include back-iron.

In a specific embodiment, the diameters of conical magnets 220 are set so that the length of the flux path in each of conical magnets 220 is relatively large with respect to the four air gaps 551a to 551d, thereby establishing a favorable magnet load line. Note that each of the four air gaps 551a to 551d provides for a flux interaction region to facilitate magnetic flux interaction between (or through) pole faces and the magnet. Note further that a flux path in either conical magnet 220a or 220b is shown to align along the axis of magnetization (i.e., from the south pole to the north pole), which can contribute to low magnet manufacturing costs and to magnets that can generate a relatively high output torque per unit volume (or size). The coercivity of the magnet, which is the property of the magnet that determines how well a magnet will keep its internal flux alignment in the influence of strong external magnetic fields, can be optimally selected by using appropriate magnet materials for a specific application.

In at least one embodiment, rotor-stator structure 550 (FIG. 5B) generates at least a portion of magnetic flux path 560 that extends substantially linearly from about surface portion 521a of the magnet surface of first conical magnet 220a to about surface portion 521b of the magnet surface of second conical magnet 220b. In one instance, the portion of the magnetic flux path con-
sists essentially of surface portion 521a of first conical magnet 220a, surface portion 521b of the second conical magnet 220b, at least one of the field pole members, such as field pole member 206a, and two or more air gaps, such as air gaps 551a and 551b.

[0066] In at least one embodiment of the present invention, conical magnets 220a and 220b can have at least the following two magnetic properties. First, conical magnet 220a and 220b are able to produce magnetic flux, such as measured in terms of flux density, "B," with units of Tesla (CGS units of Gauss). "CGS" refers to units described in terms of the centimeter, the gram, and the second. Second, the magnet materials of conical magnet 220a and 220b are such that the magnets resist demagnetization. Materials that have an ability to highly resist demagnetization are often described as having "high coercivity," as is well known in the art. Suitable values of demagnetizing fields can be used to drive a specific magnet material flux density output to zero. As such, magnet materials that have relatively high values of coercivity generally indicate that a magnet material is capable of withstanding large values of adverse external magnetic field intensities without suffering demagnetization effects. In a specific embodiment, conical magnet 220a and 220b are composed of magnet materials having a recoil permeability value relatively close to 1.00 and sufficient coercivity, H_d, under operating conditions as to be reliable in reasonably expected conditions of operation.

[0067] Magnet materials are often characterized in part by a maximum energy product of such materials. In addition, magnet materials may be characterized by "Br," which is the magnetic flux density output from a magnet material when measured in a closed circuit and no measured external magnetic fields are being applied to that magnetic material. That maximum flux density value is frequently denoted as "Br." A high value of Br indicates that a magnet material is capable of large magnetic flux production per pole area (i.e., a high flux density). At least one embodiment, conical magnets 220a and 220b use magnets having high flux production capability (e.g., having high values of "Br") in configurations where relatively high torque is desired in relatively small device volumes.

[0068] In various embodiments, conical magnets 220a and 220b (or other magnets) use high-valued Br magnets that can be relatively short in the axial direction and use a cone angle of about 30 degrees, for example, from the axis of rotation. But in some embodiments, conical magnets 220a and 220b (or other magnets suitable for practicing the present invention) use magnet materials having lower cost and lower values of Br. In this case, the magnets generally are implemented with an air gap having a relatively larger area than those associated with higher values of Br. In particular, an increased area for an air gap is formed by increasing the axial length of a magnet, thereby increasing the surface area of a magnetic surface confronting a respective pole face. As such, lesser cone angles (e.g., less than 30 degrees) in a same outer diameter device (e.g., motor housing) can be used, albeit longer in the axial direction. Although the output torque performance, and K_m, can remain the same over many embodiments, the manufacturing cost can be less in the low-valued Br version even though there can be an increase in axial length.

[0069] While various embodiments of the present invention cover a multitude of design motor and/or generator designs using any of known available magnet materials, at least one embodiment uses magnet materials with low ratios of values of B to values of adverse applied field intensity, H, such ratios, as is typically specified in many magnet material data sheets, being measured at the respective material’s Br point, those ratios defining the "recoil permeability at Br" of such materials. While in some cases magnet materials need not only be limited to high values of coercivity, the magnet materials should exhibit predictable output flux densities when subjected to expected adverse magnetic field or thermal conditions. As such, the value of "recoil permeability" can be at least one factor when considering a motor and/or generator design using an exemplary rotor-stator structure, according to one embodiment of the present invention.

[0070] Recoil permeability is generally an expression of the relationship between values of B and the values of adverse applied field intensity. The values of recoil permeability are typically evaluated in terms of CGS units (because the permeability of air is 1.0 in CGS units) and can be determined by dividing a value of B (e.g., expressed in Tesla), near or at Br, by a value of adverse applied field intensity (e.g., H, near or at Hc, expressed in Oerstead). For some magnet materials, an average recoil permeability value can be determined and may be useful in magnet material selection. In one embodiment, recoil permeability can be defined for various magnetic materials by Magnetic Materials Producers Association ("MMPA") Standard 0100-00, as maintained by the International Magnetics Association ("IMA"). Note that (dimensionless) relative recoil permeability can also be given when using S.I. units.

[0071] Generally, values of recoil permeability are not less than 1.0. The closer that a recoil permeability value is to 1.0, however, the higher the coercivity can be for a specific measured material. In most embodiments of the present invention, a value of recoil permeability is typically less than 1.3. Typical high-coercivity magnet materials, such as magnets composed of neodymium-iron ("NdFe") and variants thereof, can have a recoil permeability value of about 1.04 in CGS units. An example of such a variant is Neodymium-Iron-Boron, or "NdFeB." Common low-cost ceramic magnets, such as those composed of ferrite ceramic, can have a ratio value of about 1.25, which permits ceramic magnets to perform adequately in most applications. Note that the average recoil permeability of typical high performance ceramic magnets is usually within a range of 1.06 to 1.2 in CGS units, more or less.

[0072] Coils 208 wound around each of field pole mem-
As shown, ampere-turn magnetic flux 570c and 570d exit according to one embodiment of the present invention.

...magnet flux, with the exception that conical magnets 220a and 220b have effective properties similar to that of air as viewed by the ampere turn-generated flux. As such, the ampere-turn flux generated within field pole member 206a (e.g., within coil region 506) is present at the pole faces adjacent to conical magnets 220a and 220b of FIGs. 5A and 5B.

