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(54) **MULTI-TUNNEL ELECTRIC
MOTOR/GENERATOR**

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(51) **Int. Cl.**

H02K 3/28 (2006.01)

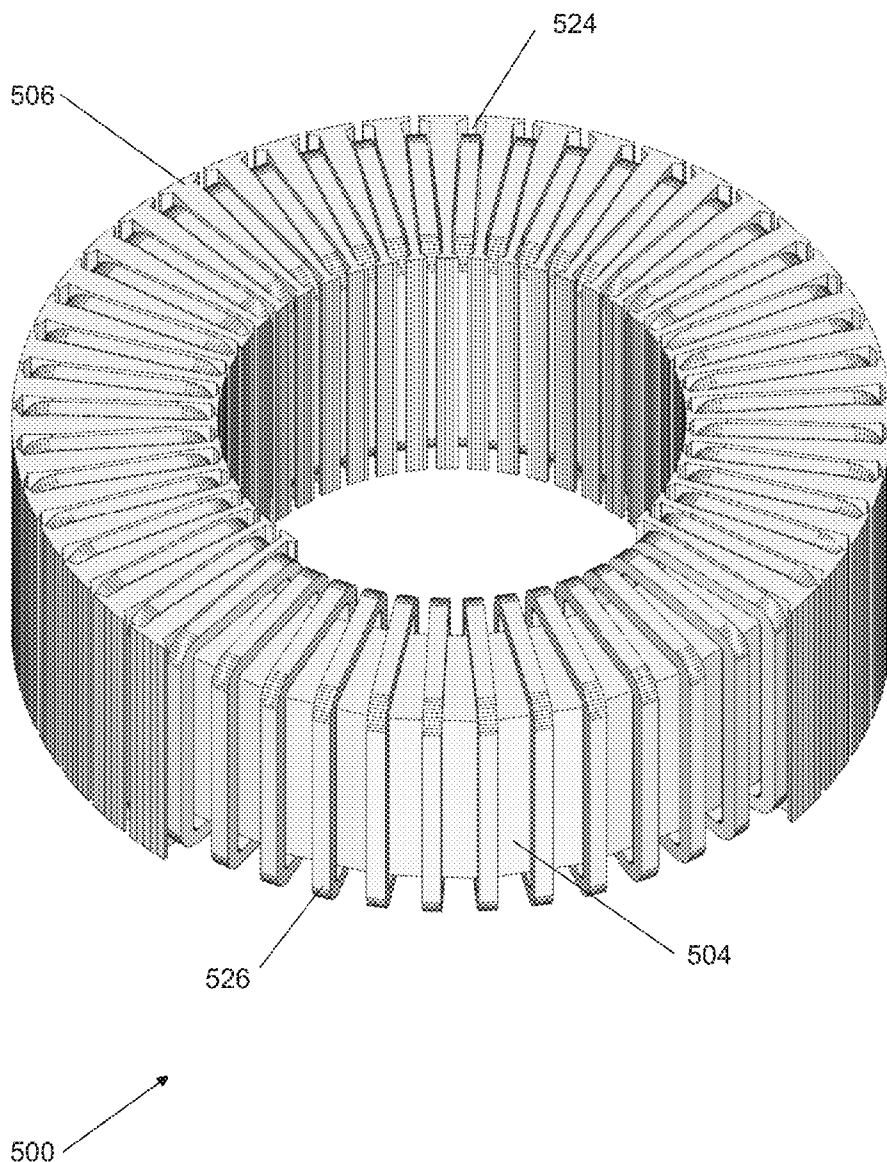
H02K 1/06 (2006.01)

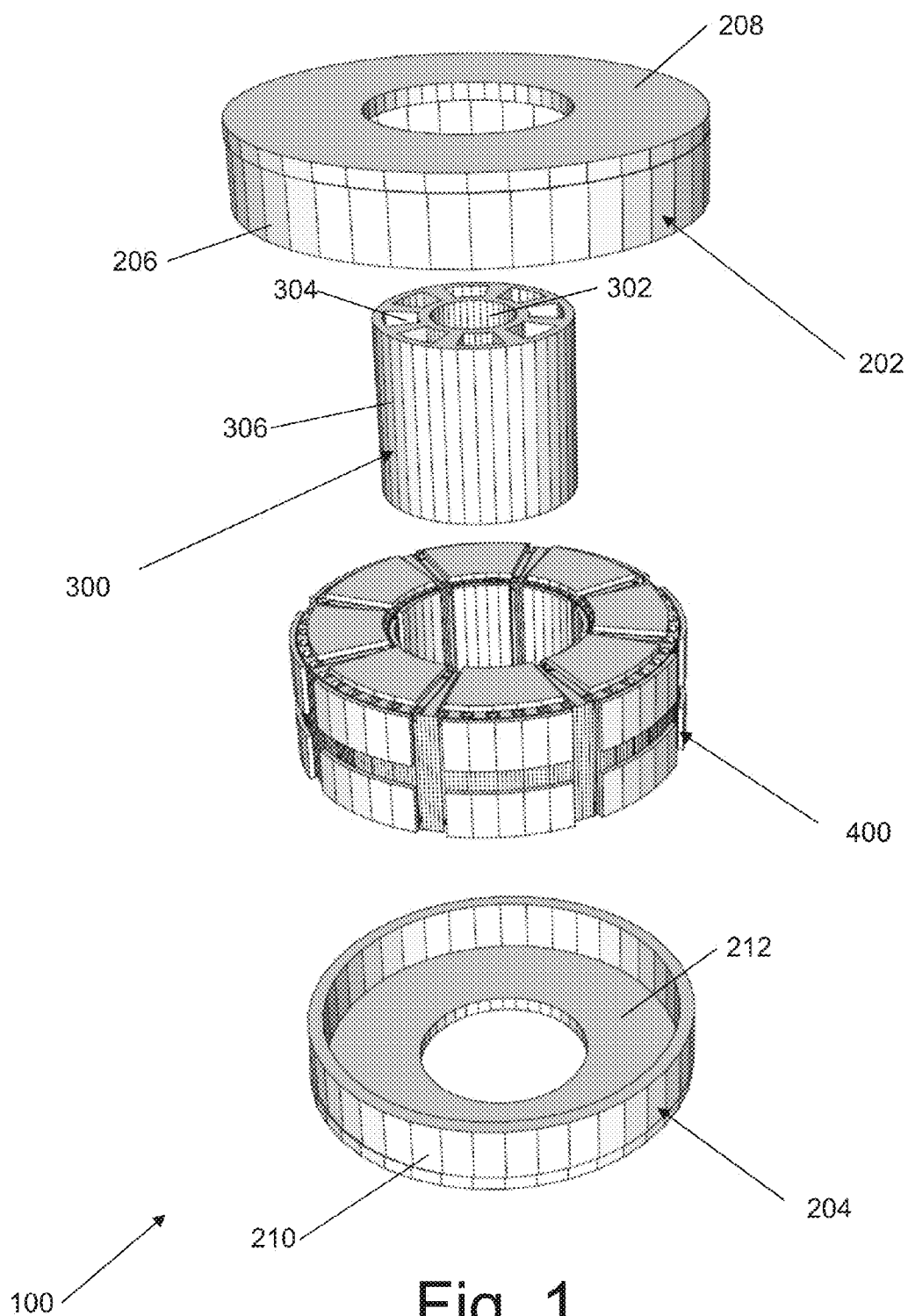
(52) **U.S. Cl.**

CPC . **H02K 3/28** (2013.01); **H02K 1/06** (2013.01)

(57) **ABSTRACT**

Disclosed are various embodiments for a motor/generator where the stator is a coil assembly and the rotor is a magnetic toroidal cylindrical tunnel or where the rotor is a coil assembly and the stator is a magnetic toroidal cylindrical tunnel.





