



- (51) **International Patent Classification:**
E21B 17/02 (2006.01) *E21B 41/00* (2006.01)
E21B 17/03 (2006.01)
- (21) **International Application Number:**
PCT/US2015/064041
- (22) **International Filing Date:**
4 December 2015 (04.12.2015)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (71) **Applicant:** HALLIBURTON ENERGY SERVICES, INC. [US/US]; 3000 N. Sam Houston Parkway E., Houston, Texas 77032 (US).
- (72) **Inventors:** AGNIHOTRI, Mukul M.; 26325 Northgate Crossing Blvd., Apt. 827, Spring, Texas 77373 (US). RA-JAGOPALAN, Satish; 17710 Jacobs Ladder Court, Tomball, Texas 77377 (US).
- (74) **Agent:** HEYMAN, Paula D.; Baker Botts L.L.P., 98 San Jacinto Blvd., Suite 1500, Austin, Texas 78701 (US).
- (81) **Designated States** (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) **Designated States** (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU,

[Continued on next page]

(54) **Title:** MAGNETIC COUPLING FOR DOWNHOLE APPLICATIONS

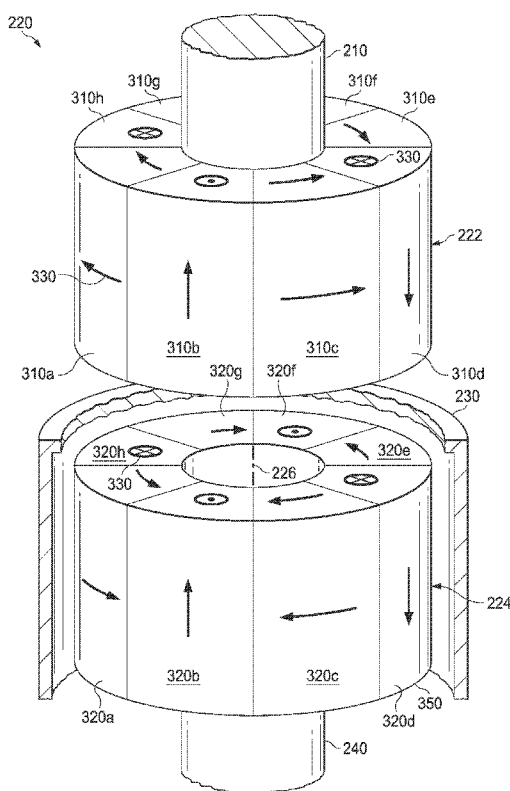


FIG. 3

(57) **Abstract:** The present disclosure relates to a magnetic coupling of a downhole tool that includes a first annular array of magnetic sections, a second annular array of magnetic sections coupled to the first annular array by a magnetic field that transfers rotational motion from the first annular array to the second annular array, and a barrier disposed between the first annular array and the second annular array, the barrier including an erosion-resistant layer. The present disclosure also relates to a method of bootstrapping a magnetic coupling of a downhole tool. The method includes supplying electrical current from a battery to an electromagnetic coil in the magnetic coupling, transferring rotational motion from the magnetic coupling to an alternating current (AC) source and supplying electrical current from the AC source to the electromagnetic coil.



LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,
SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ,
GW, KM, ML, MR, NE, SN, TD, TG).

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

Declarations under Rule 4.17:

— *as to the identity of the inventor (Rule 4.17(i))*

MAGNETIC COUPLING FOR DOWNHOLE APPLICATIONS

TECHNICAL FIELD

The present disclosure relates generally to drilling tools and, more particularly,
5 to magnetic coupling for downhole applications.

BACKGROUND

Natural resources, such as oil and gas, often reside in various forms within a subterranean geological formation that may be located onshore or offshore. These
10 natural resources can be recovered by drilling a wellbore that penetrates the formation.

A variety of fluids are used in both drilling and completing the wellbore. For example, during the drilling of the wellbore, a portion of the drill string may be immersed in a drilling fluid used to cool the drill bit, lubricate the rotating drill string
15 to prevent it from sticking to the walls of the wellbore, prevent blowouts by serving as a hydrostatic head to the entrance into the wellbore of formation fluids, and remove drill cuttings from the wellbore, among other uses. Other portions of the drill string may be immersed in oil, in air, or in other suitable media.

The drill string used in such drilling operations may include a variety of
20 components. Some components may capture energy from the flow of drilling fluid through the drill string. For example, the drill string may include a turbine that produces rotational motion. Other components may make use of such rotational motion. For example the drill string may include a pump driven by a swash plate, an actuator such as a ball screw, or a generator that produces electrical current used to
25 operate other equipment within the drill string. Such other equipment may include sensors, telemetry components, measurement while drilling (MWD) tools, logging-while-drilling (LWD) tools, or other components.

BRIEF DESCRIPTION OF THE DRAWINGS

30 For a more complete understanding of the present invention and its features and advantages, reference is now made to the following description, taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is an elevation view of an exemplary drilling system;

FIGURE 2 is a section view of a portion of an exemplary drill string containing a magnetic coupling;

FIGURE 3 is a perspective view of an exemplary axial magnetic coupling;

5 FIGURE 4 is an elevation section view of an exemplary radial magnetic coupling;

FIGURE 5 is a plan section view of an exemplary radial magnetic coupling;

FIGURE 6 is a circuit diagram of an exemplary bootstrap circuit for energizing electromagnetic coils in a magnetic coupling; and

10 FIGURE 7 is a flow chart of an exemplary method for bootstrapping a magnetic coupling.

DETAILED DESCRIPTION

The present disclosure describes magnetic couplings used to transfer
15 mechanical power from a prime mover such as a turbine or other source of rotational motion to a load that includes equipment that can make use of that motion, such as a generator. The turbine is driven by the flow of drilling fluid. A barrier is interposed between the drive side of the magnetic coupling and the follower side of the magnetic coupling to prevent the drilling fluid, which is electrically conductive, from
20 interfering with the operation of the load. The magnetic coupling includes a pair of Halbach arrays, each of which includes a series of magnetic sections arranged to enhance the magnetic field in the space between the two arrays while diminishing or eliminating the field on the opposite side of each array. As a result, the amount of torque that is transmitted by the magnetic coupling is greater than the torque
25 transmitted by a coupling using conventional magnetic arrays. The magnetic coupling may use electromagnetic coils in the place of some permanent magnets, allowing the strength of the magnetic coupling to be tuned to meet varying operational requirements. Additionally, the power used to energize the electromagnetic coils in the magnetic coupling may be supplied by the load driven by the coupling, once the
30 coupling begins to turn.