In at least one specific embodiment, coils 208 can include foil conductors that are conductors having a rectangular cross-section with a relatively large width and a relatively small height. Foil conductors with insulation between layers can be used in place of wire to decrease winding resistance and increase current handling capacity in the same available winding volume. Use of a foil conductor can also decrease the inductance of the winding. In one embodiment, the insulation is affixed to one side of the foil to isolate the foil conductor in subsequent windings around the core. That is, only one side of the foil conductors need be insulated since that one side insulates a non-insulated side of a previous wound portion of the foil conductor (or foil coil). Advantageously, this reduces the amount of insulation required for coils 208, thereby saving resources, increasing packing density and increasing the number of ampere turns (while decreasing the number of conductor turns) in a space otherwise filled by fully insulated conductors (i.e., insulated on all sides, such as an insulated wire). As the foil conductor also provides for relatively smaller bending radii, it can thereby decrease the winding resistances usually common in conductors having sharper bends. By decreasing the resistance, this type of conductor can also conserve power in generating amp-turn flux, especially in battery-powered motor applications.

FIG. 5C depicts an example of a second flux path exiting a pole face of the active field pole member that generates that ampere-turn magnetic flux, according to one embodiment of the present invention. In this figure, ampere-turn ("AT")-generated flux is generated in active field pole member 204a and then exits from pole face 513a of FIG. 5C (or as shown as pole face 505b in FIG. 5B) while dividing approximately in half to form flux 570a and 570b. Then, ampere-turn flux 570a enters pole face 213b, and ampere-turn flux 570b enters pole face 513c. Then, respective portions of the second flux path then travel longitudinally through the other field pole members (e.g., field pole members 206b and 206c) to the other ends of those other field pole members to return to active field pole member 204a, which initially generated the second flux path.

FIG. 5D depicts an example of the second flux path(s) returning to a pole face of the active field pole member that generated the ampere-turn magnetic flux, according to one embodiment of the present invention. As shown, ampere-turn magnetic flux 570c and 570d exit respective pole faces 207b and 207c to enter pole face 307a, thereby completing the magnetic circuit of the second flux path (i.e., the ampere-turn magnetic flux path).

Conceptually, the magnetic fields generated by the ampere-turns in each field pole member of active field pole members 204a, 204b, and 204c in FIG. 5D can be viewed as regions of magnetic potential at each of the pole faces at the end regions or pole shoes of the active field pole members. In the air gaps between the confronting surfaces of the conical magnets and their adjacent pole faces, the flux of the first flux path and the flux of the second flux path interact in a manner familiar to those skilled in the art, where such an interaction is useful to generate torque by an electric motor implementing rotor-stator structure 200, according to at least one embodiment of the present invention. The first and the second flux paths of rotor-stator structure 200 are efficient, at least in part, because the flux is contained within the core regions 506 (FIG. 5A) of field pole members 206 by the currents running through coils 208. The magnet flux generated by each of the conical magnets 220 interacts in a flux interaction region with the magnetic flux from pole faces of active field pole members 204. As such, flux leakage paths, if any, are generally limited to relatively very small regions at pole shoes 507a and 507b (FIG. 5A), both of which include the sides and the backs of field pole members 206. As the first and second flux paths are also mostly straight in the magnetically permeable material of field pole members 206, these field pole members are well suited to be implemented with anisotropic (e.g., grain-oriented), magnetic materials in an efficient manner. As such, field pole members 206 can be composed of any anisotropic, magnetic materials capable of carrying higher flux densities and lowering magnetic losses in the direction of magnetic orientation, such as along the grains of grain-oriented materials, as compared to the use of isotropic, non-grain oriented, magnetic materials.

To illustrate, consider that an exemplary anisotropic (e.g., grain-oriented) material can have a magnetic saturation value of at least 2.03 Tesla (20,300 Gauss), whereas a typical isotropic lamination material, such as “ML9” laminations, have a saturation value of 1.96 Tesla (19,600 Gauss). Moreover, the applied field required for the anisotropic material to reach saturation is only 10,000 A/m (126 Oersted) as compared to 36,600 A/m (460 Oersted) for the isotropic material. Core losses for the anisotropic grain-oriented material (e.g., laminations of 0.36 mm (0.014 inch) thick) can be about 1.46 m² s⁻³ (0.66 Watts per pound) at 60 Hz with 1.50 Tesla (15,000 Gauss) induction. By contrast, a typical isotropic material can have core losses of about 3.62 m² s⁻³ (1.64 Watts per pound) under similar conditions. In view of the foregoing, the use of anisotropic materials in forming field pole members 206 is advantageous over the use of isotropic materials. According to at least one embodiment, a relatively straight shape for field pole members 206 enables effective use of anisotropic materials, unlike magnetic flux paths of traditional motors.

Unlike output torque generation of conventional...
motors, the output torque generated by rotor-stator structures 200 of various embodiments of the present invention need not be proportional to the radius from the axis of rotation of shaft 222 to the active air gaps 551a to 551d (FIG. 5B). All other factors being the same, increasing the radial distance of the pole faces and air gaps from shaft 222 does not change the output torque in the way that traditional motor design formulas indicate. For example, traditional motor design concepts teach that the regions carrying ampere-turn flux should be designed to have low reluctance paths, including the part of the ampere-turn magnetic flux path that is the air gap. According to various embodiments of the present invention, the ampere-turn flux path has a relatively high reluctance path through the space occupied by permanent magnets, such as conical magnets 220, yet peak torque production is relatively high in comparison to that of most traditional motors of the same size or weight (again, with other factors being equal). In a specific embodiment, the magnet materials that constitute conical magnets 220 have a magnet permeability value similar to that of air, and as such, the volume of each conical magnet 220 appears as an additional air gap to the ampere-turn magnetic circuit. In at least one embodiment, the output torque generated by an electrodynamic machine is proportional, in whole or in part, to the volumes of conical magnets 220.

In operation of rotor-stator structure 200, coils 208 are sequentially energized to cause rotation of rotor assembly 202. The energized coils generate magnetic potentials at the pole faces. These magnetic potentials tend to re-orient the internal field directions of the magnets (e.g., conical magnets 220) to the direction of the applied external field. The external field, in effect, presents an angularly-directed demagnetizing field to conical magnets 220 such that the demagnetizing field is capable of reaching relatively large amplitudes when a motor implementing rotor-stator structure 200 is under high torque loads. The intense demagnetizing field can detrimentally re-magnetize magnet materials of conical magnets 220 that have insufficient coercivity. For this reason, at least one embodiment of the present invention uses magnet materials suited for high torque loading and have: (1) a low B-to-adverse-applied-field intensity ratio, and (2) a relatively low recoil permeability, such as less than 1.3, for example.