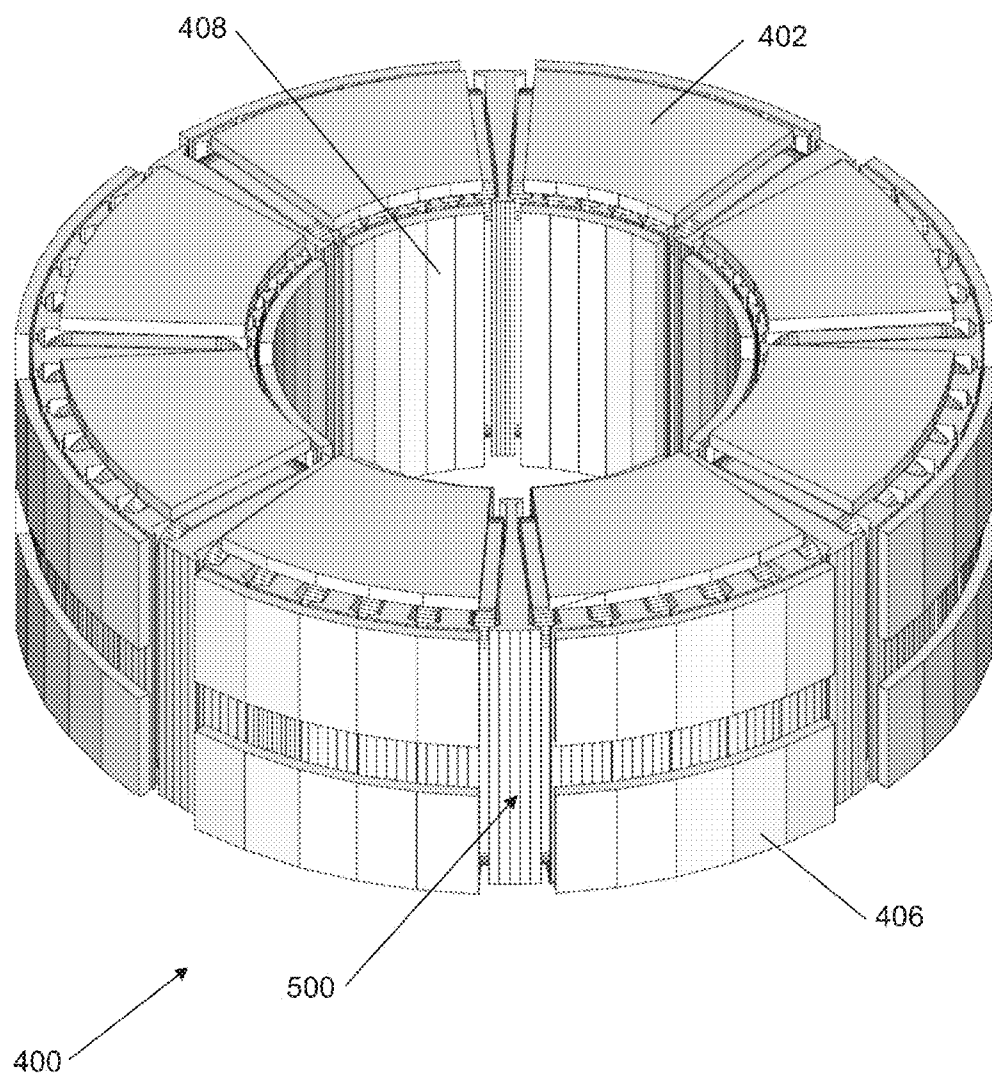


Fig. 2

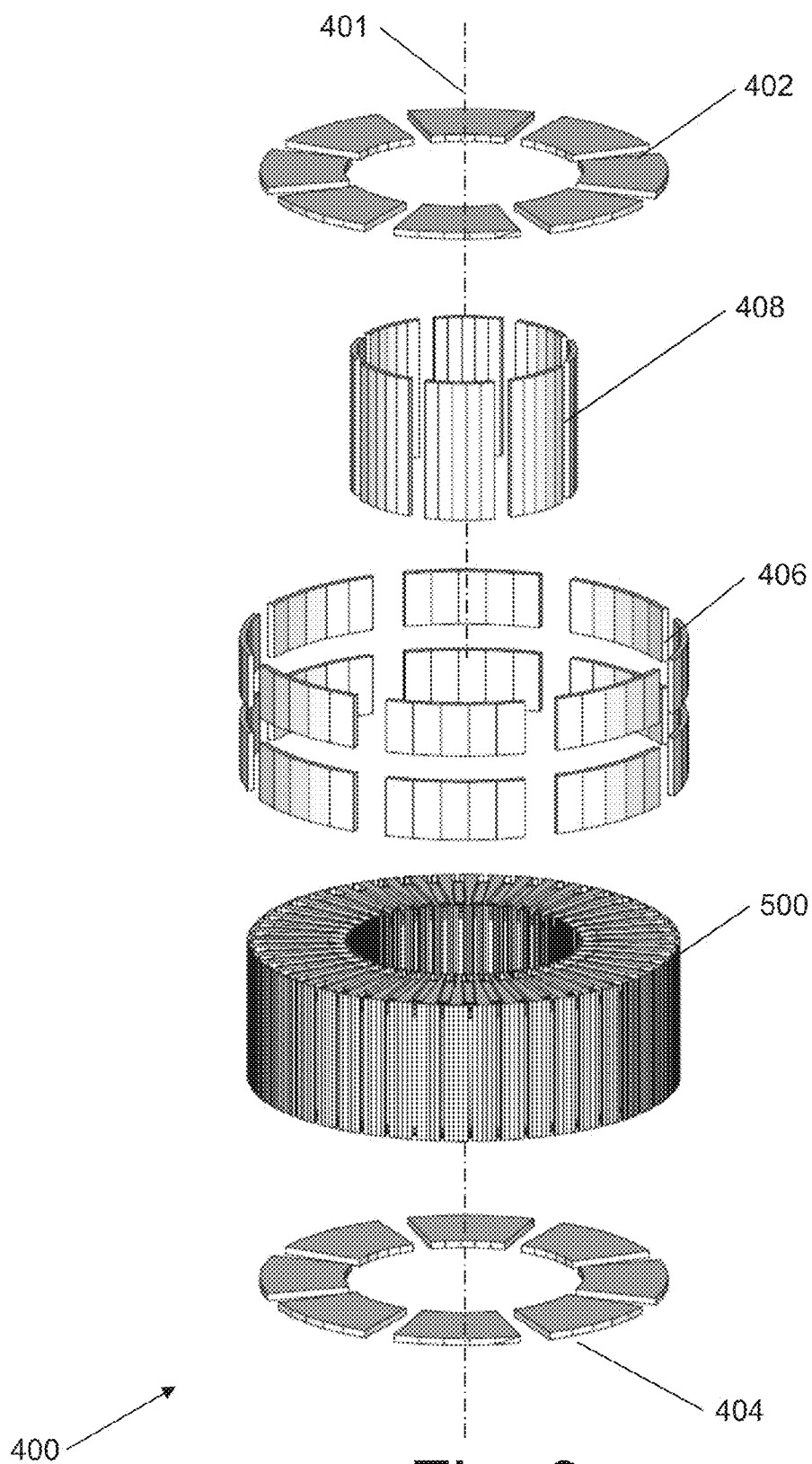


Fig. 3

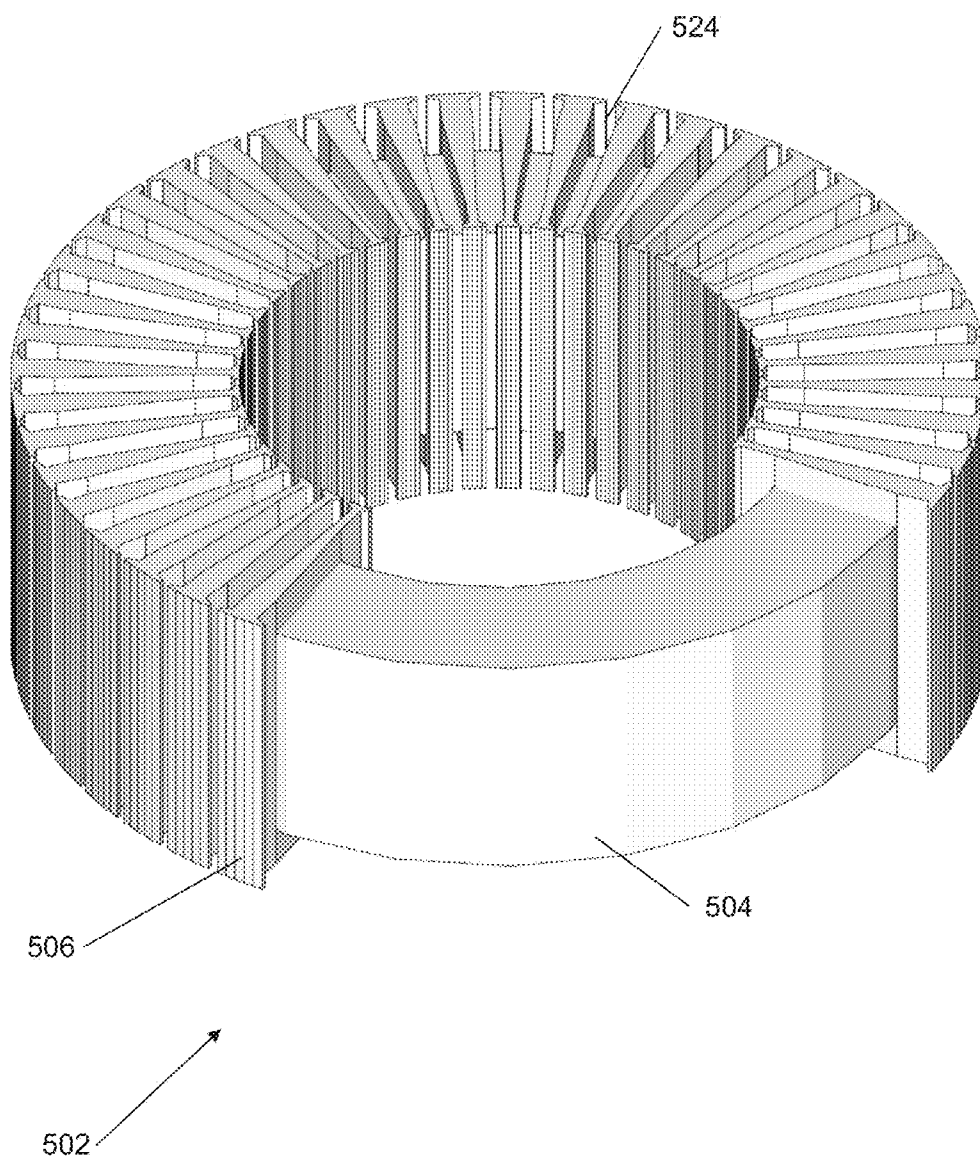


Fig. 4A

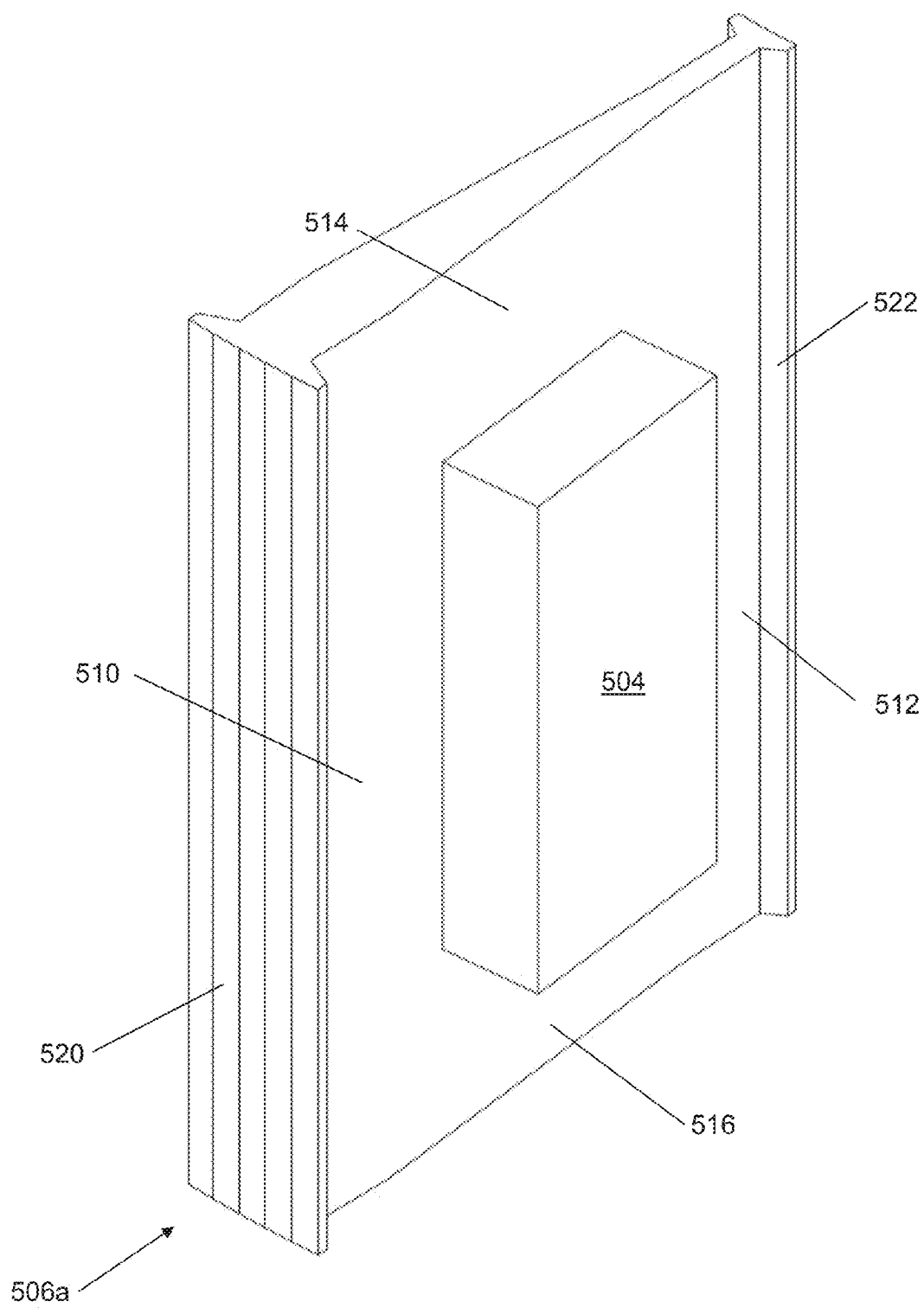


Fig. 4B

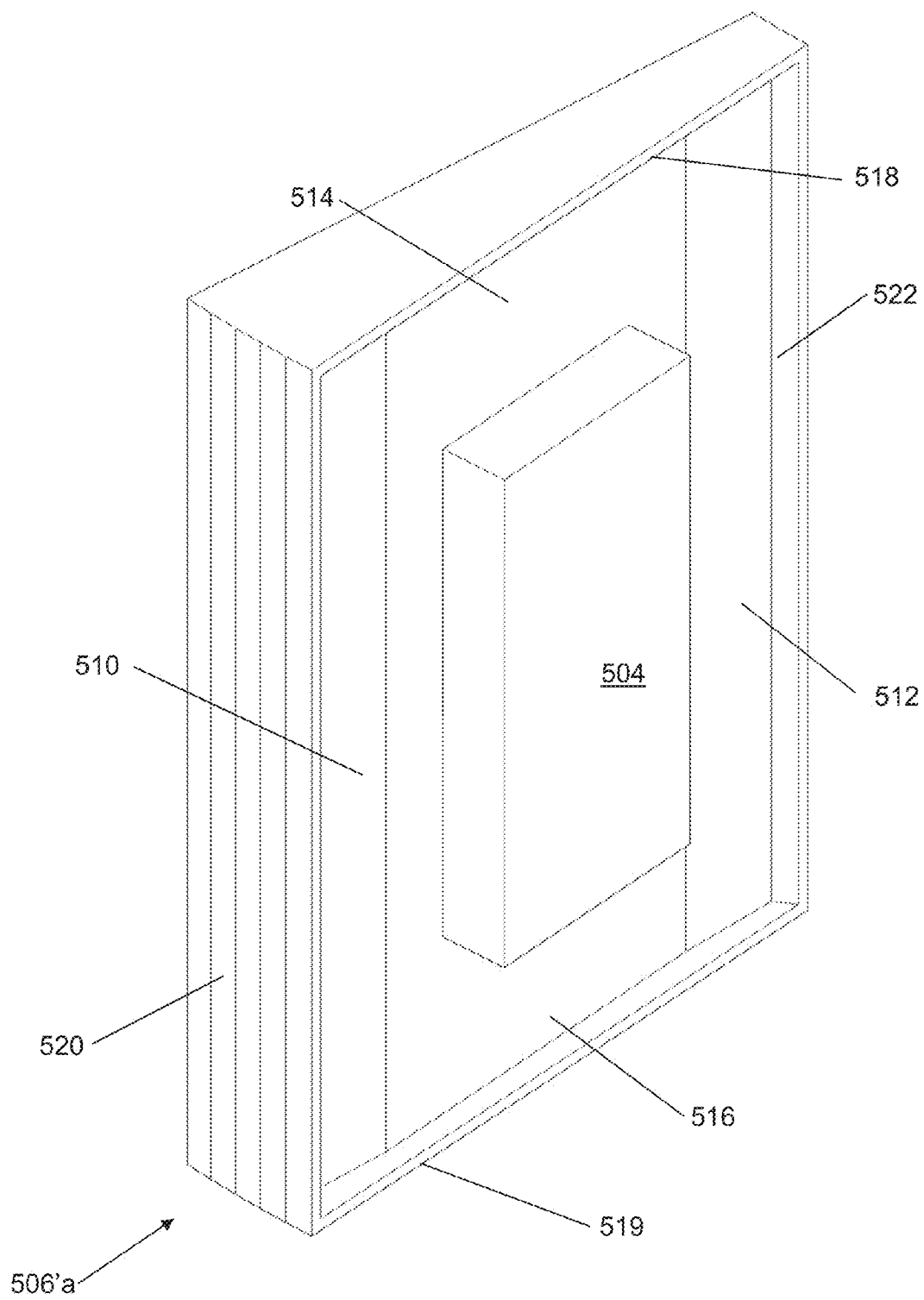


Fig. 4C

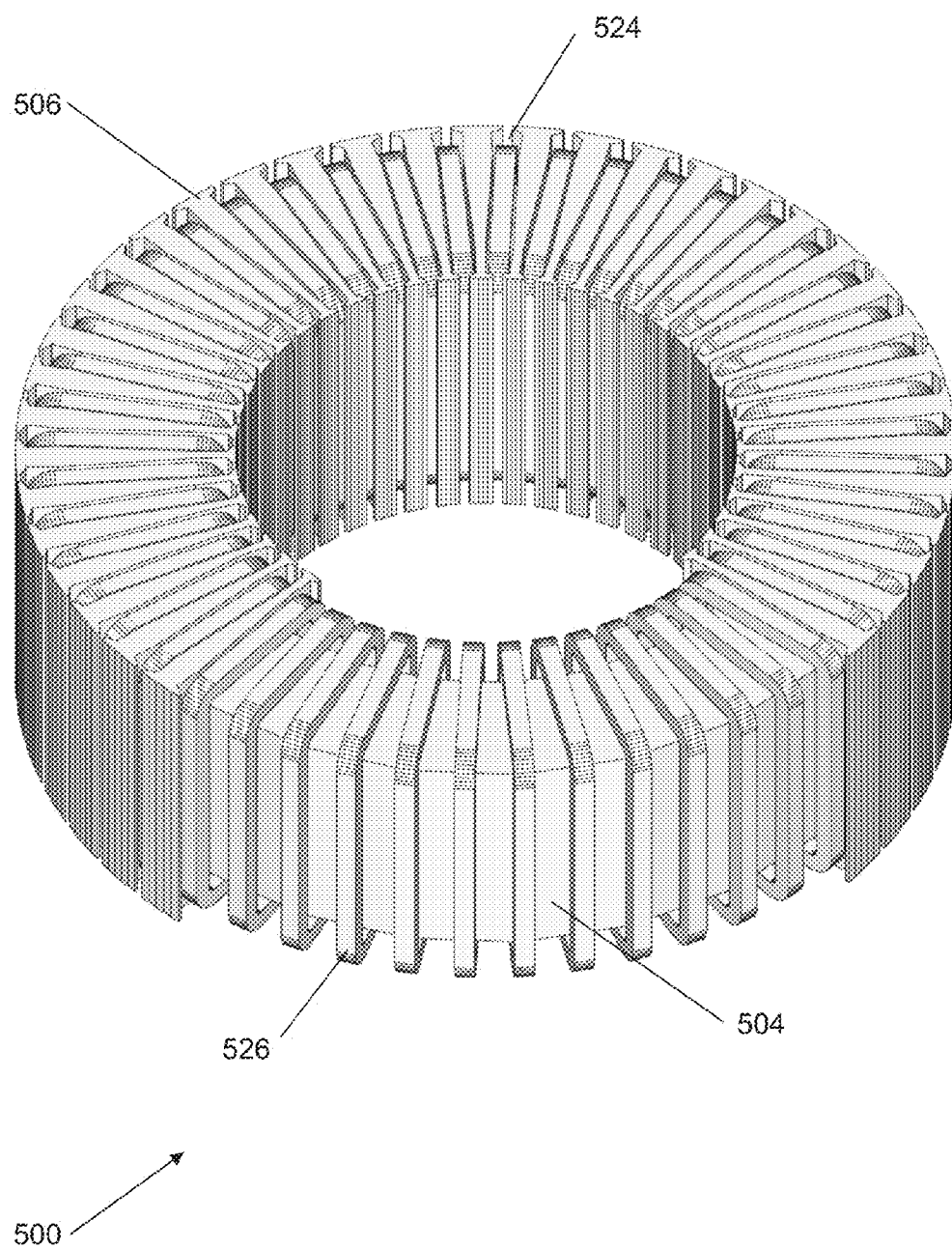


Fig. 4D

