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(54) **SUBSTANTIALLY PARALLEL FLUX UNCLUTTERED ROTOR MACHINES**

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(57) **ABSTRACT**

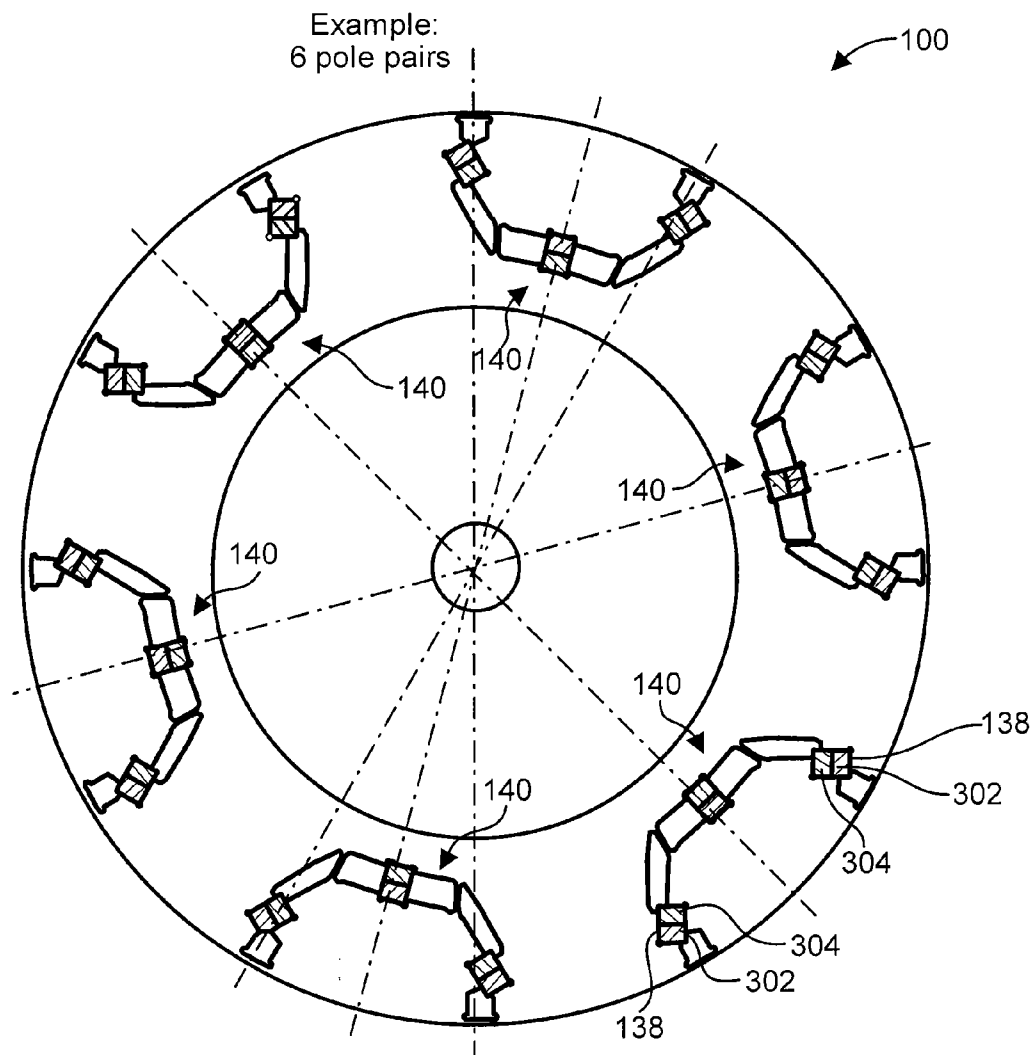
A permanent magnet-less and brushless synchronous system includes a stator that generates a magnetic rotating field when sourced by polyphase alternating currents. An uncluttered rotor is positioned within the magnetic rotating field and is spaced apart from the stator. An excitation core is spaced apart from the stator and the uncluttered rotor and magnetically couples the uncluttered rotor. The brushless excitation source generates a magnet torque by inducing magnetic poles near an outer peripheral surface of the uncluttered rotor, and the stator currents also generate a reluctance torque by a reaction of the difference between the direct and quadrature magnetic paths of the uncluttered rotor. The system can be used either as a motor or a generator

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Related U.S. Application Data

(60) Provisional application No. 61/199,841, filed on Nov. 20, 2008.