In an embodiment of the present invention, the produced torque is through the natural inclination of the magnets, such as conical magnets 220, to seek the lowest energy position. Accordingly, the magnet poles of conical magnets 220, which can be permanent magnets, tend to rotate toward regions of greatest magnetic attraction and away from regions of magnetic repulsion, where-by such regions of “magnetic potential” are created at the air gaps at both ends of energized active field pole members 204 by the ampere-turn generated magnetic fields. Since a magnet having a relatively high coercivity will resist attempts to angularly displace the direction of its internal magnetic field, this resistance to angular dis-placement is manifested as mechanical torque on the body of the permanent magnet, thereby transferring torque to the shaft. As such, the magnets (e.g., conical magnets 220) can develop and then transfer torque to the shaft as useful output torque applied to a load.

FIGS. 6A, 6B and 6C illustrate an end view 600 of another exemplary rotor-stator structure, according to another embodiment of the present invention. FIGS 6A and 6B show end views 600 of a rotor-stator structure while FIG. 6C is a partial sectional view A-A of FIG. 6B. FIG. 6A shows active field pole members 604 each having a skewed pole face 607 at an end of a respective field pole member 606. Each skewed pole face 607 has a contoured surface that generally tracks the surface characteristics of that of a confronting surface portion of an adjacent magnet, such as conical magnet 220a, to form an air gap having, for example, a relatively constant air gap thickness. Air gap thickness generally refers to the orthogonal distance between a pole face and a confronting surface of a magnet. The skewed pole faces 607 are, at least in part, defined by surface edges and/or sides of field pole members 606 that are slightly angled or skewed with respect to the magnetization direction (e.g., direction of polarization) of an adjacent magnet. Skewed edges and/or sides are shown in FIG. 6A as first skewed edges 650 and second skewed edges 652, both of which are configured as edges of field pole members 606 to form skewed field pole gaps 660 when active field pole members 604 are arranged in a rotor-stator structure. As an example, consider that first skewed edge 650c is configured to form an angle 622 with respect to at least one direction of polarization 630 of a magnet (not shown). Consider further that second skewed edge 652b is configured to form an angle 620 with respect to at least one direction of polarization 630 of an adjacent magnet. Angles 620, 622 can be the same angle or can be any other angle that is suitable for forming field pole gaps 660 that are skewed in relation to the directions of polarization of one or more magnets. Note that FIG. 6C is a partial sectional view showing skewed edges being configured so that the radial plane of magnetic polarization 631 does not align with either of field pole edge 650 or field pole edge 652. In particular, field pole edge 650c and field pole edge 652b both do not align (i.e., are skewed) relative to plane of magnetization 631.

FIG. 6B is an end view 670 showing skewed pole face edges at both ends of field pole members 606. By implementing skewed field pole gaps 660 of FIG. 6A in a rotor-stator structure, detent torque (“cogging”) is reduced. In at least one embodiment, skewed field pole gaps 660 are adapted for use with permanent magnets that are diametrically polarized, such as conical magnets 220. In this instance, end view 670 of FIG. 6B is an end view showing pole faces 607 that are configured to surface contours similar to that of an adjacent conical magnet 220a, pole faces 607 being similar to those shown in FIG. 6A. Also shown in FIG. 6B are first skewed edges 680 and second skewed edges 682, which are associated with pole faces at the other end of field pole members.
606 (e.g., at the other pole shoe opposite than that associated with first skewed edges 650 and second skewed edges 652 as indicated by the broken lines). First skewed edges 680 and second skewed edges 682 in this case have angles similar to those of first skewed edges 650 and second skewed edges 652, respectively, but face a magnet surface associated with conical magnet 220b, for example. As such, the angular directions of the field pole gaps formed by edges 650 and 652 are opposite in the angular direction of the field pole gaps formed by edges 680 and 682. Consequently, the diametrically polarized magnets will generally not align with a field pole gap having pole face sides similar to those that form field pole gap "G" between planes 310 and 320 (FIG. 3), which can be a source of cogging torque in an electric motor. Note that distance between edges 650 and 652, as well as between edges 680 and 682, can be configured to be as narrow as necessary to minimize the cogging effects of the field pole gaps.

[0083] FIGs. 7A and 7B illustrate an exemplary field pole member, according to one embodiment of the present invention. Although each of field pole members 206a, 206b, and 206c can be composed of a single piece of magnetically permeable material (e.g., a piece formed by a metal injection molding process, forging, casting or any other method of manufacture), these field pole members can also be composed of multiple pieces, as is shown in FIGs. 7A and 7B. FIG. 7A depicts one of field pole members 206 as a stacked field pole member 700 composed of a number of laminations 704 integrated together. In this instance, stacked field pole member 700 has an outer surface 702 having a cylindrical outside diameter with an arc and a relatively straight inner surface 706 to increase the coil packing density while still leaving room for the rotating shaft. Field pole member end regions 720 generally include pole faces 707 for interacting with the flux of permanent magnets at each end of field pole member 700, whereas a central portion 722 (i.e., a central field pole member portion) generally includes a core region between pole faces 707, such as coil region 506 (FIG. 5A). A coil (not shown) can be wound more or less about central portion 722. FIG. 7B is a perspective view of stacked field pole member 700 and laminations 704, which can be composed of an anisotropic material. In this example, the anisotropic material includes grain-oriented material.

[0084] Note also that various winding patterns can be implemented in any of the field pole members described, for example, in FIGs. 7A to 7B to enhance performance. For instance, a cantered or full-coveraging winding can cover substantially all of the sides and/or the back of field pole member 700, at both ends of the structure, to reduce the flux that might leak from one field pole member to another. As such, the wire of a coil need not be wound in planes perpendicular to the long axis of the field pole member, but at an oblique angle. With coils being placed close to the magnetic air gap, those coils can be more effective in reducing flux leakage, for example, in pole shoe regions. Note that the above-described winding patterns are applicable to any of the field pole members described herein.

[0085] FIG. 8 illustrates another exemplary field pole member having skewed pole faces, according to a specific embodiment of the present invention. As shown, stacked field pole member 800 is constructed from a number of laminations 804, similar to stacked field pole member 700. Laminations 804 are patterned to provide skewed pole faces 807. Pole face 807 is bound by both a first skewed edge 850 and a second skewed edge 852, whereas the other pole face 807 at the other pole shoe is bound by a first skewed edge 880 and a second skewed edge 882. Note that edges 850, 852, 880 and 882 can respectively correspond to edges 650, 652, 680, and 682 of FIG. 6B. In some cases, laminations 804 (as well as laminations 704) advantageously can be formed (e.g., stamped out) in a series of either similarly or differently patterned shapes from a single substrate (e.g., a sheet of metal or the like) of different substrates in a manner that minimizes waste during manufacturing. Further, the manufacture of laminations 704 (FIG. 7B) and 804 (FIG. 8), for example, does not waste materials typically jettisoned to create circular holes in circular stator structures.