Embodiments of the present disclosure and its advantages are best understood by referring to FIGURES 1 through 7, where like numbers are used to indicate like and corresponding parts.

FIGURE 1 is an elevation view of an exemplary drilling system. Drilling system 100 includes well surface or well site 106. Various types of drilling equipment such as a rotary table, drilling fluid pumps and drilling fluid tanks (not expressly shown) are located at well surface or well site 106. For example, well site 106 may include drilling rig 102 that has various characteristics and features associated with a “land drilling rig.” However, drilling systems incorporating teachings of the present disclosure may be satisfactorily used with drilling equipment located on offshore platforms, drill ships, semi-submersibles and drilling barges (not expressly shown). Well site 106 and drilling rig 102 are located above subterranean region 107.

Drilling system 100 also includes drill string 103 associated with drill bit 101 that may be used to form a wide variety of wellbores or bore holes such as wellbore 114. A portion of wellbore 114 that is closer to well surface 106 is referred to as uphole, and a portion of wellbore 114 that is further from well surface 106 is referred to as downhole. Wellbore 114 may be defined in part by casing string 110 that extends from well surface 106 to a selected downhole location. Portions of wellbore 114 that do not include casing string 110 are described as open hole.

Various drilling fluids are used during the drilling of wellbores. The drilling fluid serves many purposes, including cooling the drill bit, lubricating the rotating drill string to prevent it from sticking to the walls of the wellbore, preventing blowouts by serving as a hydrostatic head to the entrance into the wellbore of formation fluids, and removing drill cuttings from the wellbore. Typically the drilling fluid is circulated downward through drill string 103 and drill bit 101 and then moves upward through the wellbore towards the surface through annulus 108. In open hole embodiments, annulus 108 is defined in part by outside diameter 112 of drill string 103 and inside diameter 118 of wellbore 114. In embodiments using casing string 110, annulus 108 is defined by outside diameter 112 of drill string 103 and inside diameter 111 of casing string 110. Other circulation pathways are possible, however. Drilling fluid typically includes a base fluid, for example water or salt water, mixed

with other materials or additives. As a result, drilling fluid is often electrically conductive.

Drill string 103 may include a wide variety of components configured to form wellbore 114. For example, components 122a, 122b, and 122c of drill string 103 may include, but are not limited to, drill bits (e.g., drill bit 101), coring bits, drill collars, rotary steering tools, directional drilling tools, downhole drilling motors, turbines, magnetic couplings, generators, reamers, hole enlargers, stabilizers, sensors, logging-while-drilling tools, or telemetry subs. The number and types of components 122 included in drill string 103 depend on anticipated downhole drilling conditions and the type of wellbore that will be formed by drill string 103 and rotary drill bit 101. Drill string 103 may also include one or more electrically powered components, such as sensors, logging-while-drilling (LWD) tools, controllers, telemetry subs, communication components, well logging instruments, and downhole tools associated with directional drilling of a wellbore.

Drill string 103 may also include components to provide the electrical current required to operate components of the drill string, such as component 122c discussed above. For example, component 122a may include a turbine or other type of motor immersed in the drilling fluid within drill string 103. The turbine is configured to transform the flow of the drilling fluid through drill string 103 into rotational motion of a drive shaft. Component 122b may include a generator configured to transform the rotational motion of the drive shaft into electrical current for use by other components, such as component 122c. Although this disclosure describes specific components 122a, 122b, and 122c, any suitable components of a drill string may be used. Furthermore, although this disclosure discusses a particular arrangement of components 122a, 122b, and 122c, components of drill string 103 may be arranged in any suitable positions within drill string 103.

Because drilling fluid is often electrically conductive, immersion of the generator in the drilling fluid may interfere with the operation of the generator. Therefore, the generator is contained within a load-enclosure portion of drill string 103 that contains oil, air, or other suitable non-conductive media, and is separated from the drilling fluid by a barrier such as a static seal that does not rotate relative to drill string 103 and is not penetrated by the drive shaft. A magnetic coupling, as

shown in further detail in FIGURES 2-6, is used to transfer rotational motion across the barrier, from the portion of the drive shaft connected to the turbine and immersed in the drilling fluid to the portion of the drive shaft connected to the generator and immersed in the non-conductive media. The load enclosure allows drilling fluid to
5 flow towards the downhole end of drill string 103. For example, the load enclosure may be narrower than the inner diameter of drill string 103, allowing drilling fluid to flow downhole between the load enclosure and the inner diameter of drill string 103.

Drill bit 101 typically includes one or more blades 126 located on exterior portions of rotary bit body 124 of drill bit 101. Blades 126 are any suitable type of
10 projections extending outwardly from rotary bit body 124. Drill bit 101 rotates with respect to bit rotational axis 104 in a direction defined by directional arrow 105. Blades 126 include one or more cutting elements 128 located on exterior portions of each blade 126. Blades 126 may also include one or more depth of cut controllers (not expressly shown) configured to control the depth of cut of cutting elements 128.
15 Blades 126 may further include one or more gage pads (not expressly shown) located on blades 126. Drill bit 101 may have many different designs, configurations, and/or dimensions according to the particular application of drill bit 101.

Drilling system 100 may include additional or different features, and the features of drilling system 100 may be arranged as shown in FIGURE 1, or in another
20 suitable configuration.

FIGURE 2 is a section view of a portion 200 of an exemplary drill string containing a magnetic coupling. Drill string 103 includes one or more segments of drill pipe 116 whose inner diameter defines throat 208. Turbine 202 is located within throat 208. Turbine 202 may be a motor or any apparatus that produces rotational
25 motion. For example, turbine 202 as illustrated in FIGURE 2 is an axial flow turbine including an impeller located in throat 208 of drill pipe 116 and configured to capture the kinetic energy of drilling fluid flow to produce rotational motion. Turbine 202 has several blades 204 distributed around the periphery and angled relative to the axis of drill pipe 116. Although turbine 202 is illustrated in FIGURE 2 as an axial flow
30 turbine, turbine 202 may include a transverse-flow turbine in which fluid flow through the turbine is substantially perpendicular to the rotational axis of the impeller.