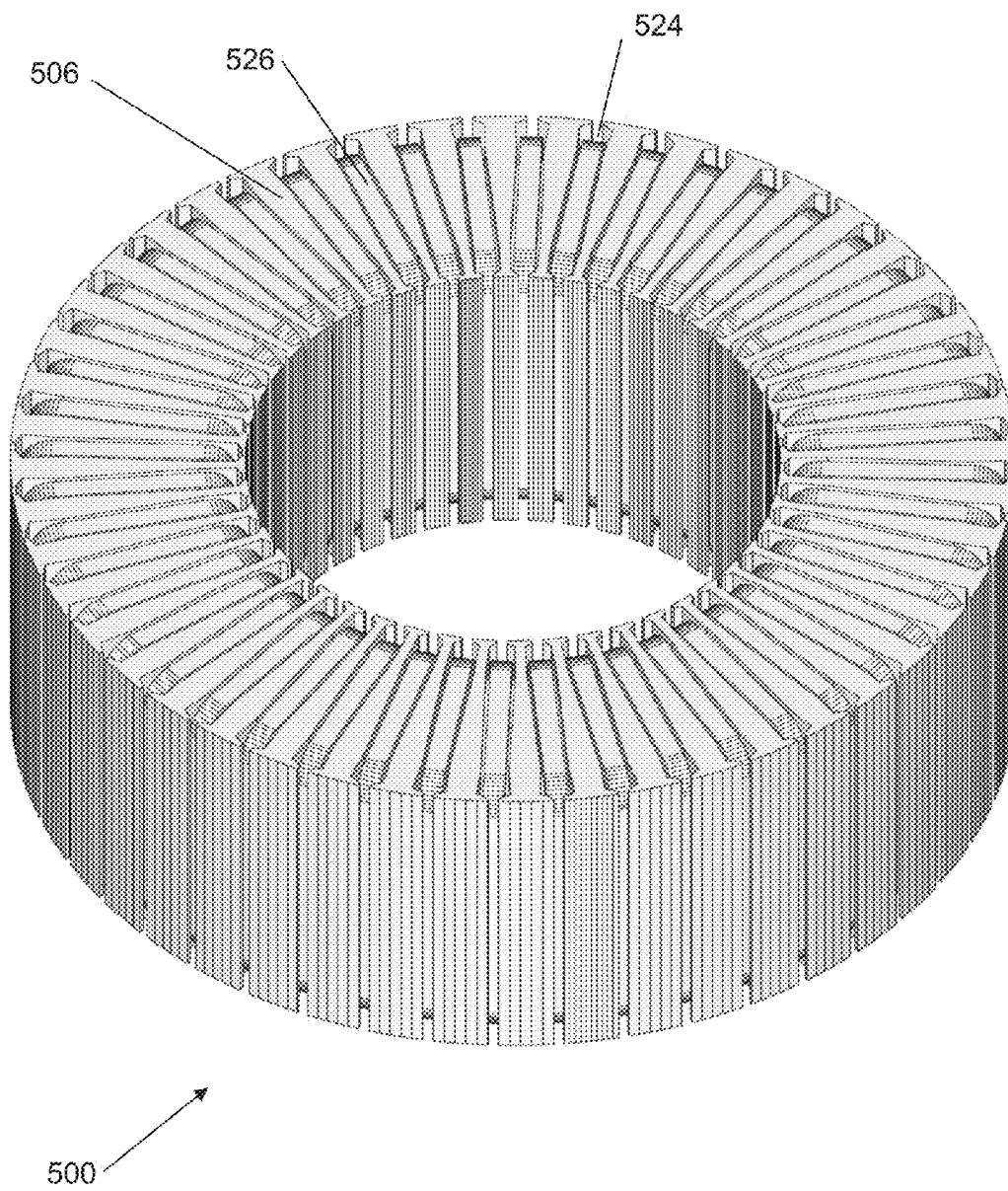


Fig. 4E

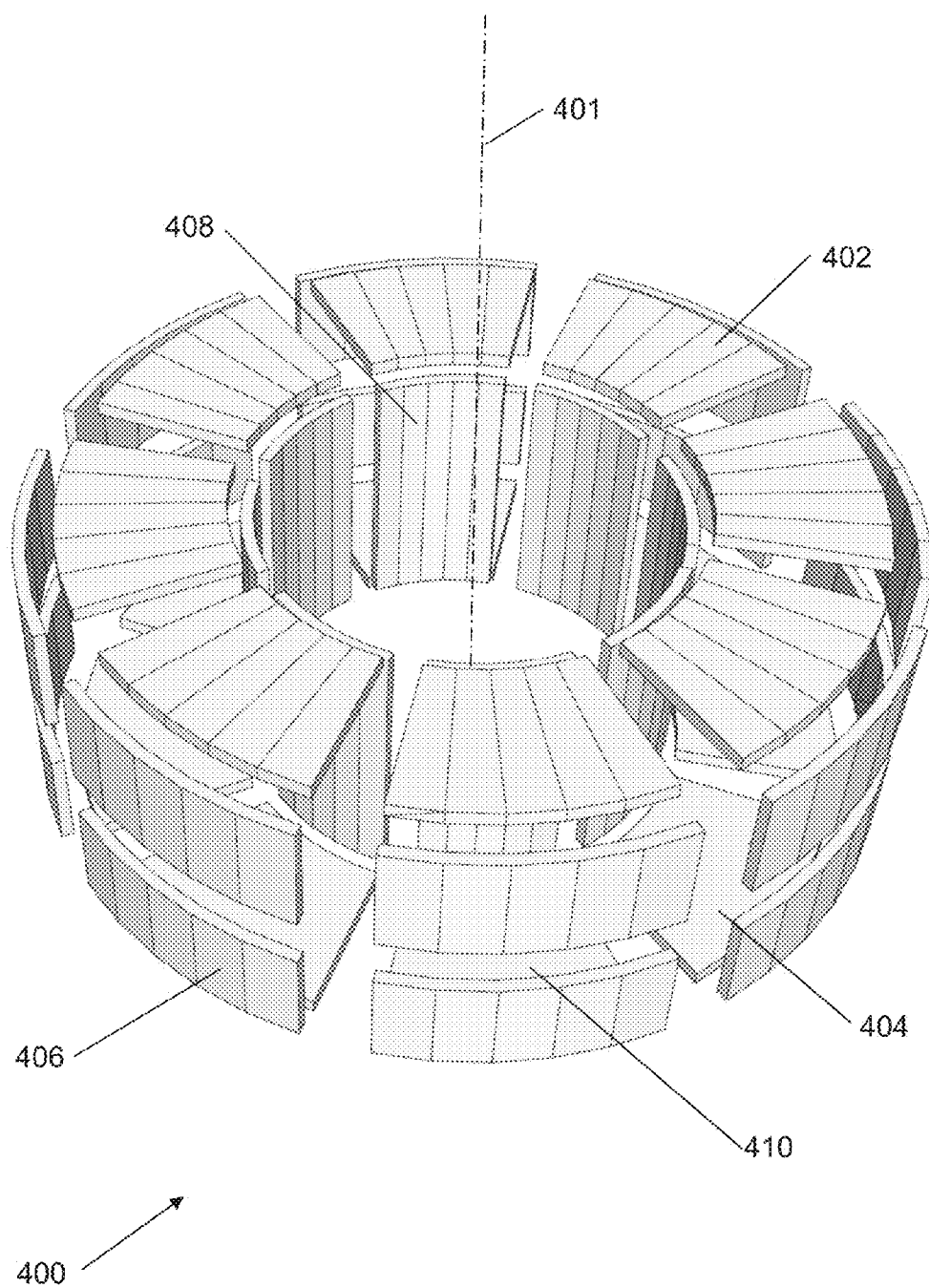


Fig. 5A

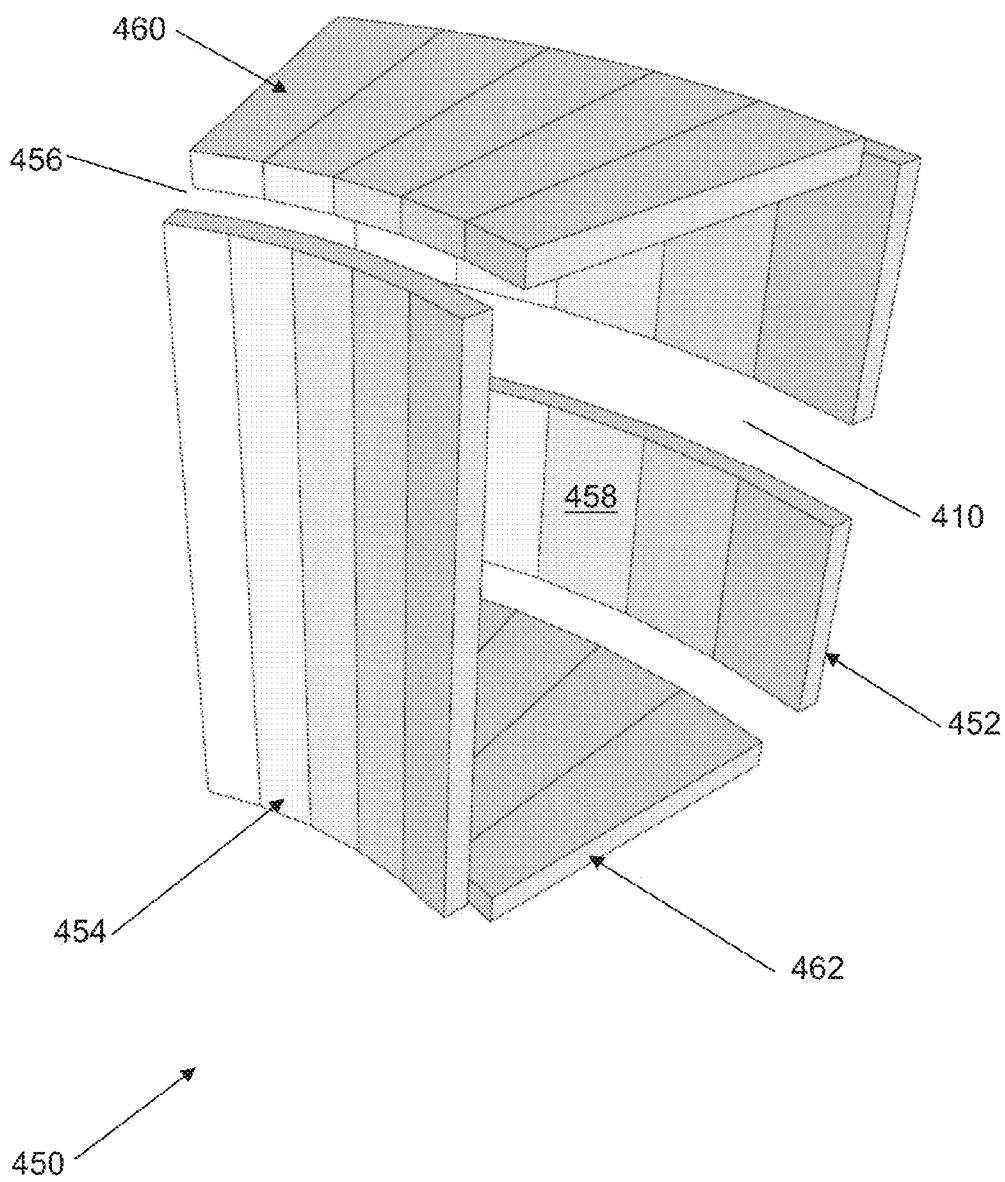


Fig. 5B

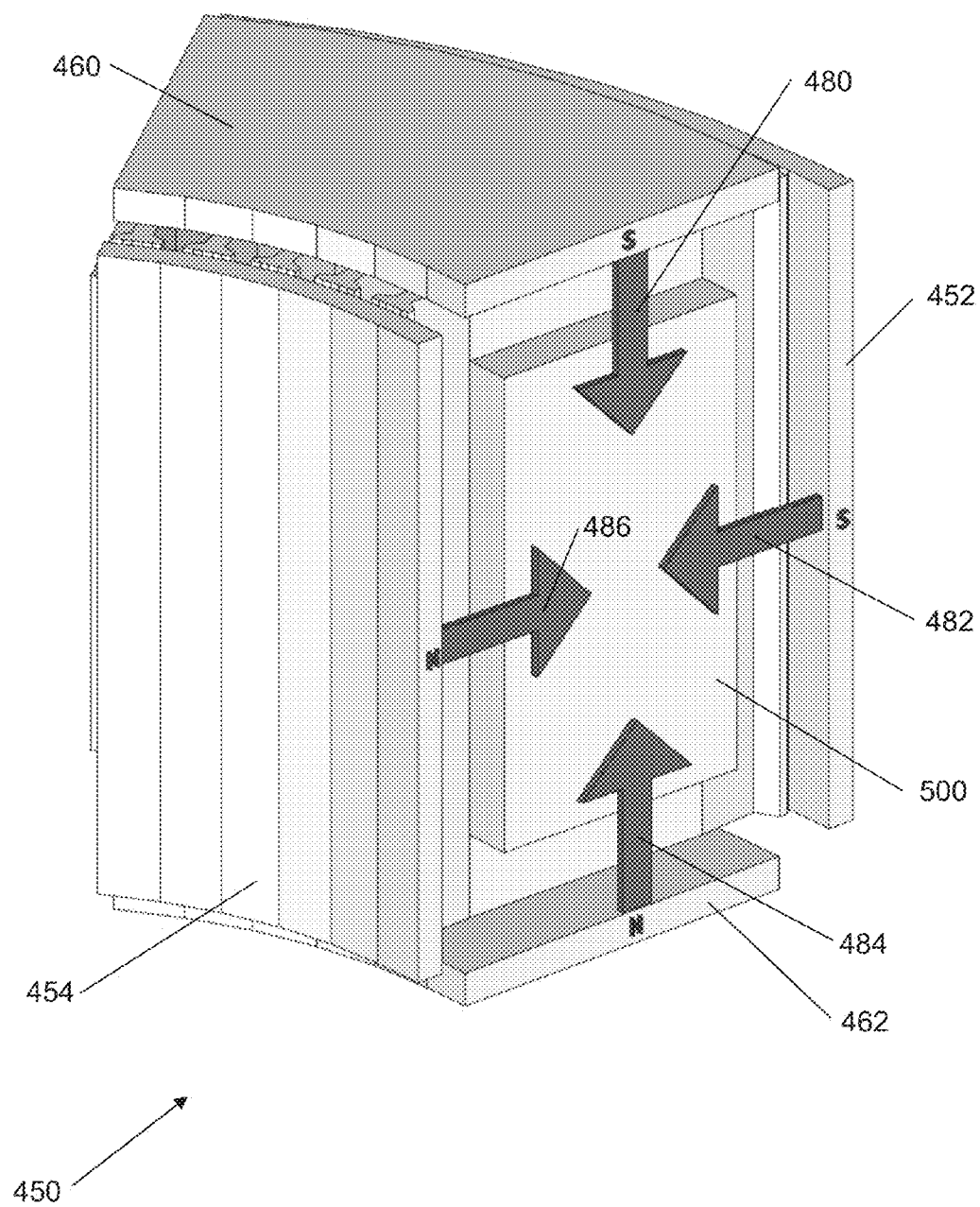


Fig. 5C

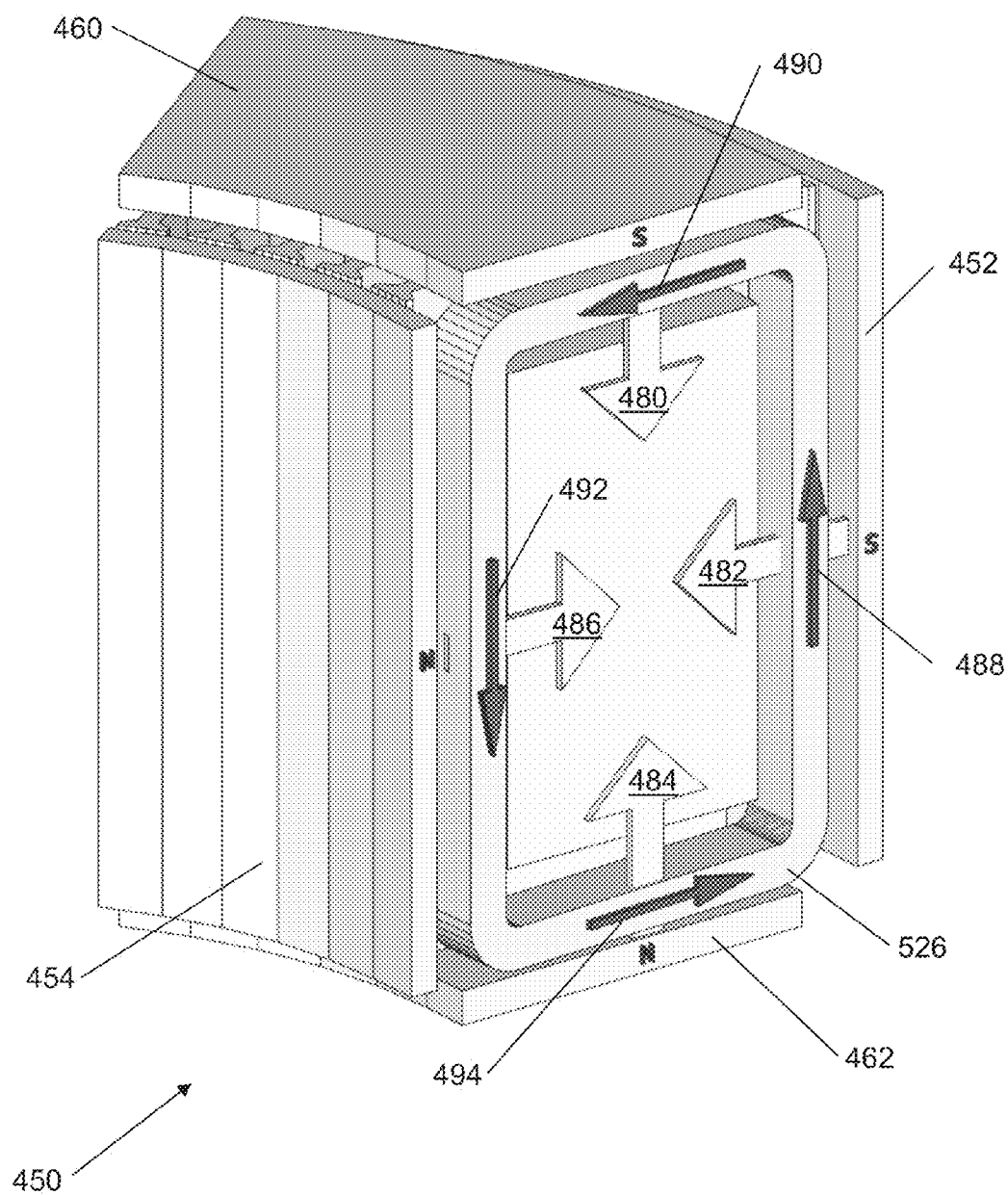


Fig. 5D

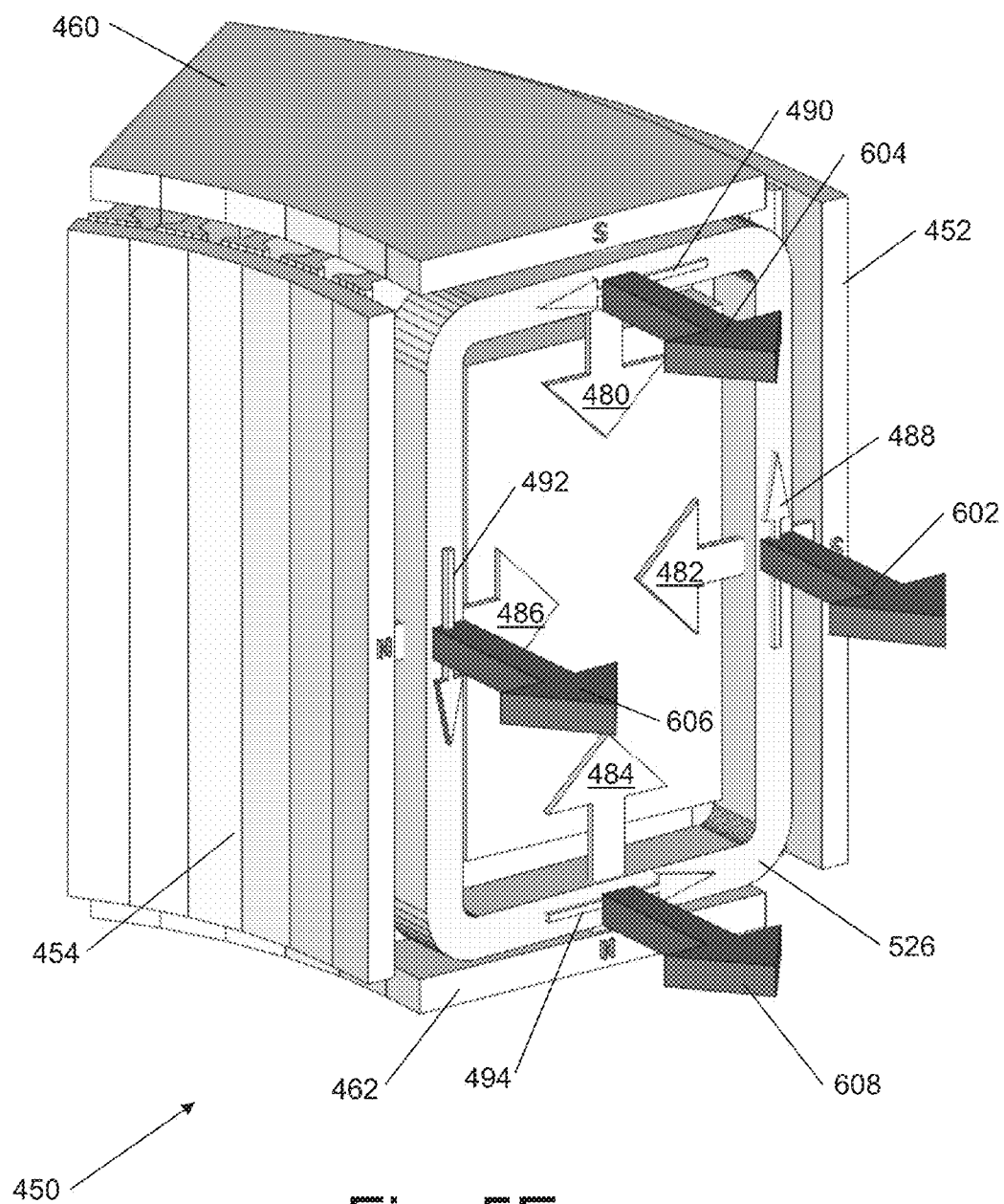