[0086] In some embodiments, laminations 704 and 804 can be assembled from laminated anisotropic material (e.g., grain-oriented) sheet stock with the direction of magnetic orientation being oriented longitudinally, such as parallel to an axis of rotation. This is so that flux can be easily conducted axially from one end of the motor to the other. The laminations can be electrically insulated from each other, which can reduce eddy current losses. In one embodiment, laminations 704 and 804 are composed of grain-oriented steel and provide various field pole members with high permeability, low loss and/or high saturation levels in a relatively low cost material. One type of anisotropic material suitable for implementing laminations 704 and 804 is cold-rolled-grain-oriented steel, or "CRGO lamination steel." To illustrate the advantages of using grain-oriented lamination in accordance with at least one embodiment, cold rolled grain oriented steel can have a permeability of 50,000 while subjected to an applied field of 1.00 Tesla (10,000 Gauss) in comparison to commonly-used isotropic laminate steel (e.g., "M19" laminates) having a permeability of about 5950, under the same conditions. Note that permeability, as described above, is in terms of direct current ("DC") permeability. Field pole members can be made from many different magnetically permeable materials, such as silicon iron alloys, steel alloys, iron alloys, nickel iron alloys, cobalt nickel alloys, magnetic powdered alloys, soft magnetic composites, and the like, according to various embodiments of the present invention. Soft magnetic composite materials, which are also known as "SMC materials," are composed of compacted, electrically insulated particles that are also magnetically permeable. As such, SMC materials exhibit relatively low eddy current losses when
compared to traditional SiFe lamination materials at relatively high frequencies. Another significant advantage of SMC materials is its ability to be formed in three dimensions through use of properly designed compaction molds and dies.

**[0087]** FIGS. 9A to 9M illustrate examples of other-shaped permanent magnets that can be implemented in a rotor-stator structure, according to various embodiments of the present invention. Although the magnets shown in FIG. 2 are conical in shape, the term “conical” is intended to be construed broadly to include one or more shapes that form one or more surfaces, or portions thereof, that when coaxially mounted on a shaft, are at an angle to the shaft such that at least one surface, when extended, would intersect an axis of rotation. So, the term “conical magnet” is meant to cover any configuration of magnet that has at least a portion of a surface that is conical or tapered toward a point coaxial with, or on, an axis of rotation. For example, at least one type of conical magnet has one or more surfaces whereby the cross-sections of the magnet at each of those surfaces generally (or on average) either increase or decrease progressively along the axial length of the magnet. In at least one specific embodiment, a relevant dimension for describing a portion of conical magnet surface is a surface boundary, such as a contoured surface area that can be oriented in space with respect to a line.

**[0088]** FIG. 9A shows a full cone-shaped magnet as an example of a conical magnet, whereas FIG. 9B depicts a conical magnet being a truncated cone magnet described as a “frustum of a right circular cone,” which is a frustum created by slicing the top off a right circular cone (e.g., the slice forming an upper base parallel to the lower base, or outer surface, of the right circular conical magnet). Note that other cone angles than is shown in FIG. 9A are within the scope of the present invention. FIG. 9C shows that a conical magnet can include cylindrical portions added to the large diameter end (or, in some cases, to the small diameter end, such as shown in FIG. 9I) to optimize magnetic flux in the circuit. FIG. 9D illustrates a conical magnet being of a “stepped” or graduated form. FIGS. 9E and 9F show examples of alternative shapes suitable for implementing a magnet in accordance with embodiments of the present invention, where a conical magnet can be a hemispherically-shaped magnet. FIGS. 9G and 9H are general representations showing that conical magnets of various embodiments can have any type of concave surface and any type of convex surface, respectively.

**[0089]** FIG. 9I shows an exemplary conical magnet in accordance with one embodiment of the present invention. Here, conical magnet 940 includes an outer surface 950 in which a cavity 952 is formed. Cavity 952 is optional and can be used to house bearings or the like. In some embodiments, cavity 952 extends inside one or more of surfaces 954, 956 and 958. Note that cavity 952 can have differing inside dimensions along its axial length. Conical magnet 940 includes three surfaces: a first cylindrical surface 954, a conical surface 956 and a second cylindrical surface 958. In various embodiments, conical magnet 940 can include: fewer or more surfaces, cylindrical surfaces having larger or small diameters, steeper or shallower angles of inclination for conical surface 956, etc. FIGS. 9J and 9K show an end view and a side view, respectively, of an exemplary conical magnet, according to one embodiment of the present invention. Conical magnet 971 is composed of two conical magnets 970 and 972. In this example, conical magnet 972 is disposed (e.g., inserted) within conical magnet 970. In one embodiment, conical magnet 970 is composed of NdFe magnetic material (or a variant thereof) and conical magnet 972 is composed of a ceramic magnetic material. In some embodiments, conical magnet 972 is absent, thereby forming a hollowed cone-shaped magnet composed of conical magnet 970 (mounting fixtures not shown). In at least one specific embodiment, conical magnet 970 can be composed of a magnetically permeable material rather than a magnet material. In one embodiment, conical magnet 970 need not extend through conical magnet 970, but rather can extend from one end to any axial length within conical magnet 970.

**[0090]** FIGS. 9L and 9M illustrate yet other conical magnets in accordance with yet other embodiments of the present invention. FIG. 9L illustrates a pyramidal-shaped magnet as a conical magnet, albeit truncated, formed with any number of truncated triangular surfaces 978. FIG. 9M illustrates a conical magnet 980 of at least one embodiment, where conical magnet 980 includes a truncated pyramidal magnet 990 including magnetic regions 992 formed either therein or thereon. Magnetic regions 992 include magnet material that is different from that of truncated pyramidal magnet 990. Each of those magnetic regions 992 can be selected to have any predetermined polarity. In one embodiment, truncated pyramidal magnet 990 is four-sided and is composed of a ceramic material (e.g., magnet material), and each magnetic region 992 (two of which are hidden from view) is composed of NdFe magnet material and that is formed upon truncated pyramidal magnet 990. In other embodiments, pyramidal magnet 990 can have any number of sides. In various embodiments, pyramidal magnet 990 is a magnet support and need not be composed of a magnet material, but rather can be composed of magnetically permeable material. In some embodiments, a magnet support 990 can be formed as having any shape as those shown in FIGS. 9A to 9H, with any number of magnetic regions 992 being disposed on magnet support 990. In that case, magnetic regions 992 can be of any shape suitable to be disposed on specific shapes of magnet support 990.