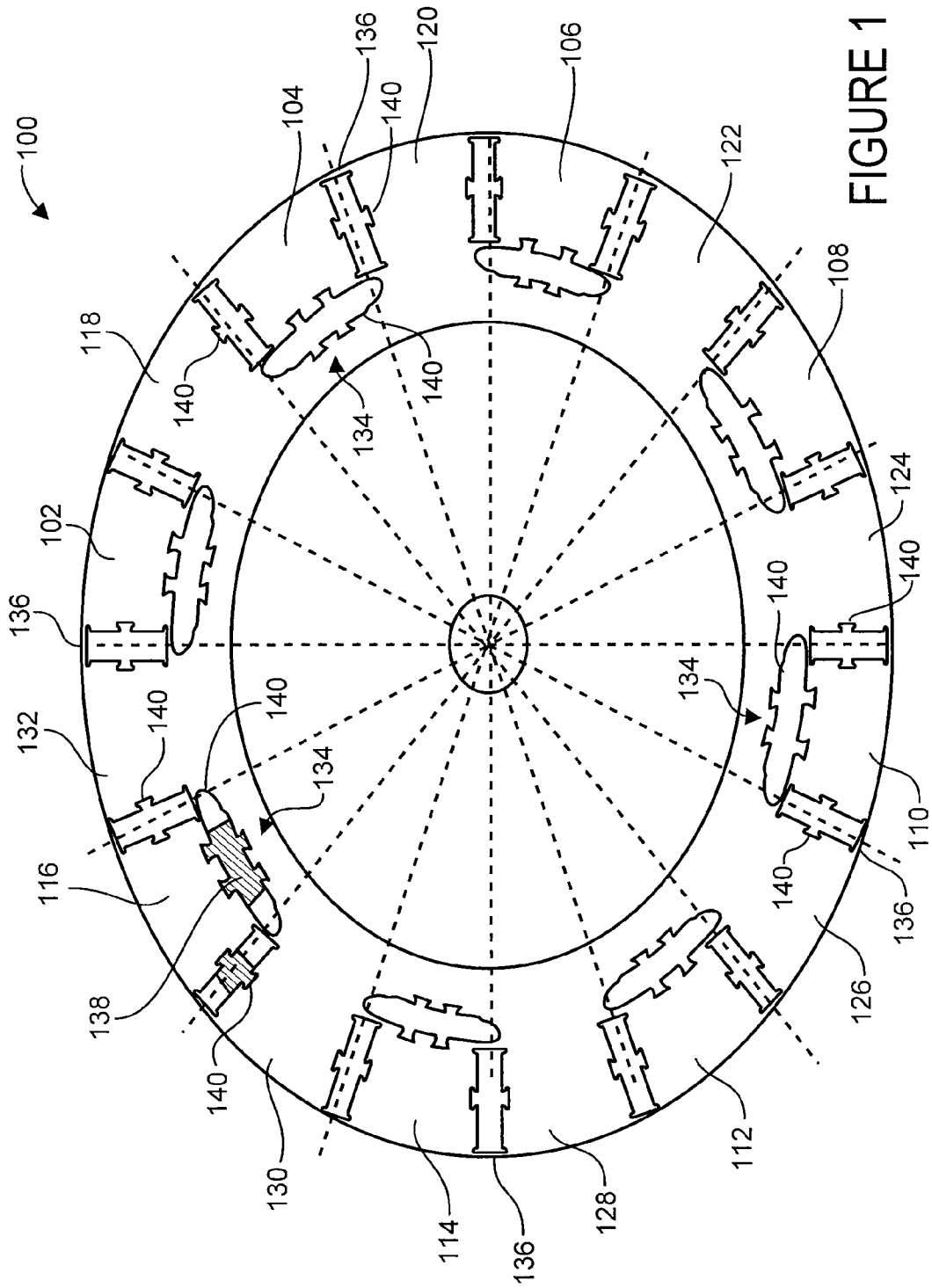
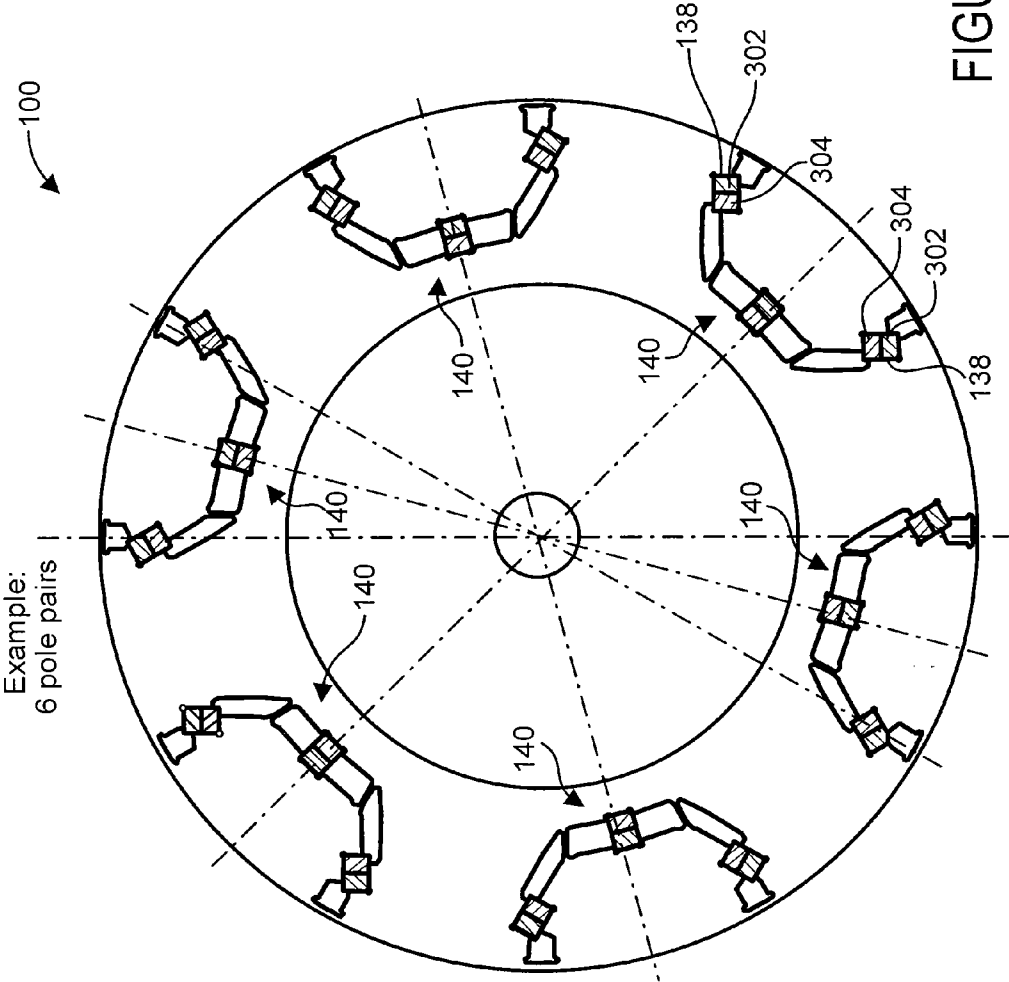