Fig. 5E

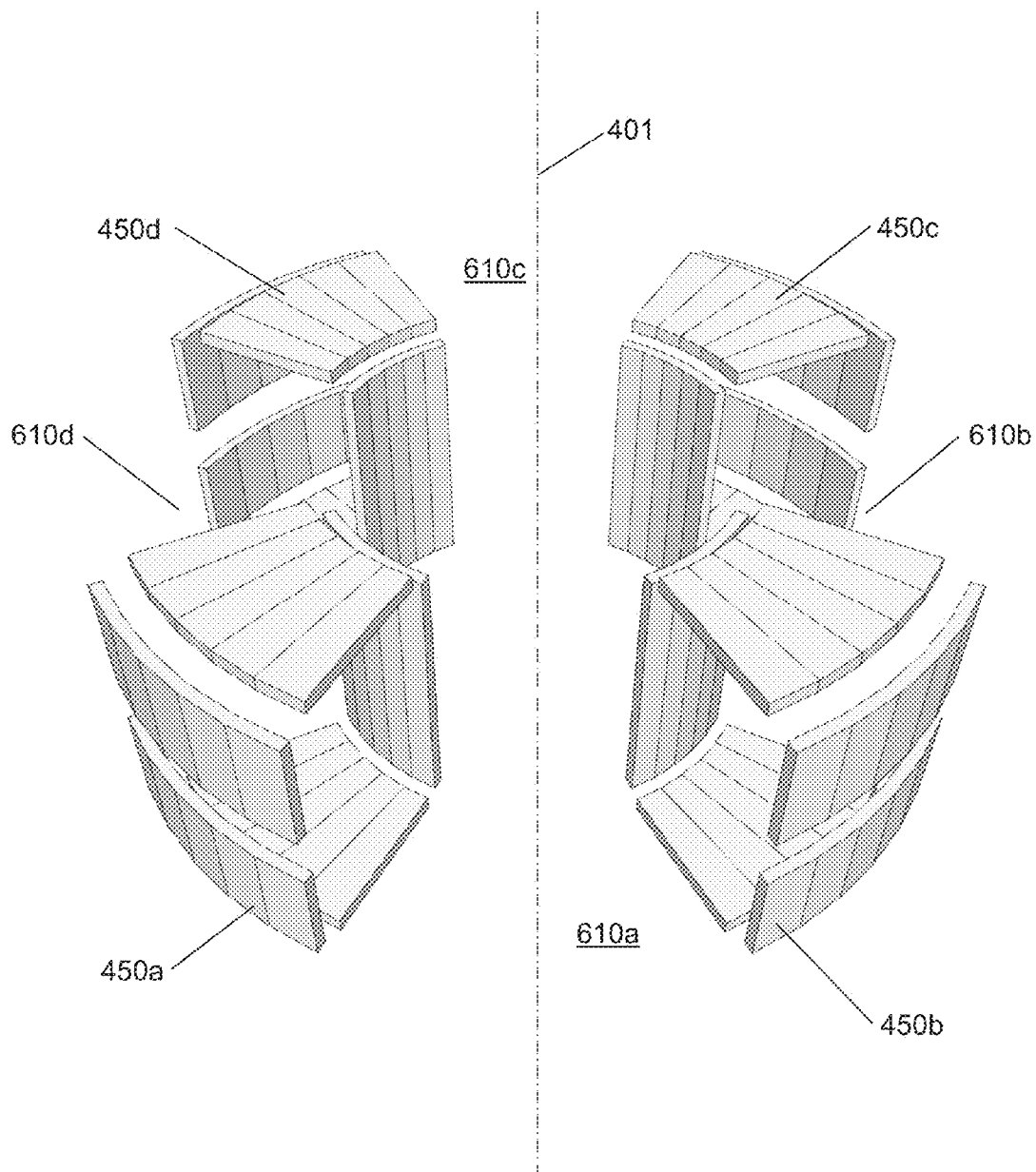


Fig. 6A

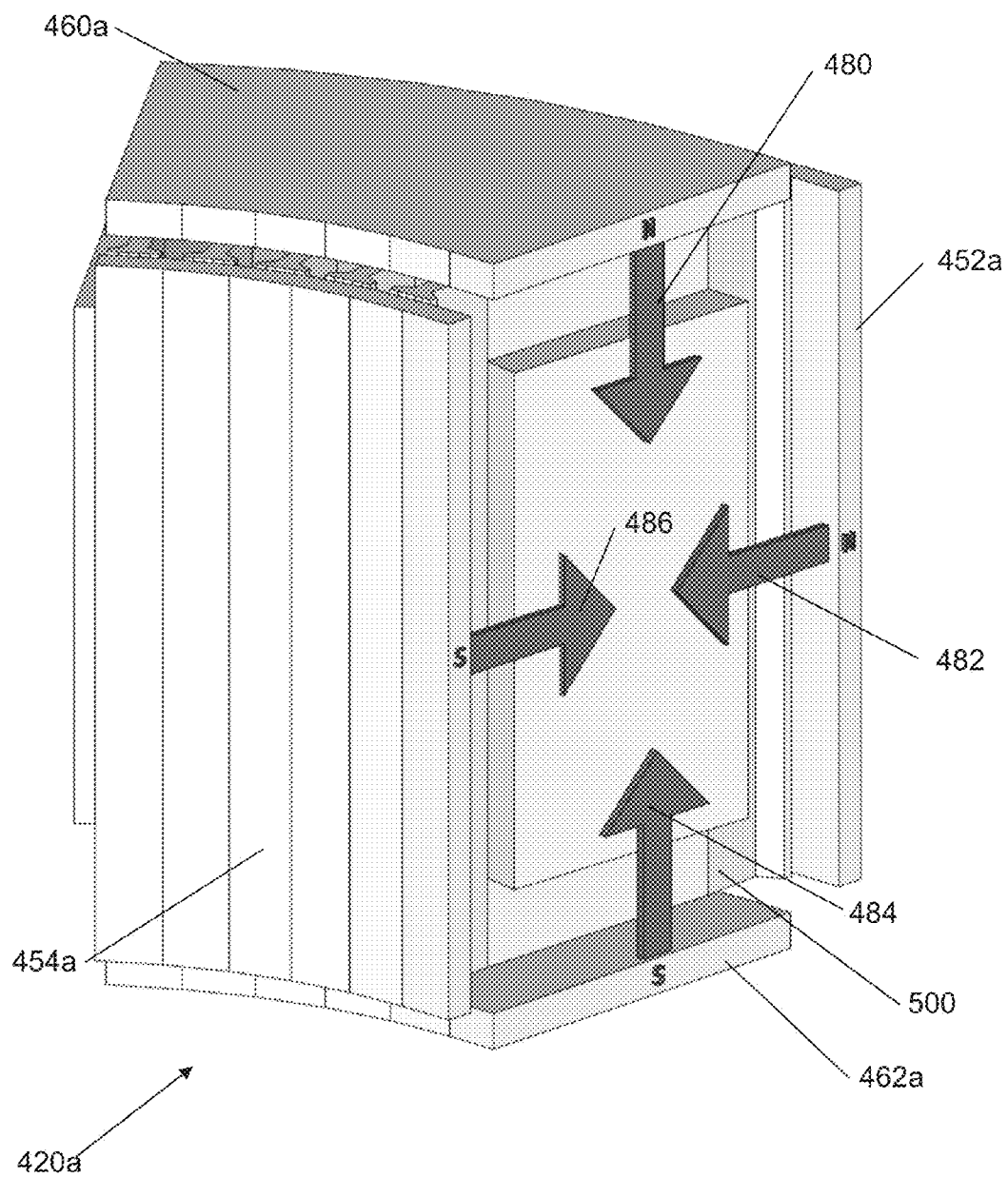


Fig. 6B

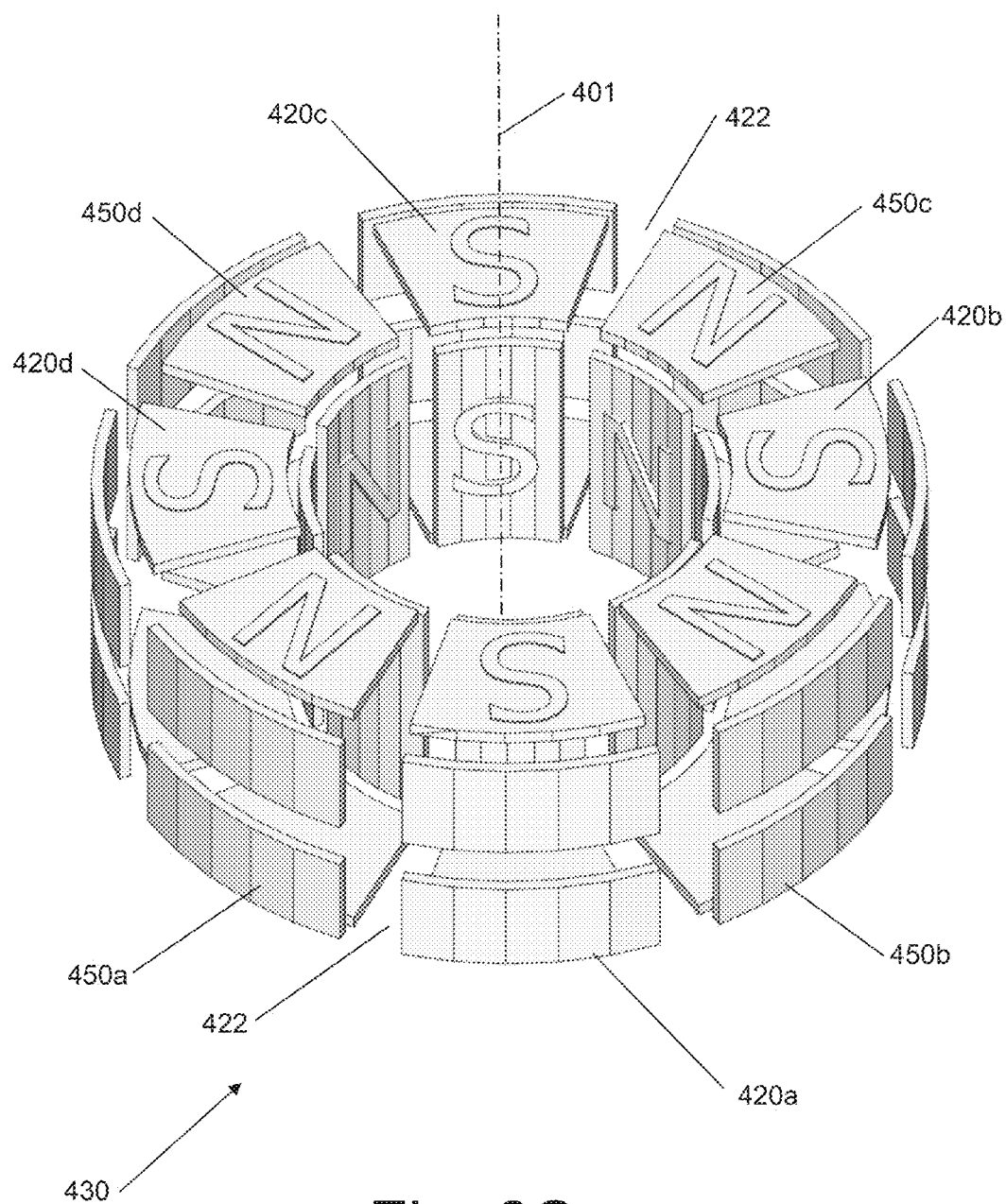


Fig. 6C

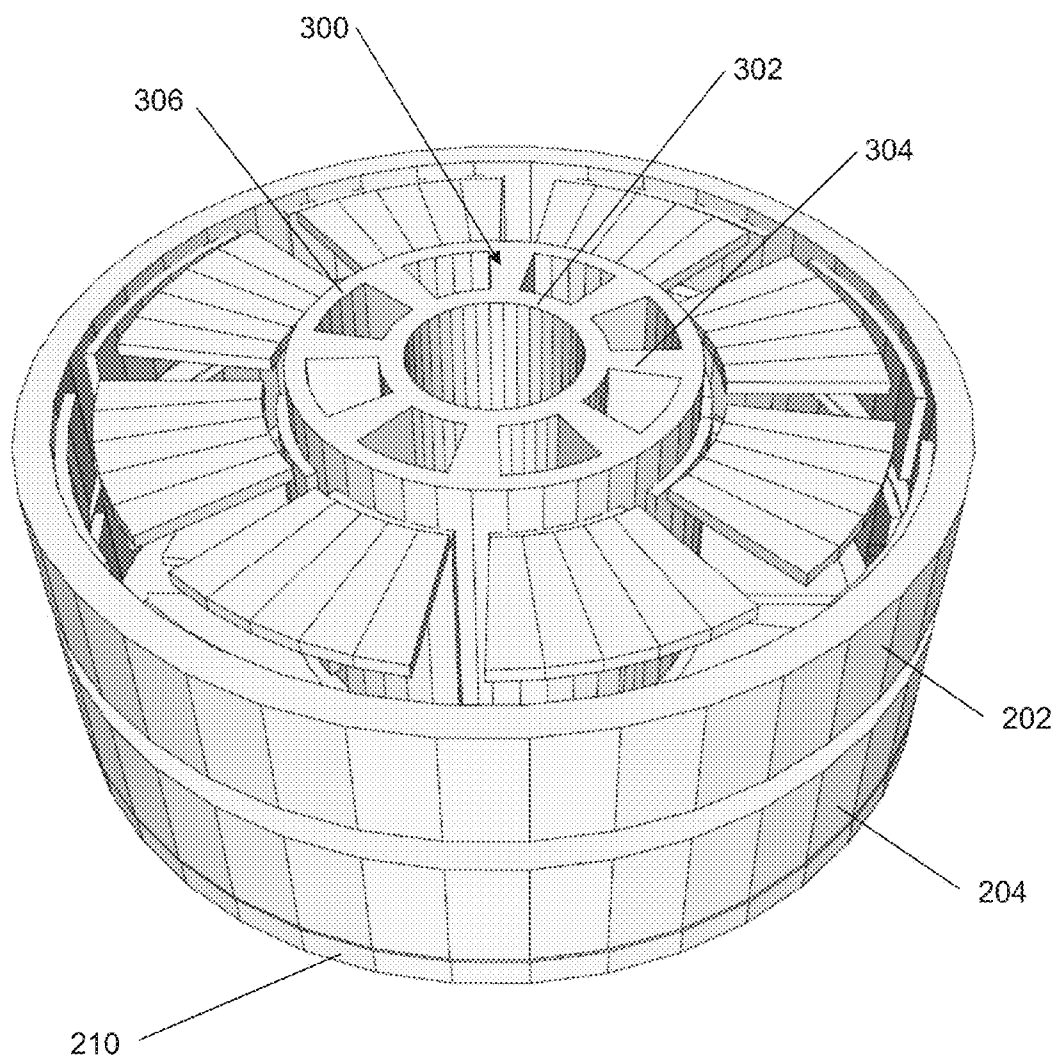


Fig. 7A

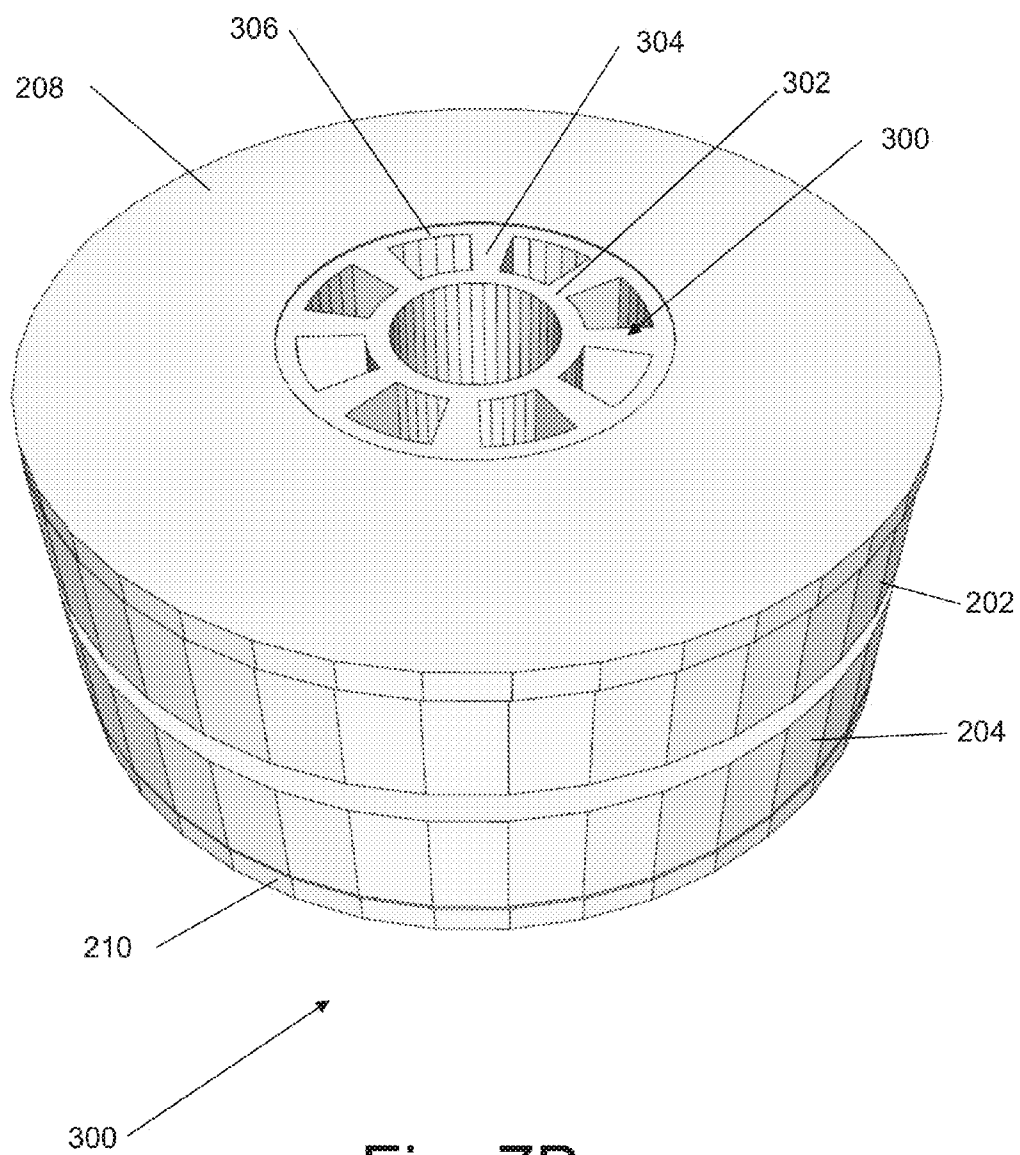


Fig. 7B

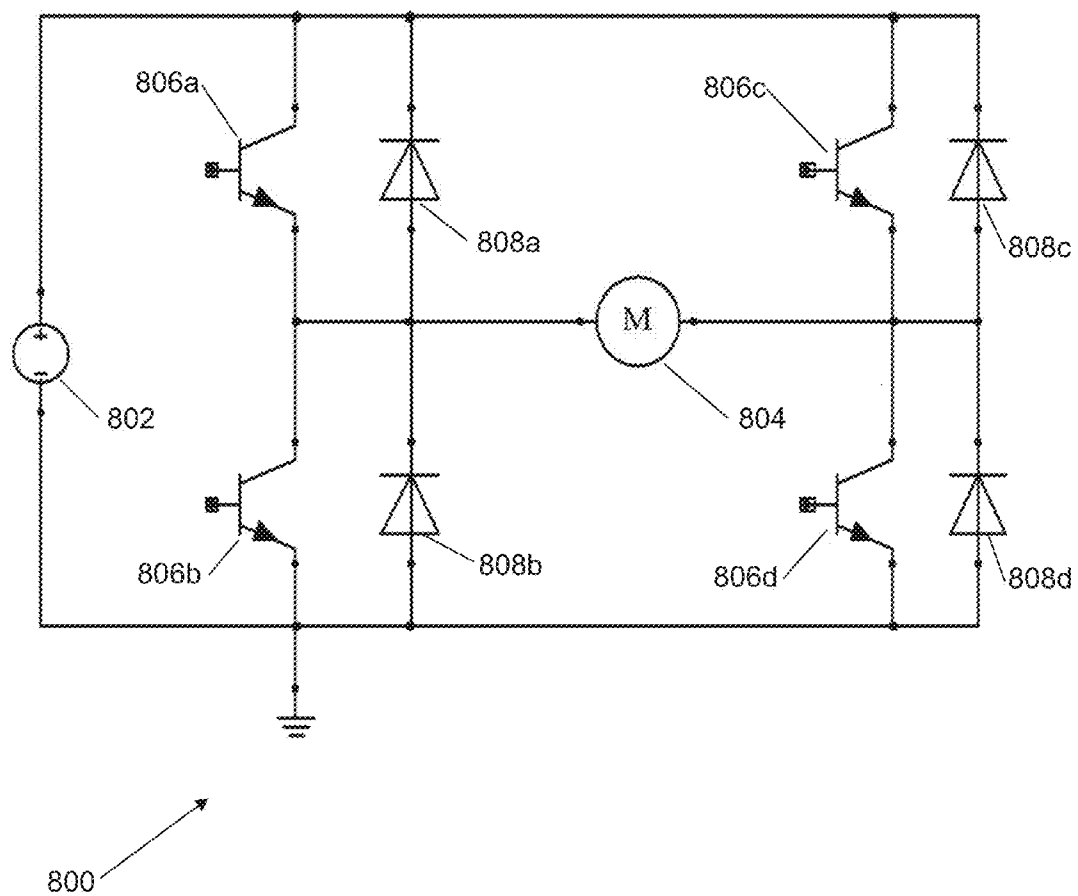


Fig. 8

MULTI-TUNNEL ELECTRIC MOTOR/GENERATOR

RELATED APPLICATIONS

[0001] This application claims the priority date from U.S. application Ser. No. 62/185,637 entitled “An Improved Electric Motor/Generator,” filed on Jun. 28, 2015, the disclosure of which is incorporated by reference for all purposes.