Turbine 202 is coupled to drive shaft 210, which runs parallel to axis 226 of throat 208. Drive shaft 210 is coupled to drive array 222 of magnetic coupling 220.

Magnetic coupling 220 includes drive array 222 and follower array 224, separated by barrier 230. Each of drive array 222 and follower array 224 includes an
5 annular array of magnetic sections, which may include permanent magnets or electromagnetic coils, arranged in a Halbach array. In a Halbach array, sections of the array that produce a magnetic flux oriented normal to the surface of the array alternate with sections that produce a magnetic flux oriented transverse to the surface of the array. As a result of this arrangement of magnetic fluxes, the magnetic field between
10 drive array 222 and follower array 224 is stronger than using only array sections that produce fluxes normal to the surface. As a result, magnetic coupling 220 is capable of transferring higher levels of torque.

As illustrated in FIGURE 2, magnetic coupling 220 is an axial coupling, in which the two arrays are of substantially similar diameter. Specifically, drive array
15 222 includes an annular array of diameter 221, with the magnetic sections arranged in a circle about axis of rotation 226. Follower array 224 also includes an annular array of diameter 221, with the magnetic sections arranged in a circle about axis of rotation 226. Drive array 222 and follower array 224 are coupled by magnetic field 228, which penetrates barrier 230. The arrangement of magnetic sections and magnetic fields in
20 drive array 222 and follower array 224 is described in more detail in connection with FIGURE 3 below.

Follower array 224 is coupled to follower shaft 240. Follower shaft 240 is coupled to load 250, for example an electrical generator.

Load enclosure 252 encloses follower array 224, follower shaft 240, and load
25 250. Barrier 230, located between drive array 222 and follower array 224, separates drilling fluid in throat 208 from oil, air, or other suitable non-conductive media within load enclosure 252. Magnetic field 228 between drive array 222 and follower array 224 penetrates barrier 230 to couple the two arrays. Barrier 230 may be coupled to the interior surface of drill pipe 116 by stays 232, so that barrier 230 does not rotate with
30 drive array 222 or follower array 224. Barrier 230 may be composed of a variety of materials in one or more layers. For example, Barrier 230 may include one or more layers of ceramic, polymers or thermoplastics such as polyether ether ketone (PEEK),

composites such as fiberglass, or other suitable materials. In some embodiments, the surface of barrier 230 in contact with drilling fluid includes a layer of titanium, which is resistant to erosion from the flow of drilling fluid. The layer of titanium included in barrier 230 may be very thin to limit the strength of eddy currents that are induced in the titanium layer by the changing magnetic flux produced by the motion of drive array 222 and follower array 224 relative to barrier 230.

Although turbine 202 is illustrated in FIGURE 2 as being located uphole from magnetic coupling 220 and load 250, these components of portion 200 may be located in any suitable arrangement. For example, turbine 202 may be located downhole from magnetic coupling 220 and load 250. As another example, turbine 202 may be located outside the outer diameter of drive array 222.

In operation, drilling fluid flows through throat 208 in the direction indicated by arrow 205. As it flows, the drilling fluid contacts blades 204 of turbine 202. Because blades 204 are angled with respect to the flow of drilling fluid, the drilling fluid pushes against blades 204 and causes turbine 202 to spin, producing rotational motion. This rotational motion is transferred to drive array 222 by drive shaft 210. Because drive array 222 is magnetically coupled to follower array 224 of magnetic coupling 220 by magnetic field 228, the rotational motion of drive array 222 is transferred to follower array 224 across barrier 230. Follower array 224 is coupled to load 250 through follower shaft 240. As a result, the rotational motion produced by turbine 202 is transmitted to load 250.

Load 250, located within load enclosure 252, utilizes the rotational motion of follower shaft 240. In some embodiments, load 250 may be a generator that transforms the rotational motion of follower shaft 240 into electrical current. For example, load 250 may be a permanent magnet alternating current generator, a transverse flux generator, a radial flux generator, an axial flux generator, a direct current generator, an alternator, or any other suitable type of generator. In some embodiments, load 250 may be a pump that transforms the rotational motion of follower shaft 240 into reciprocal motion of one or more pistons through the use of a swash plate. In some embodiments, load 250 may include an actuator that transforms the rotational motion of follower shaft 240 into linear motion, for example through the use of a ball screw. Although the present disclosure discusses particular examples of

load 250, any suitable load that makes use of rotational motion of follower shaft 240 may be used.

After drilling fluid passes turbine 202, it continues through throat 208 and around barrier 230 into fluid passage 234. For example, fluid passage 234 may be an
5 annulus between barrier 230 and drill pipe 116. From fluid passage 234, drilling fluid continues downhole toward drill bit 101, as discussed in connection with FIGURE 1.

In embodiments that include electromagnetic coils, the current supplied to the electromagnetic coils may be tuned to vary the amount of magnetic flux produced by each coil. In some embodiments, the current supplied to the electromagnetic coils is
10 lower when follower array 224 and follower shaft 240 are turning than when follower array 224 and follower shaft 240 are not turning. For example, when drive shaft 210 first begins to rotate, for example when turbine 202 is started, a large torque is typically required to cause follower shaft 240 to begin rotating to drive load 250. Under such circumstances, the power supplied to the electromagnetic coils may be
15 approximately 75% to 80% of the maximum power P_{mx} that can be provided to the electromagnetic coils, allowing magnetic coupling 220 to transfer a large torque without slipping. However, in normal operation, drive shaft 210 and follower shaft 240 typically spin rapidly to drive load 250, but only a low amount of torque is required to keep follower shaft 240 spinning at the desired high speed. As a result, the
20 power supplied to the electromagnetic coils may be reduced to approximately 40-50% of P_{mx} , saving electric power. In addition, in some embodiments, reducing the power to the electromagnetic coils allows magnetic coupling 220 to disengage when the torque applied to magnetic coupling 220 is too high, protecting valuable components on the far side of magnetic coupling 220. For example, some embodiments of load
25 250 have a maximum rotational speed at which they can safely operate. For example, in embodiments in which load 250 is an electric generator, the generator may be damaged if operated at speeds higher than approximately 4000 revolutions per minute (RPM). If drive shaft 210 approaches an unsafe rotational speed, the amount of torque required to accelerate follower shaft 240 increases, exceeding the amount of torque
30 that can be transmitted by magnetic coupling 220 when supplied approximately 40-50% of P_{mx} . As a result, magnetic coupling 220 may transmit rotational motion when driven at a safe operational speed, but disengage if driven at a higher, unsafe speed.