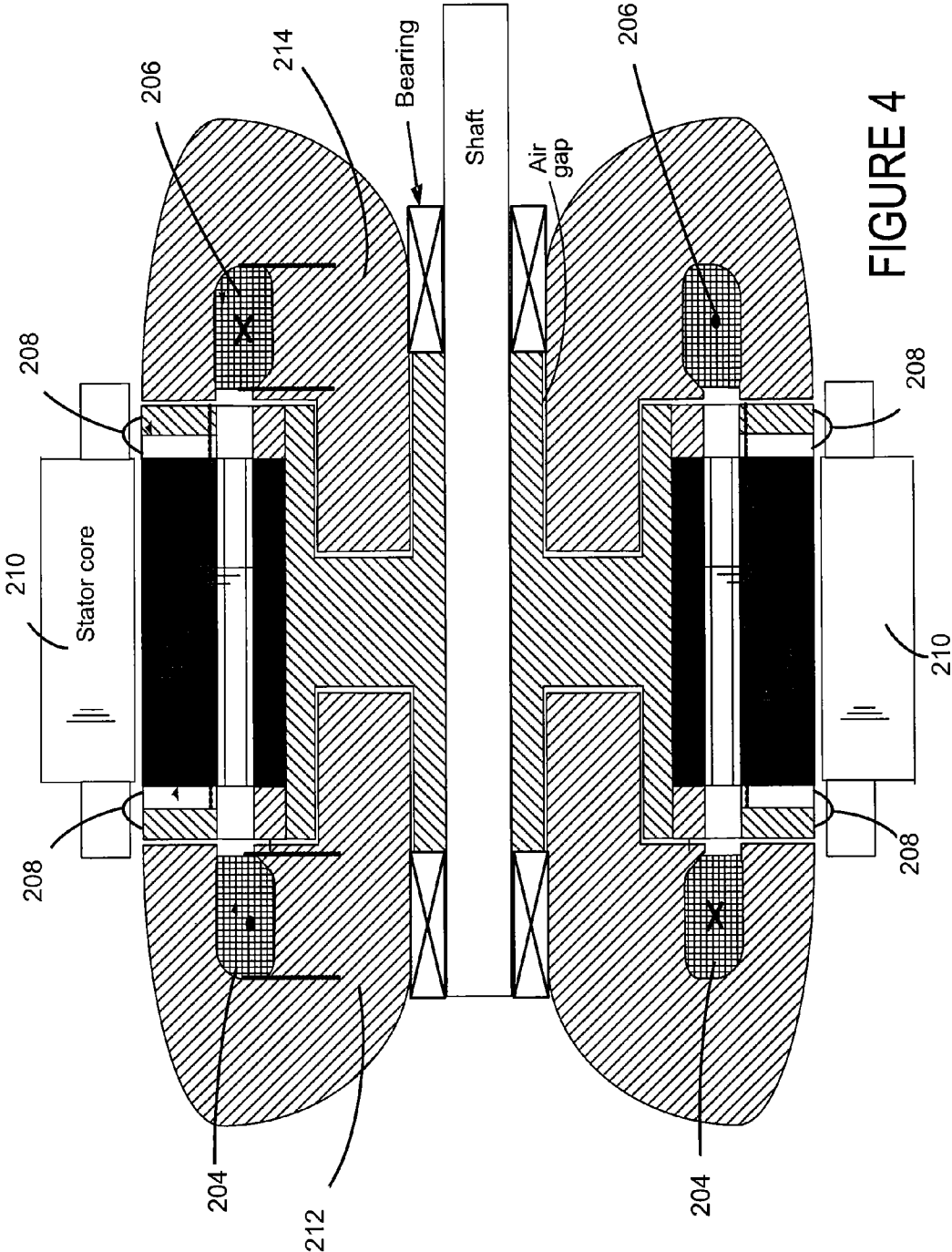