[0002] This application is commonly owned with the following U.S. patent applications: U.S. provisional patent application Ser. No. 62/144,654 entitled “A Multi-Tunnel Electric Motor/Generator,” filed on Apr. 4, 2015; U.S. provisional patent application No. “62/055,615, entitled “An Improved DC Electric Motor/Generator with Enhanced Permanent Magnetic Flux Densities,” filed on Sep. 25, 2014; U.S. provisional patent application Ser. No. 62/056,389, entitled “An Improved DC Electric Motor/Generator with Enhanced Permanent Magnetic Flux Densities,” filed on Sep. 26, 2014; U.S. application Ser. No. 13/848,048, entitled “An Improved DC Electric Motor/Generator with Enhanced Permanent Magnetic Flux Densities” filed on Mar. 20, 2013; which claims the benefit of U.S. Provisional Application Ser. No. 61/613,022, filed on Mar. 20, 2012, of which all of the disclosures are hereby incorporated by reference for all purposes.

TECHNICAL FIELD

[0003] The invention relates in general to a new and improved electric motor/generator, and in particular to an improved system and method for producing rotary motion from a electro-magnetic motor or generating electrical power from a rotary motion input.

BACKGROUND INFORMATION

[0004] Electric motors use electrical energy to produce mechanical energy, very typically through the interaction of magnetic fields and current-carrying conductors. The conversion of electrical energy into mechanical energy by electromagnetic means was first demonstrated by the British scientist Michael Faraday in 1821 and later quantified by the work of Hendrik Lorentz.

[0005] A magnetic field is generated when electric charge carriers such as electrons move through space or within an electrical conductor. The geometric shapes of the magnetic flux lines produced by moving charge carriers (electric current) are similar to the shapes of the flux lines in an electrostatic field. Magnetic flux passes through most metals with little or no effect, with certain exceptions, notably iron and nickel. These two metals, and alloys and mixtures containing them, are known as ferromagnetic materials because they may be used to concentrate magnetic lines of flux.

[0006] In a traditional electric motor, a central core of tightly wrapped current carrying material creates magnetic poles (known as the rotor) which spins or rotates at high speed between the fixed poles of a magnet (known as the stator) when an electric current is applied. The central core is typically coupled to a shaft which will also rotate with the rotor. The shaft may be used to drive gears and wheels in a rotary machine and/or convert rotational motion into motion in a straight line.

[0007] Generators are usually based on the principle of electromagnetic induction, which was discovered by Michael Faraday in 1831. Faraday discovered that when an electrical conducting material (such as copper) is moved through a magnetic field (or vice versa), an electric current will begin to flow through that material. This electromagnetic effect induces voltage or electric current into the moving conductors.

[0008] Current power generation devices such as rotary alternator/generators and linear alternators rely on Faraday's discovery to produce power. In fact, rotary generators are essentially very large quantities of wire spinning around the inside of very large magnets. In this situation, the coils of wire are called the armature because they are moving with respect to the stationary magnets (which are called the stators). Typically, the moving component is called the armature and the stationary components are called the stator or stators.

[0009] Motors and generators used today produce or utilize a sinusoidal time varying voltage. This waveform is inherent to the operation of these devices.

[0010] With conventional motors a pulsed electrical current of sufficient magnitude must be applied to produce a given torque/horsepower. Horsepower output and efficiency then is a function of design, electrical input power plus losses.

[0011] With conventional generators, an electrical current is produced when the rotor is rotated. The power generated is a function of flux strength, conductor size, number of pole pieces and speed in RPM.

[0012] In motors or generators, some form of energy drives the rotation and/or movement of the rotor. As energy becomes more scarce and expensive, what is needed are more efficient motors and generators to reduce energy consumption, and hence costs.

SUMMARY

[0013] In response to this and other problems, there is presented various embodiments disclosed in this application, including methods and systems of increasing flux density by permanent magnet manipulation using multiple magnetic tunnels. Disclosed are various embodiments for a motor/generator comprising: a rotor adapted to rotate about a longitudinal axis, the rotor comprising a plurality of magnetic tunnels, wherein the plurality of magnets forming each magnetic tunnel substantially have poles facing inward toward the semi-circular tunnel, when a rotor/stator is positioned within the tunnel, flux lines cross the tunnel from at least two directions, the semi-circular tunnel having an entrance and an exit, wherein the magnetic field of any magnetic tunnel is of an opposite polarity to the magnetic field of an adjacent magnetic tunnel.

[0014] These and other features, and advantages, will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings.

[0015] It is important to note the drawings are not intended to represent the only aspects of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. 1 is an exploded view of one embodiment of a motor/generator according to certain aspects of the present disclosure.

[0017] FIG. 2 is a detailed isometric view of a component of the motor/generator illustrated in FIG. 1.

[0018] FIG. 3 is an exploded view of the component of FIG. 2.

[0019] FIG. 4A is an isometric view of a coil assembly illustrating a central iron core and a plurality of teeth extending from the iron core where a portion of the teeth have been removed for clarity.

[0020] FIG. 4B is a detailed perspective view of a single tooth of the plurality of teeth of FIG. 4A.

[0021] FIG. 4C is a detailed perspective view of an alternative embodiment for the single tooth of the plurality of teeth of FIG. 4A.

[0022] FIG. 4D is an isometric view of the coil assembly of FIG. 4A coupled to a plurality of coil windings.

[0023] FIG. 4E is an isometric view of the rotor/stator of FIG. 4A coupled to a plurality of coil windings showing all of the rotor/stator teeth.

[0024] FIG. 5A illustrates a plurality of magnets forming one embodiment of a magnetic tunnel comprising eight magnetic cylinder segments.

[0025] FIG. 5B is a detailed perspective view illustrating one embodiment of a magnetic cylinder segment.

[0026] FIG. 5C is a detailed isometric view of one embodiment of a magnetic cylinder segment with a rotor/stator portion positioned therein illustrating the direction of the flux forces generated from the magnets comprising the magnetic cylinder segments.

[0027] FIG. 5D is a detailed isometric view of one embodiment of a magnetic cylinder segment with a rotor/stator portion and a coil winding positioned therein illustrating the direction of the flux forces generated from the magnets and the direction of the current in the coil winding.

[0028] FIG. 5E is a detailed isometric view of one embodiment of a magnetic cylinder segment of FIG. 5D illustrating the direction of force generated by the interaction of the flux forces generated by the magnets and the current in the windings.

[0029] FIG. 6A is a perspective view of four magnetic cylinder segments arranged around a longitudinal axis having similar magnetic pole orientations.

[0030] FIG. 6B is a detailed isometric view of one embodiment of a magnetic cylinder segment illustrating the magnets forming the segment have an opposite magnetic polarity to the magnets of the segment illustrated in FIG. 5C.

[0031] FIG. 6C is an isometric view of the four magnetic cylinder segments with four additional magnetic cylinder segments where the four additional magnetic cylinder segments have a magnetic pole orientation opposite to the first four magnetic cylinder segments.

[0032] FIG. 7A illustrates the magnetic cylinder of FIG. 6C coupled to a back iron circuit with a portion of the side back iron circuit removed for clarity.

[0033] FIG. 7B illustrates the magnetic cylinder of FIG. 6C coupled to a complete back iron circuit.

[0034] FIG. 8 illustrates an exemplary switch circuit which may be used with certain embodiments of the present invention.

DETAILED DESCRIPTION

[0035] Specific examples of components, signals, messages, protocols, and arrangements are described below to simplify the present disclosure. These are, of course, merely examples and are not intended to limit the invention from

that described in the claims. Well-known elements are presented without a detailed description in order not to obscure the present invention in unnecessary detail. For the most part, details unnecessary to obtain a complete understanding of the present invention have been omitted inasmuch as such details are within the skills of persons of ordinary skill in the relevant art. Details regarding conventional control circuitry, power supplies, or circuitry used to power certain components or elements described herein are omitted, as such details are within the skills of persons of ordinary skill in the relevant art.

[0036] When directions, such as upper, lower, top, bottom, clockwise, or counter-clockwise are discussed in this disclosure, such directions are meant to only supply reference directions for the illustrated figures and for orientation of components in the figures. The directions should not be read to imply actual directions used in any resulting invention or actual use. Under no circumstances, should such directions be read to limit or impart any meaning into the claims except for relative positioning.

[0037] FIG. 1 is an exploded perspective view of a motor/generator 100 illustrating a first portion of a back iron circuit 202, a second portion of a back iron circuit 204, a center hub 300, and a magnetic disc 400. The first portion back iron circuit 202 comprises a first cylindrical wall 206 made of back iron material. The first cylinder wall 206 may be coupled to a flat side wall 208 which is also made of back iron material. For purposes of this application the term “back iron” may refer to iron or a soft magnetic material, such as any ferrous compound or alloy, such as stainless steel, any nickel or cobalt alloy, or any laminated metal comprising laminated sheets of such material.

[0038] The second portion of the back iron circuit 204 similarly comprises a second cylindrical wall 210 coupled to a flat side wall 212. Thus, when assembled the first portion of the back iron circuit 202 and the second portion of the back iron circuit 204 physically surrounds the center hub 300 and the magnetic disc 400. In other embodiments, the cylindrical walls 206 and 210 have slots (not shown) defined therein to allow the passage of control wires and/or electrical conductors. In yet other embodiments, there may be a gap (not shown) between the cylindrical walls 206 and 210 and the flat side walls 208 and 212, respectively. The gap allows for the passage of control wires and/or electrical conductors as well as heat.

[0039] In certain embodiments, the hub 300 comprises an inner hub 302 for coupling to a mechanical load transferring device, such as a shaft (not shown). The hub 300 positions and structurally supports the magnetic disc 400 about the shaft (not shown). A plurality of radial arms 304 couple the inner hub 302 to an outer hub 306. In certain embodiments, the out hub 306 also comprises a portion of the back iron circuit for the magnetic disc 400.

[0040] FIG. 2 is a detailed isometric view of the magnetic disc 400. FIG. 3 is an exploded view of the magnetic disc 400. In the embodiment illustrated in FIG. 3, with respect to a longitudinal axis 401, there is a top or first side or axial ring of magnets 402. Similarly there is a bottom or second side or axial ring of magnets 404. An outer cylindrical wall or longitudinal ring of magnets 406 is longitudinally positioned between the first axial ring 402 and the second axial ring of magnets 404. An inner cylindrical wall or longitudinal ring of magnets 408 is also longitudinally positioned between the first axial ring 402 and the second axial ring of

magnets **408** and laterally positioned within the outer longitudinal ring of magnets **406**.

[0041] In certain embodiments, the magnets forming the axial rings **402-404** and longitudinal rings **408-406** discussed herein may be made of out any suitable magnetic material, such as: neodymium, Alnico alloys, ceramic permanent magnets, or electromagnets. The exact number of magnets or electromagnets will be dependent on the required magnetic field strength or mechanical configuration. The illustrated embodiment is only one way of arranging the magnets, based on certain commercially available magnets. Other arrangements are possible, especially if magnets are manufactured for this specific purpose.

[0042] A coil assembly **500** is laterally positioned between the outer longitudinal ring **406** and the inner longitudinal ring **408** and is longitudinally positioned between the first axial ring **402** and the second axial ring **404**. In certain embodiments, the coil assembly **500** may be a stator. In yet other embodiments, the coil assembly **500** may be a rotor.

[0043] Turning now to FIG. 4A, there is a partial isometric view of a coil assembly support **502**, which in one embodiment, may be a portion of a stator used in conjunction with a rotor formed by the magnetic axial rings **402-404** and magnetic longitudinal cylindrical walls **406-408** and the back iron circuit portions **202** and **204** discussed above. In certain embodiments, the coil assembly support **502** comprises a cylindrical or ring core **504** coupled to a plurality of teeth **506** radially spaced about the ring core. For purposes of clarity, FIG. 4A shows a portion of teeth **506** removed so that the ring core **504** is visible.

[0044] In certain embodiments, the ring core **504** may be made out of iron or back iron materials so that it will act as a magnetic flux force concentrator. However, other core materials may be used when design considerations such as mechanical strength, reduction of eddy currents, cooling channels, etc. are considered. As discussed above, back iron materials may be iron, an iron alloy, laminated steel iron or other soft magnet materials. In some embodiments, the ring core **504** may be hollow or have passages defined therein to allow liquid or air cooling.