FIGURE 3 is a perspective view of an exemplary axial magnetic coupling 220. As described above in connection with FIGURE 2, axial magnetic coupling 220 includes drive array 222 and follower array 224, which are of approximately the same diameter, separated by barrier 230. Drive array 222 includes an annular array of sections 310a through 310h, each of which includes a permanent magnet or electromagnetic coil that produces a magnetic flux in a particular direction. Similarly, follower array 224 includes an annular array of sections 320a through 320h, each of which includes a permanent magnet or electromagnetic coil that produces a magnetic flux in a particular direction. Together, drive array 222 and follower array 224 produce a magnetic field oriented substantially parallel to their common axis of rotation 226. The magnetic field penetrates barrier 230 and couples drive array 222 to follower array 224.

Arrows 330 indicate the orientation of the magnetic flux produced by each particular section 310a through 310h or 320a through 320h. As illustrated, sections 310a through 310h are arranged in a Halbach array, in which the sections alternate between sections in which the magnetic flux is oriented normal to the downhole surface of magnetic coupling 220, such as sections 310b and 310d, and sections in which the magnetic flux is oriented transverse to such downhole surface, such as sections 310a and 310c. In addition, as illustrated, the orientation of the magnetic flux in successive sections rotates in a consistent direction as one proceeds around the annular array. For example, section 310b of drive array 222 produces a magnetic flux oriented uphole and substantially parallel to axis 226 of magnetic coupling 220, while section 310d produces a magnetic flux oriented downhole and substantially parallel to axis 226 of magnetic coupling 220. In the alternating sections, for example, section 310a of drive array 222 produces a magnetic flux oriented transverse to axis 226, in a clockwise direction when viewed from the uphole surface of drive array 222, while section 310c of drive array 222 produces a magnetic flux oriented transverse to axis 226, in a counter-clockwise direction when viewed from the uphole surface of drive array 222. This arrangement of magnetized sections with rotating orientations increases the strength of the magnetic field on one side of the array while decreasing or eliminating the magnetic field on the other side of the array. In the embodiment

illustrated, the magnetic field of drive array 222 is enhanced on the downhole face of drive array 222, which faces follower array 224.

Sections 320a through 320h of follower array 224 are also arranged in a Halbach array, but in follower array 224 the direction in which the orientation of the magnetic flux in successive sections rotates is opposite to that in drive array 222. For example, in section 320b, the magnetic flux is oriented uphole and substantially parallel to axis 226 of magnetic coupling 220, as it is in the corresponding section 310b of drive array 222. By contrast, in section 320c, the magnetic flux is oriented transverse to axis 226, in a clockwise direction when viewed from the uphole surface of follower array 224, which is in the opposite direction from that of corresponding section 310c of drive array 222. As a result, the magnetic field of follower array 224 is enhanced on the uphole face of follower array 224, which faces drive array 222.

As a result of the enhancement of the magnetic fields on the facing surfaces of drive array 222 and follower array 224, the maximum amount of torque transmitted through magnetic coupling 220 is increased. For example, in embodiments in which the magnetic field is substantially eliminated on the non-facing sides of each array, the maximum amount of torque transmitted through magnetic coupling 220 may be approximately doubled.

In some embodiments, sections 310a through 310h of drive array 222 and sections 320a through 320h of follower array 224 include permanent magnets. Because the temperature within wellbore 114 can be high, the permanent magnets may include a material with a high magnetic coercivity, but whose magnetic flux density changes very little or not at all with increases in temperature. In particular, the permanent magnets may have a high temperature coefficient of residual flux (Br) and intrinsic coercivity (Hci) such as a Br and/or Hci greater than -0.05%/C and -0.25%/C respectively. These materials exhibit little change to temperature, which makes them suitable for downhole applications. For example, the permanent magnets in drive array 222 or follower array 224 may include samarium cobalt.

In some embodiments drive array 222 or follower array 224 include electromagnetic coils, which produce the desired magnetic flux when energized. For example, in the embodiment illustrated in FIGURE 3, follower array 224 includes electromagnetic coils in sections 320a through 320h. Such electromagnetic coils may

include cores that include steel or other ferrous materials to increase the magnetic flux produced by the coils.

In some embodiments, follower array 224 may include a slip ring (not shown) that includes conductive material located on a surface of follower array 224. For example, a slip ring may be located on downhole surface 350 of follower array 224. The slip ring may be in electrical contact with a brush (not shown) that provides electrical current to energize electromagnetic coils in sections 320a through 320h of follower array 224. A second slip ring and brush may be used to provide a return path for the electrical current. In such embodiments, the slip rings and brushes cannot be immersed in a conductive fluid, such as drilling fluid, because the conductive fluid would create a short circuit between the brushes and prevent current from reaching and energizing the electromagnetic coils. As a result, such embodiments include barrier 230 to prevent drilling fluid from coming into contact with the slip rings and brushes.

Although FIGURE 3 illustrates an axial magnetic coupling that include a particular number of sections 310a through 310h of drive array 222 and sections 320a through 320h of follower array 224, any suitable number of sections may be used. For example, in some embodiments, drive array 222 and follower array 224 may each include sixteen sections. Furthermore, although barrier 230 is illustrated in FIGURES 2 and 3 as enclosing follower array 224, follower shaft 240, and load 250, barrier 230 may be arranged in any suitable fashion. For example, in some embodiments, barrier 230 encloses drive array 222 and drive shaft 210.

Although FIGURES 2 and 3 illustrate magnetic coupling 220 as an axial magnetic coupling, in which drive array 222 and follower array 224 are of substantially similar diameter and magnetic field 228 between drive array 222 and follower array 224 is substantially parallel to the arrays' axis of rotation 226, any suitable arrangement of arrays 222 and 224 and field 228 may be used. For example, in some embodiments, magnetic coupling 220 is a radial magnetic coupling, in which follower array 224 is of substantially smaller diameter and is placed within the inner diameter of drive array 222. Alternatively, drive array 222 may be of substantially smaller diameter and is placed within the inner diameter of follower array 224.