**[0091]** In a specific embodiment of the present invention, conical magnets are anisotropic, diametrically magnetized, and shaped as a truncated cone with about 30 degrees of cone angle relative to an axis of rotation. The conical magnets, according to some embodiments, are diametrically magnetized in directions that are generally
in one or more planes that are substantially perpendicular (including perpendicular) to the axis. At least one advantage of these types of magnet configurations is that such diametric conical magnets can be magnetized in the same direction as the original magnetic orientation of the magnet material, which provides a higher energy product for the magnet (i.e., a more powerful magnet). Anisotropic magnets are also relatively easy to manufacture and have relatively high magnetic efficiency per unit magnet volume. Another advantage of a diametric (i.e., 2 pole) magnet is that in a motor having three active field pole members and three phases, there is only one electrical revolution for each mechanical revolution of the motor. Accordingly, the diametric magnet, in whole or in part, reduces eddy current losses, hysteresis ("core" or "iron") losses and electrical switching losses in a motor drive circuit. In some embodiments, a conical magnet can: (1) include a steel core instead of being solid magnet material, (2) be constructed from ring magnets exhibiting good coercivity, (3) be constructed from arc-segment magnets, (4) be molded directly onto the shaft, (5) be radially polarized, (6) include a hollow core instead of being solid magnet material, or can include any other similar characteristics.

FIG. 10 shows a multiple pole magnet, according to one embodiment of the present invention. In this example, permanent magnet 1000 is a four-pole magnet being magnetically oriented to have arcuate magnetic paths 1010 from south poles ("S") to north poles ("N"). Other numbers of poles and magnet orientations are within the scope and spirit of the present invention. Further, a multiple pole magnet, such as permanent magnet 1000, can be either a monolithic magnet or a non-monolithic magnet according to some embodiments. As used herein, the term "monolithic" as applied to a permanent magnet, suggests that the permanent magnet is composed of integrated magnetic poles, such that the permanent magnet is non-discrete and is substantially homogeneous in structure. As such, a monolithic permanent magnet lacks any physical interfaces between the magnetic poles. A monolithic magnet therefore is composed of continuous magnet material. By contrast, permanent magnet 1000 can be a non-monalithic magnet composed of separate magnets, with each separate magnet contributing an outward facing north or south pole, whereby physical interfaces exist between the separate subcomponents. As such, a non-monolithic magnet therefore can be composed of contiguous, but noncontinuous magnet material. In particular, each separate subcomponent includes continuous magnet material, but the physical interfaces give rise to discontinuities in the magnet material that constitutes the magnet as a whole. Note that the term "monolithic" can also apply to field pole members and other elements of the various rotor-stator structures of the present invention. Note that at least one embodiment, non-monolithic magnets can include those magnets where separate subcomponents are arranged at a distance from each other such that they do not contact each other.

In one embodiment of the present invention, an exemplary rotor-stator structure is disposed in an electrical motor to generate a torque amplitude that depends on the volume of the magnets, the vector directions of the interacting fields in the flux interaction regions, the flux density in flux interaction regions, the area of the air gaps, and the area of the pole faces. So, the higher the flux density produced by the permanent magnets and the higher the flux density produced by the active field pole members, the higher the torque that will be developed until significant saturation is reached in the field pole members. The magnet materials of such a rotor-stator structure should have sufficient coercivity to prevent partial or total demagnetization in an intended application.
pect of the present invention to any embodiment; rather features and aspects of one embodiment may readily be interchanged with other embodiments. For example, although the above description of the embodiments related to a motor, the discussion is applicable to all electrodynamic machines, such as a generator. Thus, the foregoing descriptions of specific embodiments of the invention are presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed; obviously, many modifications and variations are possible in view of the above teachings. The embodiments were chosen and described in order to best explain the principles of the invention and its practical applications; they thereby enable others skilled in the art to best utilize the invention and various embodiments with various modifications as are suited to the particular use contemplated. Notably, not every benefit described herein need be realized by each embodiment of the present invention; rather any specific embodiment can provide one or more of the advantages discussed above. It is intended that the following claims and their equivalents define the scope of the invention.

Claims

1. A rotor-stator structure (200) for electrodynamic machines comprising:

- conical magnets (220) having conical surfaces (221) arranged axially on an axis of rotation such that said conical surfaces face each other, said conical magnets including at least two conical magnets (220a, 220b) being positioned so that the directions of polarization (502, 504) of said at least two conical magnets are in substantially opposite directions; and
- field pole members (204, 206, 604) arranged coaxially to said axis and having flux interaction surfaces (207) formed at the ends of said field pole members and adjacent to portions (521, 561) of said conical surfaces (221) that confront said flux interaction surfaces, each of said field pole members (204) spaced from another of said field pole members by a field pole gap (G), said flux interaction surfaces and said portions of said conical surfaces defining air gaps (551), so that each of said conical magnets establishes an air gap (551) with each of said field pole members; wherein said flux interaction surfaces (207) are configured to magnetically couple said field pole members (204) to said conical magnets (220); and wherein said air gaps (551), said conical magnets (220) and said field pole members (204) are sufficient to form a closed flux path (560) that passes through at least two of said field pole members (204) in different directions and through said at least two conical magnets (220) in substantially opposite directions.

2. The rotor-stator structure of claim 1 further comprising a shaft (222) on which said conical magnets (220) are affixed, said shaft defining said axis of rotation.

3. The rotor-stator structure of claim 1 wherein said field pole members (204, 206) further comprises: a magnetically permeable material that is continuous from one end of each field pole member to the other end; and at least a portion (506) that is configured to accept an element for generating ampere-turn (“AT”) flux.

4. The rotor-stator structure of claim 1 wherein each of said field pole members (204, 206) is substantially straight.

5. The rotor-stator structure of claim 1 wherein each of said field pole members (204, 206) is substantially straight.

6. The rotor-stator structure of claim 5 wherein said rotor-stator structure excludes back-iron, thereby decreasing hysteresis losses as well as materials for manufacturing an electrodynamic machine.

7. The rotor-stator structure of claim 1 wherein at least one of said field pole members (206) is substantially straight.