FIGURE 1



Example:
6 pole pairs

FIGURE 3



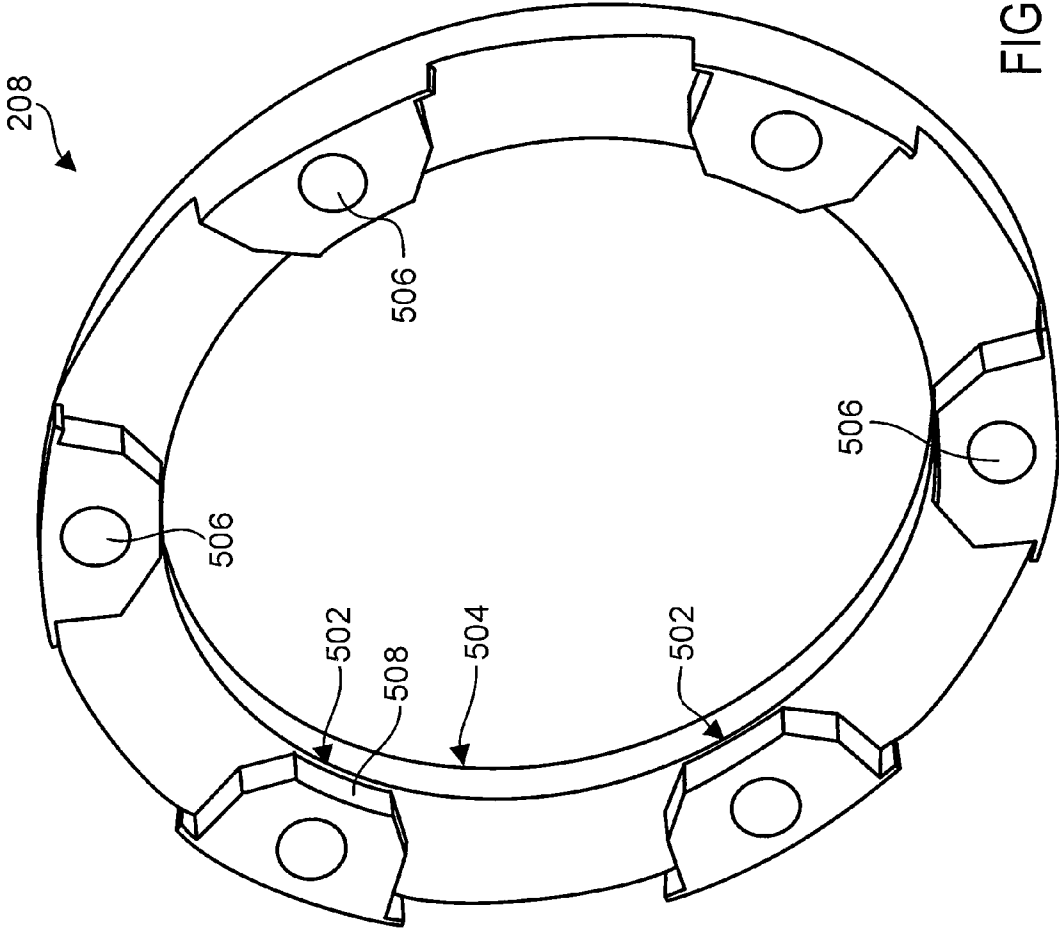


FIGURE 5

SUBSTANTIALLY PARALLEL FLUX UNCLUTTERED ROTOR MACHINES

PRIORITY CLAIM

[0001] This application claims the benefit of priority from U.S. Provisional Application No. 61/199,841, filed Nov. 20, 2008, U.S. application Ser. No. 12/274,895, filed Nov. 20, 2008, and U.S. application Ser. No. 12/_____ (Attorney Docket 13489/108 ID 2068.0), filed May 14, 2009, all of which are incorporated herein by reference.

GOVERNMENT INTEREST

[0002] This application was made with United States government support under Contract No. DE-AC05-00OR22725 awarded by the United States Department of Energy. The United States Government has certain rights in these inventions.

BACKGROUND OF THE INVENTION

[0003] 1. Technical Field

[0004] This disclosure relates to electric machines, and more specifically to synchronous systems that generate reluctance and magnet torques.

[0005] 2. Related Art

[0006] Permanent magnet machines may supply small or large amounts of power. These rotating machines convert mechanical energy into electrical energy through a rotation. Some rotating machines may convert electrical energy into mechanical energy. A rotor, which carries fixed permanent magnets, rotates in a magnetic field that induces an electromotive force in the windings of the stator core.

[0007] In vehicles, interior permanent magnets may be mounted near the outer circumference of the rotor that produces a rotating field. The rotor punching bridges that extend between the cavities that house the permanent magnets may counter the centrifugal force that may be directed away from a center or axis. As the revolution about the axis increase, centrifugal force increases and the need for stronger bridges increase. With stronger bridges, leakages flux passing though these bridges increase, which decreases motor performance.

[0008] In some applications, permanent magnet machines may not provide a good power factor at slow speeds. In other applications, the operating temperature of a permanent magnet machine may be limited. At some temperatures, permanent magnets may be become demagnetized.

[0009] In other applications the back electromotive force in the stator winding induced by the permanent magnets may limit motor speed. Performance limitations may come at a high cost, as the cost of the rare-earth permanent magnets can be substantially higher than those of iron and copper.