FIGURES 4-5, discussed in more detail below, illustrate an exemplary radial magnetic coupling.

FIGURE 4 is an elevation section view of an exemplary radial magnetic coupling 400 that may be used in place of axial magnetic coupling 220. Radial magnetic coupling 400 includes drive array 422 and follower array 424 separated by barrier 230. Unlike in the arrays in axial magnetic coupling 220, which have a substantially similar diameter, the arrays in radial magnetic coupling 400 are of unequal size, with one located within the other. For example, drive array 422 in radial magnetic coupling 400 may have an inner diameter larger than the outer diameter of follower array 424. Furthermore, follower array 424 may be located within the inner diameter of drive array 422, with drive array 422 and follower array 424 sharing a common axis of rotation 226. Although FIGURE 4 illustrates drive array 422 having the larger diameter and follower array 424 as located within the inner diameter of drive array 422, any other suitable radial arrangement of the arrays may be used. For example, follower array 424 may have an inner diameter larger than the outer diameter of drive array 422, and drive array 422 may be located within the inner diameter of follower array 424.

As with axial magnetic coupling 220, drive array 422 includes an annular array of sections, each of which includes a permanent magnet or electromagnetic coil that produces a magnetic flux in a particular direction to form a Halbach array. Similarly, follower array 424 includes an annular array of sections, each of which includes a permanent magnet or electromagnetic coil that produces a magnetic flux in a particular direction to form a Halbach array. The arrangement of magnets or electromagnetic coils in drive array 422 and follower array 424 described in more detail in connection with FIGURE 5 below

In some embodiments, drive array 422 and follower array 224 include permanent magnets. Because the temperature within wellbore 114 can be high, the permanent magnets may include materials with a high magnetic coercivity, but whose magnetic flux density changes very little or not at all with increases in temperature. In particular, the permanent magnets may have a high temperature coefficient of residual flux (Br) and intrinsic coercivity (Hcl) such as a Br and/or Hcl greater than -0.05%/C and -0.25%/C respectively. These materials exhibit little change to temperature,

which makes them suitable for downhole applications. For example, the permanent magnets in drive array 422 or follower array 424 may include samarium cobalt.

In some embodiments drive array 422 or follower array 424 include electromagnetic coils, which produce the desired magnetic flux when energized. For example, in the embodiment illustrated in FIGURE 4, follower array 424 may include electromagnetic coils in sections 420a through 420h. Such electromagnetic coils may include cores that include steel or other ferrous materials to increase the magnetic flux produced by the coils.

In some embodiments, follower array 424 includes a slip ring (not shown) that includes conductive material located on a surface of follower array 424. For example, a slip ring may be located on downhole surface 450 of follower array 424. The slip ring may be in electrical contact with a brush (not shown) that provides electrical current to energize electromagnetic coils in sections 420a through 420h of follower array 424. A second slip ring and brush may be used to provide a return path for the electrical current. In such embodiments, the slip rings and brushes cannot be immersed in a conductive fluid, such as drilling fluid, because the conductive fluid would create a short circuit between the brushes and prevent current from reaching and energizing the electromagnetic coils. As a result, such embodiments include barrier 230 to prevent drilling fluid from coming into contact with the slip rings and brushes.

Although barrier 230 is illustrated in FIGURE 4 as enclosing follower array 424 and follower shaft 240, barrier 230 may be arranged in any suitable fashion. For example, in some embodiments, barrier 230 encloses drive array 422 and drive shaft 210.

FIGURE 5 is a plan section view of exemplary radial magnetic coupling 400, cut along line A in FIGURE 4.

Drive array 422 includes an annular array of sections 510a through 510h, each of which includes a permanent magnet or electromagnetic coil that produces a magnetic flux in a particular direction. Similarly, follower array 424 includes an annular array of sections 520a through 520h, each of which includes a permanent magnet or electromagnetic coil that produces a magnetic flux in a particular direction. Together, drive array 422 and follower array 424 produce a magnetic field oriented

substantially perpendicular to their common axis of rotation 226. The magnetic field penetrates barrier 230 and couples drive array 422 to follower array 424.

Arrows 530 indicate the orientation of the magnetic flux produced by each particular section 510a through 510h or 520a through 520h. As illustrated, sections 510a through 510h are arranged in a Halbach array, in which the sections alternate between sections in which the magnetic flux is oriented normal to the inner surface of drive array 422, such as sections 510b and 510d, and sections in which the magnetic flux is oriented transverse to such inner surface, such as sections 510a and 510c. In addition, as illustrated, the orientation of the magnetic flux in successive sections rotates in a consistent direction as one proceeds around the annular array. For example, sections 510b and 510f of drive array 422 each produce a magnetic flux oriented inward toward axis 226, while sections 510d and 510h each produce a magnetic flux oriented outward away from axis 226. In the alternating sections, for example, sections 510a and 510e of drive array 422 each produce a magnetic flux oriented transverse to axis 226, in a counter-clockwise direction when viewed from the uphole surface of drive array 422, while sections 510c and 510g of drive array 422 each produce a magnetic flux oriented transverse to axis 226, in a clockwise direction when viewed from the uphole surface of drive array 422. This arrangement of magnetized sections with rotating orientations increases the strength of the magnetic field on one side of the array while decreasing or eliminating the magnetic field on the other side of the array. In the embodiment illustrated, the magnetic field of drive array 422 is enhanced on the inner surface of drive array 422, which faces the outer surface of follower array 424.

Sections 520a through 520h of follower array 224 are also arranged in a Halbach array, but here the direction in which the orientation of the magnetic flux in successive sections rotates is opposite to that in drive array 222. For example, in sections 520b and 520f, the magnetic flux is oriented inward toward axis 226, as it is in the corresponding sections 510b and 520f of drive array 422. By contrast, in section 520c, the magnetic flux is oriented transverse to axis 226, in a counter-clockwise direction when viewed from the uphole surface of follower array 424, which is in the opposite direction from that of corresponding section 510c of drive array 422. As a

result, the magnetic field of follower array 224 is enhanced on the outer surface of follower array 424, which faces the inner surface of drive array 422.

In normal operation, the electrical current required to energize electromagnetic coils in a magnetic coupling may be provided by load which is driven by the coupling.