8. The rotor-stator structure of claim 1 wherein said field pole members (206) and said conical magnets (220) are arranged to minimize linear deviations in a path portion of a magnetic flux path (116) coincident with a substantially straight line extending from a surface portion (521a, 561a) of a first conical magnet (220a) to a surface portion (521 b, 561 b) of a second conical magnet (220b), said path portion terminating at said surface portions.

9. The rotor-stator structure of claim 1 wherein said rotor-stator structure is configured to generate magnetic flux paths consisting essentially of: said first conical magnet (220a); said second conical magnet (220b); at least one of said field pole members (206); and two or more air gaps (551).

10. The rotor-stator structure of claim 1 wherein said field pole members (204, 206) comprise laminations (704, 804) to minimize eddy currents, thereby reducing power losses.

11. The rotor-stator structure of claim 10 wherein said
laminations are formed from a substrate composed of a magnetically permeable material in a manner that reduces wastage of said magnetically permeable material.

12. The rotor-stator structure of claim 10 wherein said laminations comprise a plurality of magnetically permeable laminations at least one of which is anisotropic.

13. The rotor-stator structure of claim 1 further comprising a coil (208) wound about at least one of said field pole members (206) to form at least one active field pole member (204).

14. The rotor-stator structure of claim 13 wherein said at least one field pole member (204, 206) is shaped to minimize manufacturing complexity associated with winding said coil (208) on said at least one field pole member by avoiding winding said coil via a slot.

15. The rotor-stator structure of claim 1 wherein one conical magnet (220a) of said conical magnets has a first direction of polarization (502) and another conical magnet (220b) of said conical magnets has a second direction of polarization (504), said first direction of polarization being at a polarization angle from said second direction of polarization to minimize detent torque, said polarization angle being any angle from about 150 degrees to 180 degrees.

16. The rotor-stator structure of claim 16 wherein each of said flux interaction surfaces (207) further comprises a skewed flux interaction surface (607) to reduce field pole gaps (660) between adjacent field pole members (604), thereby minimizing detent torque.

17. The rotor-stator structure of claim 16 wherein said skewed flux interaction surface (607) includes a first edge (650) defining a first side of a field pole gap and a second edge (652) defining a second side of another field pole gap, whereby said first edge and said second edge maintain angles (620, 622) that do not align with a direction of polarization (630) of at least one of said conical magnets, wherein one first edge (650b) of a first field pole member (604b) and one second edge (652a) of a second field pole member (604a) form said field pole gap (660).

18. The rotor-stator structure of claim 1 wherein each of said field pole members (204, 206, 604) is an elongated field pole member having a length dimension in an axial direction greater than a width dimension.

19. The rotor-stator structure of claim 1 wherein said flux path (560) passes through at least two of said field pole members (206) in different directions.

20. The rotor-stator structure of claim 1 wherein said directions of polarization (502, 504) are configured to form a flux path portion of said closed flux path (560) within the interior of each of said conical magnets (220), said flux path portion extending through a plane that includes said axis of rotation.

21. The rotor-stator structure of claim 20 wherein said flux path portion extends from a first point to a second point, wherein said first point and said second point lie on conical surface portions (521, 561) associated with the same conical surface (221).

22. The rotor-stator structure of claim 21 wherein said directions of polarization (502, 504) are each substantially perpendicular to said axis of rotation.

23. The rotor-stator structure of claim 22 wherein said directions of polarization (502, 504) are each perpendicular to said axis of rotation.

Patentansprüche

1. Rotor-Stator-Struktur (200) für elektrodynamische Maschinen, die Folgendes umfasst:

   konusförmige Magnete (220) mit konusförmigen Oberflächen (221), die axial auf einer Rotationsachse so angeordnet sind, dass die konusförmigen Oberflächen einander zugewandt sind, wobei die konusförmigen Magnete zumindest zwei konusförmige Magnete (220a, 220b) umfassen, die so angeordnet sind, dass die Polarisationsrichtungen (502, 504) der zumindest zwei konusförmigen Magnete einander im Wesentlichen entgegengesetzt sind; und

   Feldpolelemente (204, 206, 604), die koaxial in Bezug auf die Achse angeordnet sind und Flusswechselwirkungs Oberflächen (207) aufweisen, die an den Enden der Feldpolelemente ausgebildet sind und in Bezug auf Abschnitte (521, 561) der konusförmigen Oberflächen (221), die den Flusswechselwirkungs Oberflächen zugeordnet sind, benachbart sind, wobei die Feldpolelemente (204) in Bezug aufeinander durch einen Feldpolspalt (G) beobachtet sind, wobei die Flusswechselwirkungs Oberflächen und die Abschnitte der konusförmigen Oberflächen Luftspalte (551) definieren, sodass jeder der konusförmigen Magnete mit jedem der Feldpolelemente einen Luftspalt (551) bildet; worin die Flusswechselwirkungs Oberflächen (207) ausgebildet sind, um die Feldpolelemente (204) magnetisch an die konusförmigen Magnete (220) zu koppeln; und

   worin die Luftspalte (551), die konusförmigen Magnete (220) und die Feldpolelemente (204)
ausreichen, um einen geschlossenen Magnetflusspfad (560) zu bilden, der durch zumindest zwei der Feldpolelemente (204) in verschiedenen Richtungen und durch die zumindest zwei konusförmigen Magnetmagnete (220) in im Wesentlichen entgegengesetzten Richtungen verläuft.

2. Rotor-Stator-Struktur nach Anspruch 1, die ferner eine Welle (222) umfasst, an der die konusförmigen Magnetmagnete (220) befestigt sind, wobei die Welle die Rotationsachse definiert.

3. Rotor-Stator-Struktur nach Anspruch 1, in der die konusförmigen Oberflächen (221) jeweils einen Neigungswinkel (501) in Bezug auf die Rotationsachse aufweisen, wobei es sich um einen Winkel von etwa 10° bis etwa 80° handelt.


5. Rotor-Stator-Struktur nach Anspruch 1, die ferner eine Spule (208) umfasst, die um jedes der Feldpolelemente (206) gewunden ist, um aktive Feldpolelemente (204) zu bilden.


7. Rotor-Stator-Struktur nach Anspruch 1, in der zumindest eines der Feldpolelemente (206) im Wesentlichen gerade ist.

8. Rotor-Stator-Struktur nach Anspruch 1, in der die Feldpolelemente (206) und die konusförmigen Magnetmagnete (220) angeordnet sind, um lineare Abweichungen in einem Pfadabschnitt des Magnetflusspfads (116), der mit einer im Wesentlichen geraden Linie zusammenfällt, die sich von einem Oberflächenabschnitt (521 a, 561 a) eines ersten konusförmigen Magnetmagneten (220a) zu einem Oberflächenabschnitt (521 b, 561 b) eines zweiten konusförmigen Magnetmagneten (220b) erstreckt, wobei der Pfadabschnitt an den Oberflächenabschnittenden endet.