SUMMARY

[0010] A permanent magnet-less synchronous system includes a stator that generates a magnetic rotating field when sourced by an alternating current. An uncluttered rotor is positioned within the magnetic rotating field and spaced apart from the stator. An excitation coil is spaced apart from the stator and the uncluttered rotor and is magnetically coupled to the uncluttered rotor. The excitation source generates a magnet torque by inducing magnetic poles near an outer peripheral surface of the uncluttered rotor, which interact with the stator currents. This interaction generates a magnet torque.

The stator currents also interact with the unequal magnetic paths along a direct axis and a quadrature axis of the rotor to produce a reluctance torque.

[0011] Other systems, methods, features, and advantages of the invention will be, or will become, apparent to one with skill in the art upon examination of the following figures and detailed description. It is intended that all such additional systems, methods, features and advantages be included within this description, be within the scope of the invention, and be protected by the following claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The invention can be better understood with reference to the following drawings and description. The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention. Moreover, in the figures, like referenced numerals designate corresponding parts throughout the different views.

[0013] FIG. 1 is a side view of an exemplary uncluttered rotor.

[0014] FIG. 2 is a top cross-sectional view of an exemplary motor.

[0015] FIG. 3 is a side view of an alternative exemplary uncluttered rotor.

[0016] FIG. 4 is a top cross-sectional view of an alternative exemplary motor.

[0017] FIG. 5 is a side isometric view of an exemplary end piece.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0018] A synchronous system generates high power density through a reluctance torque and magnet torque at a high torque to weight ratio. Without permanent magnets, some of these brushless, slip-ring-less, and commutator-less constructions have reduced sizes, lower weights (e.g., due to their frameless or bracket-less constructions) and less core losses. In vehicles that may use radial or axial gap motors, there may be little to no core losses when the system runs free without field excitations. The high power density and driving torque of these systems may be used in other applications that have short, intermediate, or long core lengths. Dynamic balances are improved when systems do not include rotating rotor windings that may tend to shift at high temperature and speed. In these systems and others, the excitation fields may be cut off to enhance safety, fields may be boosted to increase or reach peak acceleration power in short time periods, power factors may be optimized, and efficiency may increase due to the adjustable excitation and stator fields. Fuel efficiency may increase not only from the motor but also from the devices that supply the electric power to the motor due to improved power factors of the motor and the adjustable field control to optimize the back electromotive force in the stator winding that may be connected to power supply devices. The synchronous systems may be mass produced and may have higher power densities and lower power costs per kilowatt than some induction systems. Some synchronous systems are highly efficient in comparison to some permanent magnet motor constructions. The systems may be operated as an alternating current machine, a motor, or a generator, for example.

[0019] Some synchronous systems include an uncluttered rotor that rotates within an outer substantially cylindrical stator between two or more stationary elements that comprise

the excitation source. The stationary elements may comprise substantially similar ring-like conducting elements formed by rotating a closed loop (e.g., like an ellipse, circle, or irregular curve) about an axis of rotation. In some synchronous systems, the elements provide mechanical support for the uncluttered rotor while providing a portion of the flux carrying path that renders a portion of the system's magnet torque. Because the excitation fields are adjustable (through an excitation controller), some systems counter the electromotive force (EMF) that is proportional to the system's speed or engine speed if coupled to a vehicle (e.g., EMF may increase with speed) by controlling excitation field strength that may further improve the system's power factor control. EMF control may occur in response to an output of a speed sensor (e.g., the sensor may monitor rotor rotation, shaft rotation, speed of the prime mover, etc.) that communicates with the excitation controller directly or indirectly through other controllers, sensors, conditioning devices, etc.

[0020] When failure occurs, such as when a stator short is detected by an energy detector (e.g., that may comprise a current or voltage sensor, for example, that monitors system elements and identifies excessive current and/or voltage conditions), the computer hardware (e.g., a processor) in communication with an input/output controller (or processor) or front-end processor of the excitation controller may shutoff or lower the output of the excitation source. Unlike some permanent magnet machines, without an excitation field, some synchronous systems do not function as a generator or resist the rotation driven by the prime mover under a system failure. Through the brushless excitation and the inducement of non-permanent magnet poles on the uncluttered rotor, the permanent magnet-less, brushless, slip-ring-less systems generate a reluctance torque and a magnetic torque.

[0021] FIG. 1 is a side view of an exemplary uncluttered rotor **100** and FIG. 2 is a top cross-sectional view of an exemplary motor **200**. In cross-section, the excitation cores **212** and **214** of FIG. 2 may include toroidal-like excitation coils (e.g., the toroidal-like excitation cores **214** and **212** may couple two separate conductors or coils as shown in cross-section to the left and right of the uncluttered rotor **100**). The excitation cores **212** and **214** provide mechanical support for the uncluttered rotor **100** and render a portion of the flux carrying path through a non-salient coupling. The dual function of the excitation cores **212** and **214** may act as the end bracket for housing the bearing as well as the excitation flux carrier may source one or more direct current (dc) excitation fields that render a magnet torque. The excitation flux path flows through the uncluttered rotor's pole portions (or pieces) **102-132**. The magnetic pole pieces **102-116** of the same polar sign may be partially enclosed by a body **134** (e.g., U-like shape or parabolic-like) formed by grooves **140** (or cut-out portions) about the outer periphery of the uncluttered rotor **100**. Symmetry may be maintained by positioning the magnetic poles of opposite polarity **118-132** having the same polar sign outside of the partially enclosed body **134** or U-like shape (e.g., adjacent poles are of opposite polarity). In FIG. 1, the uncluttered rotor **100** comprises sixteen poles **102-132**. Eight pole pieces **102-116** of one polarity are enclosed by the U-like shapes (selected U-like shape portions are identified as **134**) and eight pole pieces **118-132** of a second opposite polarity are positioned outside of the body **134** or U-like shapes. Although sixteen pole portions are illustrated in this example, more or less pole portions are used in alternate systems. In these and each of the other synchronous systems