5 For example, load 250, discussed in connection with FIGURE 2, may include an electrical generator. The generator may provide current to energize electromagnetic coils in follower array 224, discussed in connection with FIGURES 2 and 3. However, before magnetic coupling 220, discussed in connection with FIGURES 2 and 3, begins to turn, the generator may produce no electrical current. As a result, a

10 separate power source is used to initially energize the electromagnetic coils until a normal operating speed is reached.

FIGURE 6 is a circuit diagram of an exemplary bootstrap circuit for energizing electromagnetic coils in a magnetic coupling. For example, bootstrap circuit 600 may be used to energize electromagnetic coils in follower array 224,

15 discussed in connection with FIGURES 2 and 3, or in follower array 424, discussed in connection with FIGURES 4 and 5. In the embodiment illustrated in FIGURE 6, electromagnetic coils are present in follower array 424 of magnetic coupling 400. Circuit 600 allows a battery to initially energize the electromagnetic coils in follower array 424 before magnetic coupling 400 begins to turn, then allow a separate power

20 source, such as a generator or alternator powered by the motion of follower array 424, to sustain the electromagnetic coils during normal operation.

Circuit 600 includes battery 610, which is electrically coupled to direct current to direct current (DC/DC) converter 620 through switch 612. The positive terminal of DC/DC converter 620 is electrically coupled to magnetic coupling 400 through node

25 622, diode 630, and node 626. The negative terminal of DC/DC converter 620 is electrically coupled to magnetic coupling 400 through node 624.

Circuit 600 also includes alternating current (AC) source 640. In some embodiments, AC source 640 is coupled through follower shaft 240 (not shown) to follower array 424, discussed in connection with FIGURES 4 and 5. For example,

30 load 250, discussed in connection with FIGURE 2, may include AC source 640. Current source 640 transforms the rotational motion of follower shaft 240 into electrical current. In some embodiments, AC source 640 is a generator, as discussed

in connection with load 250 in FIGURE 2. AC source 640 is electrically coupled to AC/DC converter 650, which in turn is electrically coupled to DC/DC converter 660. The positive terminal of DC/DC converter 620 is electrically coupled to magnetic coupling 400 through node 662, diode 670, and node 626. The negative terminal of DC/DC converter 660 is electrically coupled to magnetic coupling 400 through node 664.

In operation, battery 610 supplies initial power to the electromagnetic coils in follower array 424 before magnetic coupling 400 begins to turn. When drive array 422 first begins to turn, switch 612 is closed, permitting current to flow from battery 610 to power electronics such as direct current to direct current (DC/DC) converter 620. DC/DC converter 620 produces a voltage V_{batt} at node 622 relative to node 624. As a result, current flows from node 622 through diode 630 to node 626, through one or more electromagnetic coils in follower array 424, energizing the coils, through node 624 and back to DC/DC converter 620. As a result of the current flow through the coils, follower array 424 magnetically couples to drive array 422 and thereby begins to turn in conjunction with drive array 422, turning follower shaft 240 (not shown).

When follower shaft 240 is turning, it supplies rotational motion to load 250, which may include AC source 640. AC source 640 transforms the rotational motion of follower shaft 240 into electrical current. AC source 640 supplies an alternating current to AC/DC converter 650. AC/DC converter 650 in turn supplies a direct current to DC/DC converter 660. DC/DC converter 660 produces a voltage V_{gen} at node 662 relative to node 664. When AC source 640 is spinning sufficiently rapidly, DC/DC converter 660 may supply sufficient current that V_{gen} exceeds V_{batt} . As a result, current flows from node 662 through diode 670 to node 626, through one or more electromagnetic coils in follower array 424, energizing the coils, through node 664 and back to DC/DC converter 660. At this point, current from battery 610 is no longer used to energize the coils, and switch 612 may be opened.

Although FIGURE 6 illustrates circuit 600 including a radial magnetic coupling, any suitable magnetic coupling may be used. For example, an axial magnetic coupling such as magnetic coupling 220, discussed in connection with FIGURES 2 and 3, may be used in place of magnetic coupling 400.

FIGURE 7 is a flow chart of an exemplary method 700 for bootstrapping a magnetic coupling.

Method 700 may begin at step 710, in which current is supplied from a battery to an electromagnetic coil in a magnetic coupling. For example, as discussed above in connection with FIGURE 6, when switch 612 is closed, battery 610 provides current to an electromagnetic coil in follower array 424 of magnetic coupling 400 through DC/DC converter 620, diode 630, and nodes 622, 624, and 626.

In step 720, the drive array and follower arrays in the magnetic coupling are coupled using the electromagnetic coil. As a result of the current flow supplied in step 710, the electromagnetic coil in the magnetic coupling is energized and produces a magnetic field. For example, the electromagnetic coil in follower array 424 produces a field as described above in connection with FIGURES 5 and 6. This magnetic field (in conjunction with the field produced by magnetic sections in drive array 422) couples drive array 422 and follower array 424.

In step 730, rotational motion is transferred to an AC source using the magnetic coupling. For example, rotational motion from turbine 202, discussed with reference to FIGURE 2, may be transferred to load 250 using drive shaft 210, magnetic coupling 400, and follower shaft 240. As discussed above in connection with FIGURE 6, load 250 may include AC source 640, which transforms that rotational motion into electrical current.

In step 740, current is supplied from the AC source to the electromagnetic coil. For example, as discussed above in connection with FIGURE 6, AC source 640 provides current to the electromagnetic coil in follower array 424 through AC/DC converter 650, DC/DC converter 660, diode 670, and nodes 662, 664, and 666.

In step 750, the battery stops supplying current to the electromagnetic coil. For example, as discussed above in connection with FIGURE 6, once follower shaft 240 is spinning sufficiently rapidly, AC source 640 supplies sufficient current to energize the electromagnetic coils in follower array 424. As a result, battery 610 is disconnected by opening switch 612.

Modifications, additions, or omissions may be made to method 700 without departing from the scope of the present disclosure. For example, the order of the steps may be performed in a different manner than that described and some steps may be

performed at the same time. Additionally, each individual step may include additional steps without departing from the scope of the present disclosure.