9. Rotor-Stator-Struktur nach Anspruch 1, in der die Rotor-Stator-Struktur ausgebildet ist, um magnetische Magnetflusspfade zu erzeugen, die im Wesentlichen aus Folgendem bestehen: dem ersten konusförmigen Magnetmagneten (220a); dem zweiten konusförmigen Magnetmagneten (220b); zumindest einem der Feldpolelemente (206) und zwei oder mehr Luftspalte (551).

10. Rotor-Stator-Struktur nach Anspruch 1, in der die Feldpolelemente (204, 206) Lamellen (704, 804) umfassen, um Wirbelströme zu minimieren, wodurch Leistungsverluste reduziert werden.

11. Rotor-Stator-Struktur nach Anspruch 10, in der die Lamellen aus einem Substrat, das aus einem magnetisch permeablen Material besteht, so ausgebildet sind, dass der Verbrauch des magnetisch permeablen Materials reduziert wird.

12. Rotor-Stator-Struktur nach Anspruch 10, in der die Lamellen eine Vielzahl magnetisch permeabler Lamellen umfassen, wobei zumindest eine von diesen anisotrop ist.

13. Rotor-Stator-Struktur nach Anspruch 1, in der ferner eine Spule (208) umfasst, die um zumindest eines der Feldpolelemente (206) gewunden ist, um zumindest ein aktives Feldpolelement (204) zu bilden.

14. Rotor-Stator-Struktur nach Anspruch 13, in der das zumindest eine Feldpolelement (204, 206) so geformt ist, dass die Komplexität der Herstellung in Zusammenhang damit, dass die Spule (208) um das zumindest eine Feldpolelement gewickelt wird, minimiert wird, indem vermieden wird, dass die Spule durch einen Spalt gewickelt wird.

15. Rotor-Stator-Struktur nach Anspruch 1, in der ein konusförmiger Magnet (220a) der konusförmigen Magnetmagnete eine erste Polarisationsrichtung (502) aufweist und ein anderer konusförmiger Magnet (220b) der konusförmigen Magnetmagnete eine zweite Polarisationsrichtung (504) aufweist, wobei die erste Polarisationsrichtung in Bezug auf die zweite Polarisationsrichtung einen solchen Polarisationswinkel aufweist, um das Haltemoment zu minimieren, wobei es sich bei diesem Polarisationswinkel um einen beliebigen Winkel von etwa 150° bis etwa 180° handelt.

16. Rotor-Stator-Struktur nach Anspruch 1, in der jede der Flusswechselwirkungsoberflächen (207) ferner eine schräge Flusswechselwirkungsoberfläche (607) umfasst, um die Feldpolspalten (660) zwischen benachbarten Feldpolelementen (604) zu reduzieren, wodurch das Haltemoment minimiert wird.

17. Rotor-Stator-Struktur nach Anspruch 16, in der die schräge Flusswechselwirkungsoberfläche (607) eine erste Kante (650), die eine erste Seite eines Feldpolspalts (652), die eine zweite Seite eines anderen Feldpolspalts defi-
niert, umfasst, wobei die erste Kante und die zweite Kante (620, 522) nicht fluchtend mit der Polarisationsrichtung (630) zumindest eines der konusförmigen Magneten ausgerichtet sind, wobei eine erste Kante (650b) eines ersten Feldpolelements (604b) und eine zweite Kante (652b) eines zweiten Feldpolelements (604a) den Feldpolspalt (660) bilden.

18. Rotor-Stator-Struktur nach Anspruch 1, worin jedes der Feldpolelemente (204, 206, 604) ein längliches Feldpolelement ist, dessen Längendimension in axialer Richtung größer ist als seine Breitendimension.

19. Rotor-Stator-Struktur nach Anspruch 1, worin der Magnetflusspfad (560) durch zumindest zwei der Feldpolelemente (206) in verschiedenen Richtungen verläuft.

20. Rotor-Stator-Struktur nach Anspruch 1, worin die Polarisationsrichtungen (502, 504) ausgebildet sind, um im Inneren jedes der konusförmigen Magnete (220) einen Magnetflussfadabschnitt des geschlossenen Magnetflusspfads (560) zu bilden, wobei sich der Magnetflussfadabschnitt durch eine Ebene erstreckt, die die Rotationsachse umfasst.

21. Rotor-Stator-Struktur nach Anspruch 20, worin sich der Magnetflussfadabschnitt von einem ersten Punkt zu einem zweiten Punkt erstreckt, wobei der erste Punkt und der zweite Punkt auf konusförmigen Oberflächenabschnitten (521, 561) derselben konusförmigen Oberfläche (221) liegen.

22. Rotor-Stator-Struktur nach Anspruch 21, worin die Polarisationsrichtungen (502, 504) jeweils im Wesentlichen im rechten Winkel auf die Rotationsachse stehen.

23. Rotor-Stator-Struktur nach Anspruch 22, worin die Polarisationsrichtungen (502, 504) im rechten Winkel auf die Rotationsachse stehen.

Revlendications

1. Structure rotor-stator (200) pour des machines électrodymaniques comprenant:

- des aimants coniques (220) ayant des surfaces coniques (221) agencées axialement sur un axe de rotation de telle sorte que lesdites surfaces coniques se font face, lesdits aimants coniques incluant au moins deux aimants coniques (220a, 220b) positionnés de façon que les directions de polarisation (502, 504) desdits au moins deux aimants coniques soient dans des directions sensiblement opposées; et des éléments de pôle de champ (204, 206, 604) agencés coaxialement audit axe et ayant des surfaces d’interaction de flux (207) formées aux extrémités desdits éléments de pôle de champ et adjacentes à des portions (521, 561) desdites surfaces coniques (221) qui sont confrontées auxdites surfaces d’interaction de flux, chacun desdits éléments de pôle de champ (204) étant espacé d’un autre desdits éléments de pôle de champ par un entrefer de champ (G), lesdites surfaces d’interaction de flux et lesdites portions desdites surfaces coniques définissant des entrefers (551) de sorte que chacun desdits aimants coniques établit un entrefer (551) avec chacun desdits éléments de pôle de champ; où lesdites surfaces d’interaction de flux (207) sont configurées pour coupler magnétiquement lesdits éléments de pôle de champ (204) auxdits aimants coniques (220); et où lesdits entrefers (551), lesdits aimants coniques (220) et lesdits éléments de pôle de champ (204) sont suffisants pour former un chemin d’écoulement fermé (560) qui passe à travers au moins deux desdits éléments de pôle de champ (204) dans différentes directions et à travers lesdits au moins deux aimants coniques (220) dans des directions sensiblement opposées.