[0045] One embodiment of an individual tooth **506a** and a small portion of the ring core **504** are illustrated in FIG. 4B. The tooth **506a** may be made from a material similar to the material forming the core **504**, for example, iron or laminated steel. In the illustrated embodiment, each tooth **506a** extends from the ring core **504** in radial (e.g., horizontal) and longitudinal (e.g., vertical) directions. Thus, each tooth **506a** comprises an outer vertical portion **510** extending radially away from the longitudinal axis **401** (FIG. 3), an inner vertical portion **512** extending radially toward the longitudinal axis **401**, a top horizontal portion **514** extending in one vertical longitudinal direction, and a bottom horizontal portion **516** extending in the opposing vertical or longitudinal direction. The ring core **504** is coupled to and supports the individual tooth **506a**.

[0046] In certain embodiments, an exterior fin **520** couples to the exterior portion of the outer vertical member **510** and extends outward from the vertical portion **510** in both circumferential (or tangential) directions with respect to the longitudinal axis **401**. Similarly, an interior fin **522** couples to an interior portion of the inner vertical portion **512** and extends outward from the vertical member **512** in both circumferential (or tangential) directions. As used in this

disclosure, the term “circumferential direction” means the tangential or rotational direction about an axis, such as axis **401**.

[0047] An alternative embodiment of an individual tooth **506'a** and a small portion of the ring core **504** are illustrated in FIG. 4C. The tooth **506'a** is similar to the tooth **506a** described above in reference to FIG. 4B except that the tooth **506'a** also has horizontal fins extending from the top horizontal portion **514** and the lower horizontal portion **516**. Specifically, a top horizontal fin **518** extends in both horizontal circumferential directions from an edge of the top horizontal portion **514**. Similarly, a bottom horizontal fin **519** extends in both horizontal circumferential directions from an edge of the bottom horizontal portion **516**. From a structural perspective the thickness of the fins **518** and **519** maybe thicker closer to the joint with the respective horizontal members **514** and **516** and tapers as the fins extend away from the joints.

[0048] Adjacent teeth **506** or **506'** supported by the core ring **504** form radial slots **524** within the coil assembly support structure **502**, as illustrated in FIG. 4A. In contrast, FIG. 4D (which omits a portion of the teeth **506**) illustrates individual coils or coil windings **526** positioned radially about the ring core **504** and within the slots **524** formed by the teeth **506** or **506'**. FIG. 4E illustrates a complete coil assembly **500** showing all of the teeth **506** and coil windings **526** positioned within the slots **524**.

[0049] Each individual coil **526** in the coil assembly **500** may be made from a conductive material, such as copper (or a similar alloy) wire and may be constructed using conventional winding techniques known in the art. In certain embodiments, concentrated windings may be used. In certain embodiments, the individual coils **526** may be essentially cylindrical or rectangular in shape being wound around the ring core **504** having a center opening sized to allow the individual coil **526** to be secured to the ring core.

[0050] By positioning the individual coils **526** within the slots **524** defined by the teeth **506** or **506'**, the coils are surrounded by a more substantial heat sink capabilities of the teeth which, in certain embodiments, can be can incorporate cooling passages directly into the material forming the teeth. This allows much higher current densities than conventional motor geometries. Additionally, positioning the plurality of coils **526** within the slots **524** and between teeth **506** reduces the air gap between the coils. By reducing the air gap, the coil assembly **500** can contribute to the overall torque produced by the motor or generator. In certain embodiments, the horizontal fins **518** and **519**, the circumferential fins **520** and **522** of the teeth **506a** or **506'a** of the coil assembly reduce the air gap between the structure of the coil to allow flux forces to flow from one fin to an adjacent fin when the coils are energized and the coil assembly **500** begins to move relative to the magnetic tunnel. Thus, all portions of the coil support assembly **502** contribute to the overall torque developed by the system.

[0051] The number of individual coils **526** can be any number that will physically fit within the desired volume and of a conductor length and size that produces the desired electrical or mechanical output as known in the art. In yet other embodiments, the coils **526** may be essentially one continuous coil, similar to a Gramme Ring as is known in the art.

[0052] FIG. 5A is a perspective view of a toroidal magnetic cylinder **430** forming a ring-like magnetic tunnel

positioned about the longitudinal axis **401**. As described previously, with respect to the longitudinal axis **401**, the toroidal magnetic cylinder **430** comprises a top axial ring of side wall magnets **402**. Similarly there is a second or bottom axial ring of side wall magnets **404**. An outer cylindrical wall or longitudinal ring of magnets **406** is positioned longitudinally between the first axial ring **402** and the second axial ring of magnets **404**. Depending on the embodiment, the outer longitudinal ring of magnets **406** may comprise an axial slot **410** to accommodate a support structure, a cooling mechanism, and/or wires and conductors. An inner cylindrical wall or longitudinal ring of magnets **408** is also longitudinally positioned between the first axial ring **402** and the second axial ring of magnets **408** and axially positioned within the outer longitudinal ring of magnets **406**.

[0053] In other embodiments, the inner longitudinal ring of magnets **408** may include an axial slot (similar to slot **410**, but not shown). In yet further embodiments, the first axial ring **402** or the second axial ring of magnets **404** may include a side circular slot (not shown). Such slots are designed to accommodate a support structure, a cooling mechanism and/or wires or conductors. One advantage of a slot defined within the inner longitudinal ring of magnets **408** (as opposed to the outer longitudinal ring of magnets **406**) is that the inner longitudinal ring of magnets **408** produces less torque than the outer ring of magnets **406**. Thus, by using the full width of the outer longitudinal ring of magnets **408**, greater torque can be produced.

[0054] In the embodiment illustrated in FIG. 5A, the toroidal magnetic cylinder **430** comprises eight toroidal magnetic cylinder segments (or magnetic tunnel segments). In other embodiments, there may be two, four, six, ten, twelve segments or more. The number of segments will depend on the particular design and performance characteristics for particular application.

[0055] FIG. 5B is a perspective view of a single toroidal magnetic cylinder segment **450** (or a magnetic tunnel segment) which defines a magnetic tunnel **458** or portion of a circular path. As illustrated, the toroidal magnetic cylinder segment **450** has an outer magnetic wall **452** (which is a portion of the outer cylinder wall **406**) and an inner magnetic wall **454** (which is a portion of the inner magnetic cylinder wall **408**). In addition to the partial cylindrical magnetic walls **452** and **454**, there are also be magnetic axial or lateral walls **460** and **462** which in this illustrated embodiment may be made of a plurality of wedge shape members or magnets. Axial wall **460** may be a portion of the first side or ring wall **402** and axial wall **462** may be a portion of the second side or ring wall **404**.

[0056] In the illustrated embodiment, there may be slots between the walls, such as slot **456** between the wall **454** and the wall **460**. As discussed above, in certain embodiments, there may also be slots within the walls, such as slot **410** which is defined within the wall **452**. The individual magnets in the magnetic walls **452**, **454**, **460**, and **462** all have their magnetic poles orientated towards or away from an interior of the tunnel **458** of the toroidal magnetic cylinder segment **450** to form a “closed” magnetic tunnel segment. In other words, the magnetic poles of the magnets forming the outer wall **452** and the inner wall **454** have their magnetic poles orientated to radially point towards the longitudinal axis **401** (FIG. 5A). In contrast, the magnetic poles of the

magnets forming the first axial wall **460** and the second axial wall **462** have their magnetic poles orientated parallel with the longitudinal axis **401**.

[0057] The term “closed magnetic tunnel” as used in this disclosure refers to using an arrangement of the magnets forming the cylinder segment **450** that “forces” or “bends” the flux forces from one side of the tunnel to the other (or in a circumferential direction) without letting most of the magnetic flux forces escape through a slot or other opening. Thus, the slot widths are limited to keep flux forces from exiting through the slots. In other embodiments, additional magnets may be inserted into the slots to keep the flux forces channeled to a predetermined or a circumferential direction.

[0058] FIG. 5C is an isometric view of the toroidal cylinder segment **450** having a portion of the coil assembly **500** positioned within the interior of the segment. In this embodiment, the magnets forming the top axial wall **460** and the outer longitudinal wall **452** have their south magnetic poles facing towards the interior of the tunnel **458**. (For a matter of drawing interpretation convenience, an “S” is placed on the side of the axial wall **460** and longitudinal **452** to indicate that their south poles are facing inward.) In contrast, the magnets forming the inner longitudinal wall **454** and the bottom axial wall **462** have their north magnetic poles facing towards the interior of the tunnel **458** (Thus, an “N” is placed on the side of the axial wall **462** and longitudinal **454** to indicate that their north poles are facing inward.). When the coil assembly is positioned within the toroidal cylinder segment **450** as illustrated, the flux lines tend to flow from the north poles of the magnetic walls directly across the coil assembly to the south poles on the opposing side of the magnetic walls.

[0059] To illustrate, the top axial wall **460** is labeled with an “S” on its side face and an arrow **480** pointing towards the center of the toroidal segment **450** to represent the direction of the flux forces generated from the south poles of the magnet(s) forming the top axial wall **460**. Similarly, the outer longitudinal wall **452** is labeled with an “S” on its side face and an arrow **482** pointing towards the center of the toroidal segment **450** to represent the direction of the flux forces generated from the south poles of the magnet(s) forming the outer longitudinal wall **452**. In contrast, the bottom axial wall **462** is labeled with an “N” on its side face and an arrow **484** pointing towards the center of the toroidal segment **450** to represent the direction of the flux forces generated from the north poles of the magnet(s) forming the bottom axial wall **462**. The inner longitudinal wall **454** is labeled with an “N” on its side face and an arrow **486** pointing towards the center of the toroidal segment **450** to represent the direction of the flux forces generated from the north poles of the magnet(s) forming the inner longitudinal wall **454**.

[0060] FIG. 5D is an isometric view of the toroidal cylinder segment **450** but with a coil **526** positioned around the portion of the coil assembly **500**. When the motor/generator **100** is in motor mode, current from an external source (not shown) is applied to the coils, such as coil **526**. In the illustrated embodiment, the current flows in a counterclockwise manner as illustrated by the arrow **488** which illustrates the current in the coil **526** flowing in an upwards direction. The current then flows in a right to left manner as illustrated by the arrow **490** when the current is in the upper portion of the coil **526**. Similarly, the current flows in a downwardly

direction as illustrated by arrow 492 when the current is in a vertical leg of the coil 526. Finally, the current flows in a left to right manner when the current is in the lower portion of the coil 526 as illustrated by the arrow 494.

[0061] FIG. 5E is an isometric view of the cylinder segment 450 with the coil 526 positioned around the portion of the ring core 504 of the coil assembly 500 and the current flowing through the coil as explained above in reference to FIG. 5D. When the magnets forming the outer cylindrical wall 452 generate a flux force in the direction of the arrow 482 and the current in the coil 526 flows in an upward direction relative to the illustration, a magnetic force will be generated in the direction of the arrow 602 according to the right hand rule of magnetic force. Simultaneously, the magnets forming the lateral or top wall 460 generate a flux in the direction of the arrow 480 and the current in the coil 526 flows in a right-to-left direction relative to the illustration, a magnetic force will be generated in the direction of the arrow 604. Additionally, the magnets forming the longitudinal or inner cylindrical wall 454 generate a flux force in the direction of the arrow 486 and the current in the coil 526 flows in a downward direction relative to the illustration, a magnetic force will be generated in the direction of the arrow 606. Similarly, the magnets forming the lateral or bottom wall 462 generate a flux force in the direction of the arrow 484 and the current in the coil 526 flows in a left-to-right direction relative to the illustration, a magnetic force will be generated in the direction of the arrow 608.

[0062] Thus, the entire coil is used to generate the magnetic forces which will move the coil 526 relative to the cylinder segment 450.

[0063] In conventional configurations, the opposing poles of the magnets are usually aligned longitudinally. Thus, the magnetic flux lines will “hug” or closely follow the surface of the magnets. So, when using conventional power generating/utilization equipment, the clearances must usually be extremely tight in order to be able to act on these lines of force. By aligning like magnetic poles radially or perpendicular to the coil assembly 500 the magnetic flux forces flow from the surface of the magnets across the coil assembly. This configuration allows for greater tolerances between coils and magnetic surfaces.

[0064] One of the advantages of this configuration over conventional motors is that the end turns (in this case the radial section of the coils) are part of the “active section” of the invention. In conventional motors, the axial length of the copper conductor is the section that produces power. In conventional motors, the end turns are a penalty, adding weight and losses, but not producing power because the end region fields are not effectively linking the end windings. However, as can be seen, the entire coil winding is effectively producing torque due to the side wall or axial magnets which are axially magnetized. Therefore, essentially the entire conductor of the coils is active producing a greater force.

[0065] The windings of each coil 526 are generally configured such that they remain transverse or perpendicular to the direction of the relative movement of the magnets comprising the coil assembly 500 and parallel with the longitudinal axis 401. In other words, the coil windings are positioned such that their sides are parallel with the longitudinal axis and their ends are radially perpendicular to the longitudinal axis. The windings are also transverse with respect to the magnetic flux produced by the individual

magnets of the rotor at their interior face as described above. Consequently, the entire coil winding or windings (including end turns) may be used to generate movement (in motor mode) or voltage (in generator mode).

[0066] FIG. 6A illustrates four partial toroidal magnetic cylinders 450a, 450b, 450c and 450d arranged circumferentially around a common center or longitudinal axis 401. This arrangement leaves four open spaces 610a, 610b, 610c, and 610d between the respective cylinder segments.

[0067] In this embodiment, inserting or positioning four additional four toroidal magnetic cylinder segments 420a-420d into the spaces 610a-610d results in a complete toroidal magnetic cylinder 430 as illustrated in FIG. 6C. Thus, FIG. 6C illustrates the complete toroidal magnetic cylinder 430 formed from combining the four toroidal magnetic cylinder segments 450a-450d with the toroidal magnetic cylinder segments 420a-420d in an alternating arrangement around the longitudinal axis 401.

[0068] The magnets creating the toroidal magnetic cylinder segments 450a-450d are orientated in a specific geometric arrangement as discussed above in reference to FIG. 5E. In other words, the magnets forming the top magnetic walls 460 and outer cylinder wall 452 have their south poles facing inward towards the interior of the cylinder segment. The magnets forming the magnetic bottom wall 462 and the interior cylindrical wall 460 have their north poles facing inward towards the interior of the magnetic cylinder segment. In contrast, the adjacent toroidal magnetic cylinder segments such as the magnetic cylinder segment 420a have their magnetic poles orientated in the opposite direction.