described or to be described, the excitation coils **204** and **206** may comprise two or more conductors or coils that may have a ring like shape (e.g., like an ellipse, circle, irregular curve, toroidal-like shape, etc.)

[0022] The uncluttered rotor **100** and pole portions **102-132** may be formed from laminations bounded by two concentric circles. A solid forged core may support the laminations through an upper surface. Alternatively, the uncluttered rotor **100** may comprise lamination stacks that may be made of silicon steel. Each annulus-like shaped lamination may include multiple narrow bridges **136** of a width configured to maintain the integrity of the lamination during assembly or handling. In some systems, the dimensions of the narrow bridges **136** are not sized to counter the effect of centrifugal force. Mechanical reinforcement elements **138** may counter the centrifugal force with/without narrow bridges **136** while maintaining rotor integrity at high rotational speeds. In some applications, the width of the narrow bridges **136** may be about one millimeter or less. In some applications, the uncluttered rotor **100** may be subject to rotations greater than about ten thousand rotations-per-minute such as about fourteen thousand or more rotations-per-minute that some synchronous systems are subject to. As the rotational rates increase, these exemplary synchronous systems are not constrained by the performance limitations of thicker and/or stronger bridges that enable greater flux leakages that may impede system performance.

[0023] In FIG. 1, the mechanical reinforcement elements **138** may be received by one or more of the cross-like shaped grooves **140** or cutout portions (selected grooves are designated **140**) that bound the perimeter of the body **134** or U-like shape. The mechanical reinforcement elements **138** may be made of a non-magnetic and high mechanical strength material that passes through the one, two, or more grooves **140** (or all) of each of the laminations that may receive the mechanical reinforcement elements **138** like a keyway to render a unitary or integrated uncluttered rotor **100**. The mechanical reinforcement elements **138** may pass between a proximal and distal end of a groove **140**, and may be seated or secured by dove tail-like, notch-like, reciprocal notches, or other securing engagements of other dimensions and shapes that may be formed in all (e.g., when aligned may form a notch) or some of the laminations (e.g., a securing engagement may be formed only on the outer upper and lower surfaces of the lamination stack). Like the shape and number of grooves shown in FIGS. 1 and 3, the mechanical reinforcement elements **138** may vary in shape, size, engagement, number, etc. In FIG. 1, unitary rectangular mechanical reinforcement elements **138** of different lengths (e.g., two lengths are shown) are seated in reciprocal notches and pass through axial and radial grooves **140**. The mechanical reinforcement elements may be inserted from a common surface or may be inserted through opposite left side (shown) and right side surfaces (not shown). In FIG. 3, the arch-like structures formed by the many discontinuous grooves **140** (or cutout portions) are secured by mechanical reinforcement elements **138** comprising two (**302** and **304**) or more securing elements (e.g., joining elements) having tapered edges like a wedge. The wedge-like shaped elements pass through the entire lamination stack and may be in contact with a portion of each groove **140** or some of the grooves **140**. The wedge-like elements **302** and **304** may be biased by a preload force when inserted from a common or opposite radial surfaces of the uncluttered rotor **100**. In other synchronous systems, the wedge-like elements,

unitary rectangular elements, and other mechanical reinforcement elements may couple some or all of the laminations in combinations and may be joined to some or all of the laminations through swaging. The tensile strength, shear strength, and other mechanical properties of the mechanical reinforcement elements **138** may vary with the size of the uncluttered rotor **100**, the speed of rotation of the uncluttered rotor **100**, and in some systems, other mechanical properties or applications of the systems.

[0024] To assemble the synchronous system, a longitudinal slot milled along the rotor hub (that may receive a shaft that couples a prime mover) or keyway may join the rotor hub (not shown) to the uncluttered rotor **100**. One, two, or more bearings may further support and reduce the friction between the fixed part and rotating uncluttered rotor **100** shown in FIG. **4**. Alternative synchronous systems may provide support without bearings (e.g., bearing-less). An end-piece **208** shown in FIGS. **2**, **4**, and **5** (FIGS. **2** and **4** show an end-piece for a **16** pole machine and FIG. **5** shows an end-piece for a **12** pole machine) may couple the outer annular perimeter of the uncluttered rotor **100**. The end-piece **208** comprises raised (or protruded) portions **502** joined, milled, machined, etc., to a substantially uniform lower annulus portion **504**. The substantially symmetrical plane that comprises the raised portions **502** of the exemplary end-piece **208** shown in FIG. **5** is bounded by four linear sides, and inner and outer curved curvilinear surfaces that enclose six vertices from a one dimensional view. Shallow concavities **506** may be formed in each of the raised portions **502**. Some alternative systems do not include some or all of the concavities **506** shown in FIG. **5**.