2. Structure rotor-stator selon la revendication 1, comprenant en outre un arbre (222) sur lequel lesdits aimants coniques (220) sont fixés, ledit arbre définissant ledit axe de rotation.

3. Structure rotor-stator selon la revendication 1, dans laquelle lesdites surfaces coniques (221) ont chacune un angle d’inclinaison (501) dudit axe de rotation, ledit angle étant d’environ 10 degrés à environ 80 degrés.

4. Structure rotor-stator selon la revendication 1, dans laquelle chacun desdits éléments de pôle de champ (204, 206) comprend en outre: un matériau magnétiquement perméable qui est continu d’une extrémité à l’autre extrémité; et au moins une portion (506) qui est configurée pour accepter un élément pour produire un flux ampère-tour (“AT”).

5. Structure rotor-stator selon la revendication 1, comprenant en outre une bobine (208) enroulée autour de chacun desdits éléments de pôle de champ (206) pour former des éléments de pôle de champ actifs (204).

ainsi que des matériaux pour fabriquer une machine électrodynamique.

7. Structure rotor-stator selon la revendication 1, dans laquelle au moins un desdits éléments de pôle de champ (206) est sensiblement droit.

8. Structure rotor-stator selon la revendication 1, dans laquelle lesdits éléments de pôle de champ (206) et lesdits éléments coniques (220) sont agencés pour réduire à un minimum des écarts linéaires dans une portion d’un chemin d’écoulement magnétique (116) coïncidant avec une ligne sensiblement droite s’étendant d’une portion de surface (521a, 561a) d’un premier aimant conique (220a) à une portion de surface (521b, 561b) d’un deuxième aimant conique (220b), ladite portion de chemin se terminant auxdites portions de surface.

9. Structure rotor-stator selon la revendication 1, dans laquelle ladite structure rotor-stator est configurée pour produire des chemins de flux magnétique constitués essentiellement dudit premier aimant conique (220a); dudit deuxième aimant conique (220b), d’au moins un desdits éléments de pôle de champ (206) et de deux ou plusieurs entrefers (551).

10. Structure rotor-stator selon la revendication 1, dans laquelle lesdits éléments de pôle de champ (204, 206) comprennent des laminations (704, 804) pour réduire à un minimum des courants de Foucault, en réduisant ainsi les pertes de puissance.

11. Structure rotor-stator selon la revendication 10, dans laquelle lesdites laminations sont formées à partir d’un substrat constitué d’un matériau magnétiquement perméable d’une manière qui réduit le gaspillage dudit matériau magnétiquement perméable.

12. Structure rotor-stator selon la revendication 10, dans laquelle lesdites laminations comprennent plusieurs laminations magnétiquement perméables dont au moins une est anisotrope.

13. Structure rotor-stator selon la revendication 1, comprenant en outre une bobine (208) enroulée autour d’au moins un desdits éléments de pôle de champ (206) pour former au moins un élément de pôle de champ actif (204).

14. Structure rotor-stator selon la revendication 13, dans laquelle ledit au moins un élément de pôle de champ (204, 206) est configuré pour réduire à un minimum la complexité de fabrication associée à l’enroulement de ladite bobine (208) sur au moins un élément de pôle de champ en évitant l’enroulement de ladite bobine par une fente.

15. Structure rotor-stator selon la revendication 1, dans laquelle un aimant conique (220a) desdits aimants coniques possède une première direction de polarisation (502) et un autre aimant conique (220b) desdits aimants coniques à une seconde direction de polarisation (504), ladite première direction de polarisation étant à un angle de polarisation de ladite seconde direction de polarisation pour réduire à un minimum le couple de détente, ledit angle de polarisation étant n’importe quel angle d’environ 150 degrés à 180 degrés.

16. Structure rotor-stator selon la revendication 1, dans laquelle chacune desdites surfaces d’interaction de flux (207) comprend en outre une surface d’interaction de flux inclinée (607) pour réduire les entrefers de champ (660) entre des éléments de pôle de champ adjacents (604) en réduisant ainsi à un minimum le couple de détente.

17. Structure rotor-stator selon la revendication 16, dans laquelle ladite surface d’interaction de flux inclinée (607) comporte un premier bord (650) définissant un premier côté d’un entrefrer de champ et un second bord (652) définissant un second côté d’un autre entrefrer de champ, par quoi ledit premier bord et ledit second bord maintiennent des angles (620, 622) qui ne s’alignent pas avec une direction de polarisation (630) d’au moins un desdits aimants coniques, où un premier bord (650b) d’un premier élément de pôle de champ (604b) et un second bord (652a) d’un second élément de pôle de champ (604a) forment ledit entrefrer de champ (660).

18. Structure rotor-stator selon la revendication 1, dans laquelle chacun desdits éléments de pôle de champ (204, 206, 604) est un élément de pôle de champ oblong ayant une dimension en longueur dans une direction axiale plus grande qu’une dimension en largeur.

19. Structure rotor-stator selon la revendication 1, dans laquelle ledit chemin d’écoulement (560) passe à travers au moins deux desdits éléments de pôle de champ (206) dans des directions différentes.

20. Structure rotor-stator selon la revendication 1, dans laquelle lesdites directions de polarisation (502, 504) sont configurées pour former une portion de chemin d’écoulement dudit chemin d’écoulement fermé (560) dans l’intérieur de chacun desdits aimants coniques (220), ladite portion de chemin d’écoulement s’étendant à travers un plan qui inclut ledit axe de rotation.

21. Structure rotor-stator selon la revendication 20, dans laquelle ladite portion de chemin d’écoulement s’étend d’un premier point à un second point, où ledit
premier point et ledit second point se situent sur des portions de surface coniques (521, 561) associées à la même surface conique (221).

22. Structure rotor-stator selon la revendication 21, dans laquelle lesdites directions de polarisation (502, 504) sont chacune sensiblement perpendiculaires audit axe de rotation.

23. Structure rotor-stator selon la revendication 22, dans laquelle lesdites directions de polarisation (502, 504) sont chacune perpendiculaire audit axe de rotation.
FIG. 8

Grain Orientation

804
850
852
800
880
807
850
882
807
FIG. 9I

FIG. 9J

FIG. 9K
REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description