[0069] As illustrated in FIG. 6B, the magnets forming the magnetic walls 460a and 452a have their north poles facing inward towards the interior of the cylinder segment. (As before, “N” is placed on the side of the axial wall 460a and longitudinal 452a to indicate that their north poles are facing inward.) The magnets forming the magnetic walls 462a and 454a have their south poles facing inward towards the interior of the magnetic cylinder segment. (Similarly, an “S” is placed on the side of the axial wall 462a and longitudinal 454a to indicate that their south poles are facing inward.) Thus, the toroidal magnetic cylinder segments 420a-420d have an opposite magnetic orientation relative to the toroidal magnetic cylinder segments 450a-450d.

[0070] When the cylinder segments 420a-420d are energized, the current running through the coil windings positioned within the toroidal magnetic cylinder segments 420a-420d also runs in an opposite direction than the current running through the coil windings positioned within the magnetic cylinder segments 450a-450d so that the direction of the generated magnetic force or torque is the same throughout the entire magnetic cylinder 430.

[0071] FIG. 6C illustrates the entire toroidal magnetic cylinder 430 where the toroidal magnetic cylinder segments 450a-450d are alternated between the toroidal magnetic cylinder segments 420a-420d. For sake of illustration, some of magnetic walls are labeled with an “S” representing a facing “South” pole of a magnet wall—as opposed to the magnetic walls labeled with an “N” representing a facing “North” pole of the magnetic wall. Thus, the letters “N” and “S” are superimposed on the exterior faces of the magnetic walls to indicate the direction of magnetic pole polarity of the magnets forming the respective wall. As discussed above, although an eight segment toroidal magnetic cylinder 430 is illustrated in FIG. 6C, in other embodiments, two,

three, four, six, ten, etc. partial toroidal magnetic cylinders may be used. The number of partial toroidal magnetic cylinders selected for any given application may be based on engineering design parameters and the particular performance characteristics for an individual application. The scope of this invention specifically includes and contemplates multiple partial toroidal magnetic cylinders having an opposite polarity to the adjacent partial toroidal magnetic cylinders. For simplicity and illustrative purposes, an eight segment toroidal magnetic cylinder is described herein. However, this design choice is in no way meant to limit the choice or number of tunnels for any multi-tunnel toroidal magnetic cylinder.

[0072] In certain embodiments, the partial toroidal magnetic cylinders **450a-450d** and **420a-420d** may be sized to allow radial gaps **422** to form when the partial toroidal magnetic cylinders are assembled into the complete cylinder **430** as illustrated in FIG. **6C**.

[0073] FIG. **7A** illustrates an eight tunnel toroidal magnetic cylinder **430** of FIG. **6C** with a portion of the back iron circuit enclosing the magnetic cylinder **430**. FIG. **7B** illustrates the eight tunnel toroidal magnetic cylinder **430** fully enclosed by the back iron circuit. As discussed above, in other embodiments, there are slots or gaps between the back iron components to allow for the passage of control wires and conductors (not shown).

[0074] As discussed above, the hub **300** comprises an inner hub **302** for coupling to a mechanical load transferring device, such as a rod (not shown). A plurality of radial arms or spokes **304** structurally connect the inner hub **302** to an outer hub **306**. In certain embodiments, the outer hub **306** also comprises a portion of the back iron circuit and thus may be formed from back iron material.

[0075] In certain embodiments, the back iron circuit may be used as part of the magnetic flux path. The back iron material channels the magnetic flux produced by the magnetic toroidal cylinder **430** through the back iron material (as opposed to air) to reduce the reluctance of the magnetic circuit. In certain embodiments, therefore, the amount or thickness of the magnets forming the toroidal magnetic cylinder (if permanent magnets are used) may be reduced when using the appropriately designed back iron circuit.

[0076] In certain embodiments, the back iron circuit may include a "top" side or axial wall **208** and a "bottom" side or axial wall **210** of back iron material. The circuit may also include the circumferential rings **202** and **204** which may or may not couple to the axial walls **208** and **210**, respectively. Thus, the entire back iron circuit includes the outer cylinder wall **306** of the hub **300**, the circumferential rings **202** and **204**, and the axial walls **208** and **210** as illustrated in FIGS. **7A** and **7B**. The back iron circuit combined with the toroidal magnetic cylinder **430** may form a rotor (or a stator depending on the motor configuration).

[0077] In order maintain the generated torque and/or power the individual coils **526** in the coil assembly may be selectively energized or activated by way of a switching or controller (not shown). The individual coils **526** in the coil assembly **500** may be electrically, physically, and communicatively coupled to switching or controller which selectively and operatively provides electrical current to the individual coils in a conventional manner.

[0078] For instance, the controller may cause current to flow within the individual coil as indicated in FIGS. **5D** and **5E** when the individual coil is within a magnetic tunnel

segment with a NNSS magnetic pole configuration as illustrated in FIGS. **5D** and **5E**. On the other hand when the same individual coil moves into an adjacent magnetic tunnel segment with a SSNN magnetic pole configuration, the controller causes the current within the individual coil to flow in a direction opposite to that shown in FIGS. **5D** and **5E** so that the generated magnetic force is in the same direction as illustrated by the arrows **602**, **604**, **606**, and **608** of FIG. **5E**.

[0079] Turning back to FIGS. **4C** and **5E**, the individual coils **526** may use toroidal winding without end windings and in some embodiments be connected to each other in series. In other embodiments, a three phase winding may be used where adjacent coils are connected together to form a branch of each phase. For instance, two adjacent coils may be phase A coils, the next two adjacent coils may be phase B coils, and the next two adjacent coils may be phase C coils. This three phase configuration would then repeat for all individual coils **526** within the coil assembly. In one embodiment, there are eight (8) pairs of adjacent phase A coils for a total of 16 phase A coils. Similarly, there are eight (8) pairs of adjacent phase B coils for a total of 16 phase B coils, and there are eight (8) pairs of adjacent phase C coils for a total of 16 phase C coils. Thus, in such an embodiment, there are 48 individual coils.

[0080] When the coils are energized, the three phase winding can produce a rotating magnetic field in the air gap around the coil assembly. The rotating magnetic field interacts with the magnetic field generated by the toroidal magnetic tunnel producing torque and relative movement between the coil assembly and the toroidal magnetic tunnel.

[0081] In such embodiments, the individual coils **526** may be connected to a brushless motor controller (not shown) to be activated in a manner known in the art. For each phase, the controller can apply forward current, reverse current, or no current. In operation, the controller applies current to the phases in a sequence that continuously imparts torque to turn the magnetic toroidal tunnel in a desired direction (relative to the coil assembly) in motor mode. In certain embodiments, the controller can decode the rotor position from signals from position sensors or can infer the rotor position based on current drawn by each phase.

[0082] In yet, other embodiments, a brushed motor/generator may be used. In such embodiments, one or more commutators (not shown) may be used and positioned, for instance, within the hub **300**. In certain embodiments, the number of brushes used may equal the number of toroidal magnetic segments used in the design of the particular motor/generator. For instance, if four toroidal magnetic segments are used, then four brushes may be used. The individual coils **526** in the coil assembly may be connected in series having toroidal wound windings. In a brushed design in motor mode, a simplified switching circuit **800** such as illustrated in FIG. **8** is all that is necessary to switch the current direction as the coils enter and exit the respective toroidal magnetic segment. As illustrated in FIG. **8**, a power source **802** is electrically coupled to a brushed motor **804** via four pairs of transistors **806a-806d** and diodes **808a-808d** as is known in the art to switch the current of the four toroidal magnetic segments.

[0083] As discussed above, surrounding the coils with magnets as described above creates more flux density and the forces are now all in the direction of motion which may create more torque, minimize vibration, and minimize

noise—as compared to conventional motors where forces may try to pull the coil downwards or push it upwards (depending on the polarity), not in the direction of motion. [0084] Continuous torque and continuous power, therefore, are greatly increased. Furthermore, continuous torque density, continuous power density by volume, and continuous power density by weight are also increased when compared to conventional electric motors.

1. A rotary motor/generator comprising:

a toroidal magnetic cylinder comprising a plurality of magnetic tunnel segments radially arranged about a longitudinal axis to form a circular path, wherein the plurality of magnetic tunnel segments comprises at least:

a first magnetic tunnel segment comprising:

a first inner magnetic wall having a magnetic pole orientation that points generally towards an interior of the magnetic tunnel segment;

a first outer magnetic wall having a magnetic pole orientation that points generally towards the interior of the magnetic tunnel segment, the first outer magnetic wall positioned farther from the longitudinal axis than the first inner magnetic wall;

a first ring magnetic wall having a magnetic pole orientation that points generally towards the interior of the magnetic tunnel segment and positioned to generally span a radial distance between the first inner magnetic wall and the first outer magnetic wall;

a first opposing ring magnetic wall having a magnetic pole orientation that points generally towards the interior of the magnetic tunnel segment and positioned to generally span the radial distance between the first inner magnetic wall and the first outer magnetic wall;

wherein like magnetic poles of the first inner magnetic wall and the first ring magnetic wall are orientated in an opposite direction from the like poles of first outer magnetic wall and the first opposing ring magnetic wall;

a second magnetic tunnel segment positioned circumferentially adjacent to the first magnetic tunnel segment, the second magnetic tunnel segment comprising:

a second inner magnetic wall having a magnetic pole orientation that points generally towards an interior of the magnetic tunnel segment;

a second outer magnetic wall having a magnetic pole orientation that points generally towards the interior of the magnetic tunnel segment, the second outer magnetic wall positioned farther from the longitudinal axis than the second inner magnetic wall;

a second ring magnetic wall having a magnetic pole orientation that points generally towards the interior of the magnetic tunnel segment and positioned to generally span a radial distance between the second inner magnetic wall and the second outer magnetic wall;

a second opposing ring magnetic wall having a magnetic pole orientation that points generally towards the interior of the magnetic tunnel segment and positioned to generally span the radial

distance between the second inner magnetic wall and the second outer magnetic wall;

wherein like magnetic poles of the second inner magnetic wall and the second ring magnetic wall are orientated in an opposite direction from the like poles of second outer magnetic wall and the second opposing ring magnetic wall;

wherein the magnetic poles of the magnetic walls comprising the second magnetic cylinder segment are orientated in a direction opposite to the magnetic poles of the magnetic walls comprising the first magnetic tunnel segment;

a coil assembly positioned within the circular path and adapted to move relative to the toroidal magnetic cylinder, the coil assembly comprising:

a ring-like core;

a plurality of teeth radially positioned about the ring-like core and extending from the ring-like core to form a plurality of slots;

a plurality of coil windings wherein each coil winding in the plurality of winding is positioned within a slot within the plurality of slots.

2. The rotary generator/motor of claim 1, wherein material forming the plurality of magnetic tunnel segments is selected from the group consisting of iron, magnetic steel, or laminated steel.

3. The rotary generator/motor of claim 1, wherein the first inner magnetic wall, the first outer magnetic wall, the first ring magnetic wall and the first opposing ring magnetic wall may be formed from electromagnets.

4. The rotary generator/motor of claim 1, wherein the second inner magnetic wall, the second outer magnetic wall, the second ring magnetic wall and the second opposing ring magnetic wall may be formed from electromagnets.

5. The rotary generator/motor of claim 1, further comprising a back iron circuit surrounding the plurality of magnetic tunnel segments.

6. The rotary generator/motor of claim 1, further comprising a shaft concentrically positioned about the longitudinal axis.

7. The rotary generator/motor of claim 1, wherein substantially all of the wire windings in an individual coil is substantially positioned within a magnetic field created by the first magnetic tunnel segment when the individual coil is positioned within the magnetic tunnel segment.

8. The rotary generator/motor of claim 1, wherein a magnetic field generated by the inner magnetic wall and a current flowing within wire windings in an adjacent coil creates a tangential magnetic force in a direction of relative movement between the magnetic cylinder and the coil assembly.

9. The rotary generator/motor of claim 1, wherein the magnetic field generated by the outer magnetic wall and a current flowing within wire windings in an adjacent coil creates a tangential magnetic force in a direction of relative movement between the magnetic cylinder and the coil assembly.

10. The rotary generator/motor of claim 1, wherein the magnetic field generated by the first ring magnetic wall and a current flowing within wire windings in an adjacent coil creates a tangential magnetic force in a direction of relative movement between the magnetic cylinder and the coil assembly.

11. The rotary generator/motor of claim **1**, wherein the magnetic field generated by the opposing ring magnetic wall and a current flowing within wire windings in an adjacent coil creates a tangential magnetic force in a direction of relative movement between the magnetic cylinder and the coil assembly.

12. The rotary generator/motor of claim **1**, wherein a tangential magnetic force is generated on all sides of individual coils in the plurality of coils when the individual coil is positioned within the first magnetic tunnel segment or second magnetic tunnel segment.

13. The rotary generator/motor of claim **1**, wherein the plurality of tunnel segments includes a third magnetic tunnel segment and a fourth magnetic tunnel segment wherein the magnetic poles of the magnetic walls comprising the third magnetic cylinder segment are orientated in a direction opposite to the magnetic poles of the magnetic walls comprising the fourth magnetic tunnel segment.

14. The rotary generator/motor of claim **13**, wherein the plurality of tunnel segments includes a fifth magnetic tunnel segment and a sixth magnetic tunnel segment wherein the magnetic poles of the magnetic walls comprising the fifth magnetic cylinder segment are orientated in a direction opposite to the magnetic poles of the magnetic walls comprising the sixth magnetic tunnel segment.

15. The rotary generator/motor of claim **14**, wherein the plurality of tunnel segments includes a seventh magnetic tunnel segment and an eighth magnetic tunnel segment wherein the magnetic poles of the magnetic walls comprising the seventh magnetic cylinder segment are orientated in a direction opposite to the magnetic poles of the magnetic walls comprising the eighth magnetic tunnel segment.

16. A method of producing an electromotive force, the method comprising:

providing a first magnetic flux force in a first direction, causing a first current to flow in a second direction wherein the first current is adjacent to the first magnetic flux force to produce a first magnetic force in a direction of motion that is generally perpendicular to the first direction and the second direction,

providing a second magnetic flux force in a third direction,

causing a second current to flow in the first direction wherein the second current is adjacent to the second magnetic flux force to produce a second magnetic force in the direction of motion that is generally perpendicular to the first direction and the third direction,

providing a third magnetic flux force in a fourth direction, causing a third current to flow in the third direction wherein the third current is adjacent to the third magnetic flux force to produce a third magnetic force in the direction of motion that is generally perpendicular to the third direction and the fourth direction,

providing a fourth magnetic flux force in the second direction,

causing a fourth current to flow in the fourth direction wherein the fourth current is adjacent to the fourth magnetic flux force to produce a fourth magnetic force in the direction of motion that is generally perpendicular to the second and the fourth direction.

17. The method of claim **16**, wherein the motion is a coil assembly moving with respect to a magnetic tunnel assembly.

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