[0025] When coupled to the uncluttered rotor **100**, the inner curved linear surfaces **508** of the raised portions **502** may be substantially aligned with the open area of the body **134** or open area of the U-like shape formed by grooves **140** (or cut-out portions). While the end-piece **208** may look similar to the lamination stack that may comprise the uncluttered rotor **100**, dimensionally, the end-piece has a greater thickness (e.g., width) near the open area of the body **134** or U-like shape than outside of the open area of the body **134** or U-like shape.

[0026] Functionally, the end-piece **208** ensures that the flux generated by current flow through the toroidal-like excitation coils **204** and **206** (e.g., flowing from the ‘●’ to the ‘x’ to ensure a common polarity from the left-hand axial side and the right-hand axial side) is delivered to the pole pieces **102-116** of the same polarity. In FIGS. **2** and **4**, the hatched area or raised portions **502** of the end-piece **208** (that comprises the hatched and un-hatched areas) ensures that flux does not flow to the undesired or unwanted polarity. Instead, the toroidal-like excitation coils **204** and **206** push the flux to substantially the center of the uncluttered rotor **100** through the raised portions **502**, which may ensure that the flux is distributed substantially uniformly along substantially the entire annulus of the uncluttered rotor **100**. Through this exemplary configuration, flux leakages and losses are reduced.

[0027] The end-piece **208** of FIG. **5** may be machined, forged, sintered, or die cast for example. Like the exemplary shapes that illustrate the grooves **140** (or cutout portions) of the uncluttered rotor **100**, the shapes and the dimensions of the raised portions **502** may vary in shape and dimension in alternate systems and applications. Moreover, many types of stators may be used to generate rotating fields. Exemplary stators may include wound stators such as a double-layer,

single-layer, mush-wound, form-wound, distributed-winding, concentrated-pole, integral-slot, and fractional-slot wound stator. The stator **210** of FIG. **2** may be built from punchings or laminations, for example. The laminations may be keyed or bolted to a position adjacent the uncluttered rotor **100**. An axial air gap that may be substantially perpendicular to a radial air gap portion of an inner air gap that separates a portion of the toroidal-like excitation cores **212** and **214** and the end-piece **208**. While the stator **210** is shown in an open-air configuration in FIGS. **2** and **4**, in alternative systems an enclosure surrounds the excitation cores **214** and **212**, excitation coils **204** and **206**, uncluttered rotor **100**, and stator core **210** to protect the synchronous system from contaminants. A forced ventilation or cooling system may carry away the heat, while in other systems natural ventilation circulate air cooling currents and reduce windage noise. These configurations benefit noise sensitive applications and systems such as vehicle applications.

[0028] Other alternate systems and methods may include combinations of some or all of the structure and functions described above, incorporated by reference, or shown in one or more of each of the figures. As used in the description and throughout the claims a singular reference of an element includes and encompasses plural references unless the context clearly dictates otherwise. Also, as used in the description and throughout the claims that follow, the meaning of “in” includes “in” and “on” unless the context clearly dictates otherwise. These systems or methods may be formed from any combination of structure and function described or illustrated. Some alternative systems or devices interface structures that transport person or things such as vehicles. The system may convert one form of energy into another (e.g., convert electric current into mechanical power as a motor or alternatively, as a generator). When used as a generator, for example, mechanical energy may drive or couple the shaft causing the generator to output electrical energy through the stator windings.

[0029] While various embodiments of the invention have been described, it will be apparent to those of ordinary skill in the art that many more embodiments and implementations are possible within the scope of the invention. Accordingly, the invention is not to be restricted except in light of the attached claims and their equivalents.

What is claimed is:

1. A permanent magnet-less, brushless synchronous system comprising:
 - a stator that generates a magnetic rotating field when sourced by an alternating current;
 - an uncluttered rotor disposed within the magnetic rotating field and spaced apart from the stator to form an air gap relative to an axis of rotation; and
 - an excitation core spaced apart from the stator and the uncluttered rotor that magnetically couples the uncluttered rotor;
 where an excitation coil generates a magnet torque by inducing magnetic poles that interact with the stator currents near an outer peripheral surface of the uncluttered rotor; and
 - where the stator generates a reluctance torque by a reaction of a flux generated by the stator currents which goes through the different direct and quadrature flux paths of the uncluttered rotor.

2. The permanent magnet-less, brushless synchronous system of claim 1 where the excitation core comprises a plurality of ring-like elements.

3. The permanent magnet-less, brushless synchronous system of claim 1 where the uncluttered rotor comprises a plurality of mechanical supporting elements that provides mechanical support to each of a plurality of laminations that comprise the uncluttered rotor.

4. The permanent magnet-less, brushless synchronous system of claim 3 where the excitation core provides a flux carrying path that further renders the magnet torque.

5. The permanent magnet-less, brushless synchronous system of claim 1 where the excitation coil is configured to produce adjustable excitation fields.

6. The permanent magnet-less, brushless synchronous system of claim 1 further comprising an excitation controller that adjusts the excitation fields sourced by the exciter coil in response to an output of a vehicle speed and output sensors.