Embodiments disclosed herein include:

- 5 A. A magnetic coupling of a downhole tool that includes (a) a first annular array of magnetic sections; (b) a second annular array of magnetic sections coupled to the first annular array by a magnetic field that transfers rotational motion from the first annular array to the second annular array, and (c) a barrier disposed between the first annular array and the second annular array, the barrier including an erosion-resistant layer.
- 10 B. A drilling system that includes (a) a drill string; and (b) a magnetic coupling located within the drill string, in which the magnetic coupling includes (c) a first annular array of magnetic sections, (d) a second annular array of magnetic sections coupled to the first annular array by a magnetic field that transfers rotational motion from the first annular array to the second annular array, and (e) a barrier
- 15 disposed between the first annular array and the second annular array, the barrier having an erosion-resistant layer; (f) a motor coupled to the first annular array; and (g) a load coupled to the second annular array.
- 20 C. A method of bootstrapping a magnetic coupling of a downhole tool that includes (a) rotating a first annular array of magnetic sections in a magnetic coupling; (b) supplying current from a battery to an electromagnetic coil located within a second annular array of magnetic sections in the magnetic coupling; (c)
- 25 coupling the first annular array to the second annular array using a magnetic field produced by the electromagnetic coil; (d) transferring rotational motion from the first annular array to the second annular array using the magnetic field; (e) transferring rotational motion from the second annular array to an alternating current (AC) source configured to transform rotational motion into electrical current; and (f) supplying electrical current from the AC source to the electromagnetic coil.

Each of embodiments A, B, and C may have one or more of the following additional elements in any combination. Element 1: the first annular array has a first

30 outer diameter; the second annular array has a second outer diameter approximately equal to the first outer diameter; the first annular array and the second annular array are configured to rotate about a common axis of rotation; and the magnetic field is

oriented approximately parallel to the common axis of rotation. Element 2: the first annular array has an inner diameter; the second annular array has an outer diameter smaller than the inner diameter; the second annular array is disposed within the inner diameter of the first annular array; the first annular array and the second annular array are configured to rotate about a common axis of rotation; and the magnetic field is oriented approximately perpendicular to the common axis of rotation. Element 3: wherein the erosion-resistant layer includes a layer of titanium. Element 4: wherein the second annular array comprises a plurality of permanent magnets. Element 5: wherein a magnet among the plurality of permanent magnets is a samarium cobalt magnet. Element 6: wherein the second annular array comprises a plurality of electromagnetic coils. Element 7: further comprising a bootstrap circuit for energizing the plurality of electromagnetic coils, the bootstrap circuit including (a) a battery; and (b) a first diode coupled to the battery, the first diode permitting the battery to supply electrical current to the plurality of electromagnetic coils. Element 8: the bootstrap circuit further including (c) a current source coupled to the second annular array, the current source configured to transform rotation of the second annular array into electrical current; and (d) a second diode coupled to the current source, the second diode permitting the current source to supply electrical current to the plurality of electromagnetic coils. Element 9: wherein the magnetic coupling includes a barrier disposed between the first annular array and the second annular array, the barrier including an erosion-resistant layer.

Although the present disclosure and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the disclosure as defined by the following claims.

WHAT IS CLAIMED IS:

1. A magnetic coupling of a downhole tool comprising:
a first annular array of magnetic sections;
5 a second annular array of magnetic sections coupled to the first annular array
by a magnetic field that transfers rotational motion from the first annular array to the
second annular array; and
a barrier disposed between the first annular array and the second annular array,
the barrier including an erosion-resistant layer.
10
2. The magnetic coupling of Claim 1, wherein:
the first annular array has a first outer diameter;
the second annular array has a second outer diameter approximately equal to
the first outer diameter;
15 the first annular array and the second annular array are configured to rotate
about a common axis of rotation; and
the magnetic field is oriented approximately parallel to the common axis of
rotation.
- 20 3. The magnetic coupling of Claim 1, wherein:
the first annular array has an inner diameter;
the second annular array has an outer diameter smaller than the inner diameter;
the second annular array is disposed within the inner diameter of the first
annular array;
25 the first annular array and the second annular array are configured to rotate
about a common axis of rotation; and
the magnetic field is oriented approximately perpendicular to the common axis
of rotation.
- 30 4. The magnetic coupling of Claim 1, wherein the erosion-resistant layer
includes a layer of titanium.

5. The magnetic coupling of Claim 1, wherein the second annular array comprises a plurality of permanent magnets.

6. The magnetic coupling of Claim 5, wherein a magnet among the
5 plurality of permanent magnets is a samarium cobalt magnet.

7. The magnetic coupling of Claim 1, wherein the second annular array comprises a plurality of electromagnetic coils.

10 8. The magnetic coupling of Claim 7, further comprising a bootstrap circuit for energizing the plurality of electromagnetic coils, the bootstrap circuit comprising:

a battery; and

a first diode coupled to the battery, the first diode permitting the battery to
15 supply electrical current to the plurality of electromagnetic coils.

9. The magnetic coupling of Claim 8, the bootstrap circuit further comprising:

a current source coupled to the second annular array, the current source configured to transform rotation of the second annular array into electrical current;

20 and

a second diode coupled to the current source, the second diode permitting the current source to supply electrical current to the plurality of electromagnetic coils.

10. A drilling system comprising:

25 a drill string;

a magnetic coupling located within the drill string, the magnetic coupling including:

a first annular array of magnetic sections;

a second annular array of magnetic sections coupled to the first annular
30 array by a magnetic field that transfers rotational motion from the first annular array to the second annular array;

a barrier disposed between the first annular array and the second annular array, the barrier having an erosion-resistant layer;
a motor coupled to the first annular array; and
a load coupled to the second annular array.

5

11. The drilling system of Claim 10, wherein:

the first annular array has a first outer diameter;

the second annular array has a second outer diameter approximately equal to the first outer diameter;

10 the first annular array and the second annular array are configured to rotate about a common axis of rotation; and

the magnetic field is oriented approximately parallel to the common axis of rotation.

15 12. The drilling system of Claim 10 wherein:

the first annular array has an inner diameter;

the second annular array has an outer diameter smaller than the inner diameter;

the second annular array is disposed within the inner diameter of the first annular array;

20 the first annular array and the second annular array are configured to rotate about a common axis of rotation; and

the magnetic field is oriented approximately perpendicular to the common axis of rotation.