7. The permanent magnet-less, brushless synchronous system of claim 1 further comprising an energy detector electrically coupled to the stator and the excitation coil to monitor a current or a voltage and a processor coupled to an input/output device that shuts off the excitation field when a failure condition is detected.

8. The permanent magnet-less, brushless synchronous system of claim 7 where a failure condition comprises the detection of an excessive current or an excessive voltage drawn by the synchronous system.

9. The permanent magnet-less, brushless synchronous system of claim 1 where the uncluttered rotor comprises a plurality of U-like shaped sections distributed about an outer periphery of the uncluttered rotor and partially enclosing magnetic poles of a common polarity.

10. The permanent magnet-less, brushless synchronous system of claim 9 where the U-like shaped sections are bounded by non-continuous grooves that pass through a width of the uncluttered rotor and the open end of the U-like shaped sections form a portion of an outer perimeter of the uncluttered rotor.

11. The permanent magnet-less, brushless synchronous system of claim 10 further comprising mechanical reinforcement elements that pass between a proximal end and a distal end of one or more non-continuous grooves to render a unitary rotor.

12. The permanent magnet-less, brushless synchronous system of claim 11 where the mechanical reinforcement elements comprise a plurality of joining elements each having a thick distal end and a tapered proximal end.

13. The permanent magnet-less, brushless synchronous system of claim 11 further comprising

a plurality of narrow bridges that conductively couple adjacent poles induced on the uncluttered rotor near the outer periphery of the uncluttered rotor; and

where the plurality of mechanical reinforcement elements are configured to maintain the integrity of the uncluttered rotor to a rotation rate of more than ten thousand revolutions per minute; and

where the adjacent poles are of opposite polarity.

14. The permanent magnet-less, brushless synchronous system of claim 10 further comprising a plurality of narrow bridges that conductively couple adjacent poles induced on the uncluttered rotor near the outer periphery of the uncluttered rotor, the adjacent poles are of opposite polarity.

15. The permanent magnet-less, brushless synchronous system of claim 14 where the plurality of narrow bridges each comprise a radial thickness of about one millimeter or less.

16. The permanent magnet-less, brushless synchronous system of claim 15 where the narrow bridges are positioned adjacent to a raised area of an end-piece that is in contact with open areas of the U-like sections.

17. A permanent magnet-less synchronous system comprising:

a stator that generates a magnetic rotating field when sourced by an alternating current;

an uncluttered rotor disposed within the magnetic rotating field and spaced apart from the stator to form an air gap relative to an axis of rotation;

an excitation core spaced apart from the stator and the uncluttered rotor and magnetically coupled to the uncluttered rotor; and

an end-piece mechanically coupling the outer perimeter of the uncluttered rotor comprising a plurality of raised portions joined to a substantially uniformly dimensioned annulus portion;

where the uncluttered rotor comprises a plurality of U-like shaped sections distributed about an outer periphery of the uncluttered rotor and partially enclosing magnetic poles of a common polarity, the U-like shaped sections bounded by a plurality of non-continuous grooves that pass through a width of the uncluttered rotor; and

where the excitation source generates a magnet torque by inducing magnetic poles that interact with the stator currents near an outer peripheral surface of the uncluttered rotor; and where the stator generates a reluctance torque by a reaction of the flux generated by the stator currents which goes through the different direct and quadrature flux paths of the uncluttered rotor.

18. The permanent magnet-less, brushless synchronous system of claim 17 where the raised portions of said end-piece are substantially aligned with each open area of the U-like shaped sections bounded by the grooves.

19. The permanent magnet-less, brushless synchronous system of claim 17 where the end-piece has a greater axial width inside each open area of the U-like shaped sections than the width outside of each open area of the U-like shaped sections.

20. A permanent magnet-less, brushless synchronous system comprising:

a stator that generates a magnetic rotating field when sourced by an alternating current; and

an uncluttered rotor disposed within the magnetic rotating field and spaced apart from the stator to form an air gap relative to an axis of rotation, the uncluttered rotor comprising a plurality of U-like shaped sections bounded by a plurality of non-continuous grooves that pass through a width of the uncluttered rotor;

an excitation core spaced apart from the stator and the uncluttered rotor and magnetically coupled to the uncluttered rotor;

an end-piece mechanically coupling the outer perimeter of the uncluttered rotor comprising a plurality of raised portions joined to a substantially uniformly dimensioned annulus portion; and

a plurality of mechanical reinforcement elements that pass between a proximal end and a distal end of one or more non-continuous grooves to render a unitary rotor;

where the excitation coil generates a magnet torque by inducing magnetic poles that interact with the stator currents near an outer peripheral surface of the uncluttered rotor; and

where the stator generates a reluctance torque by a reaction of the flux generated by the stator currents which goes through the different direct and quadrature flux paths of the uncluttered rotor.

21. The permanent magnet-less, brushless synchronous system of claim **20** where the stator comprises a wound stator.

22. The permanent magnet-less, brushless synchronous system of claim **20** where the stator comprises a double-layer stator, a single-layer stator, a mush-wound stator, a form-wound stator, a distributed-winding stator, a concentrated-pole stator, an integral-slot stator or a fractional-slot wound stator.

23. The permanent magnet-less, brushless synchronous system of claim **20** where the synchronous system comprises a generator that receives mechanical energy and outputs electrical energy.

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