25 13 The drilling system of Claim 10, wherein the erosion-resistant layer includes a layer of titanium.

14. The drilling system of Claim 10, wherein the second annular array comprises a plurality of permanent magnets.

30

15. The drilling system of Claim 10, wherein a magnet among the plurality of permanent magnets is a samarium cobalt magnet.

16. The drilling system of Claim 10, wherein the second annular array comprises a plurality of electromagnetic coils.

5 17. The drilling system of Claim 16, further comprising a bootstrap circuit for energizing the plurality of electromagnetic coils, the bootstrap circuit comprising:

a battery; and

a first diode coupled to the battery, the first diode permitting the battery to supply electrical current to the plurality of electromagnetic coils.

10

18. The drilling system of Claim 17, the bootstrap circuit further comprising:

a current source coupled to the plurality of electromagnetic coils; and

15 a second diode coupled to the current source, the second diode permitting the current source to supply current to the plurality of electromagnetic coils.

19. The drilling system of Claim 10, wherein the load is a generator.

20 20. A method of bootstrapping a magnetic coupling of a downhole tool, comprising:

rotating a first annular array of magnetic sections in a magnetic coupling;

supplying current from a battery to an electromagnetic coil located within a second annular array of magnetic sections in the magnetic coupling;

25 coupling the first annular array to the second annular array using a magnetic field produced by the electromagnetic coil;

transferring rotational motion from the first annular array to the second annular array using the magnetic field;

transferring rotational motion from the second annular array to an alternating current (AC) source configured to transform rotational motion into electrical current;

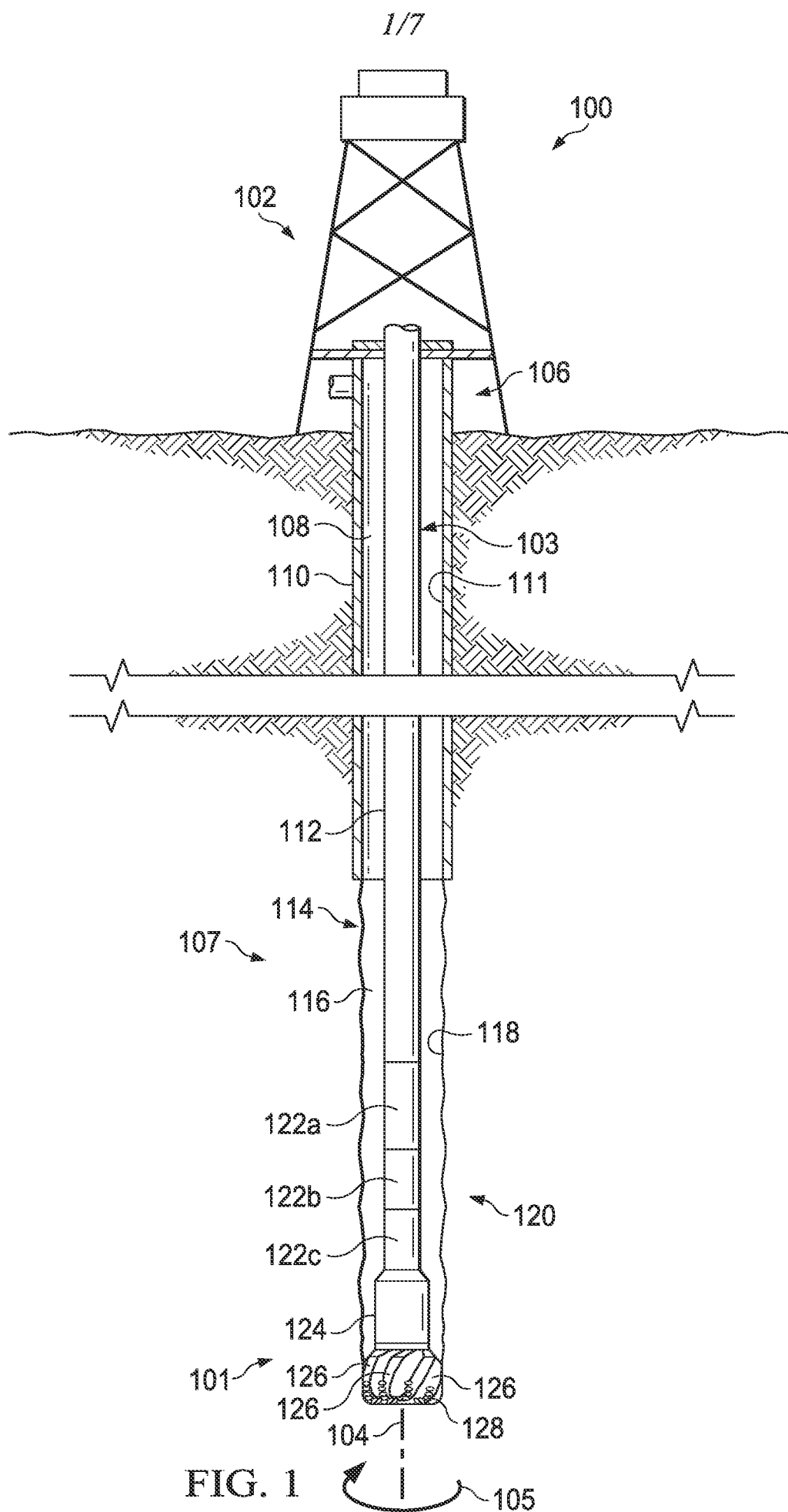
30 and

supplying electrical current from the AC source to the electromagnetic coil.

21. The method of Claim 20, wherein the magnetic coupling includes a barrier disposed between the first annular array and the second annular array, the barrier including an erosion-resistant layer.

5 22. The method of Claim 20, wherein:
the first annular array has a first outer diameter;
the second annular array has a second outer diameter approximately equal to
the first outer diameter;
the first annular array and the second annular array are configured to rotate
10 about a common axis of rotation; and
the magnetic field is oriented approximately parallel to the axis of rotation.

23. The method of Claim 20, wherein:
the first annular array has an inner diameter;
15 the second annular array has an outer diameter smaller than the inner diameter;
the second annular array is disposed within the inner diameter of the first
annular array;
the first annular array and the second annular array are configured to rotate
about a common axis of rotation; and
20 the magnetic field is oriented approximately perpendicular to the axis of
rotation.



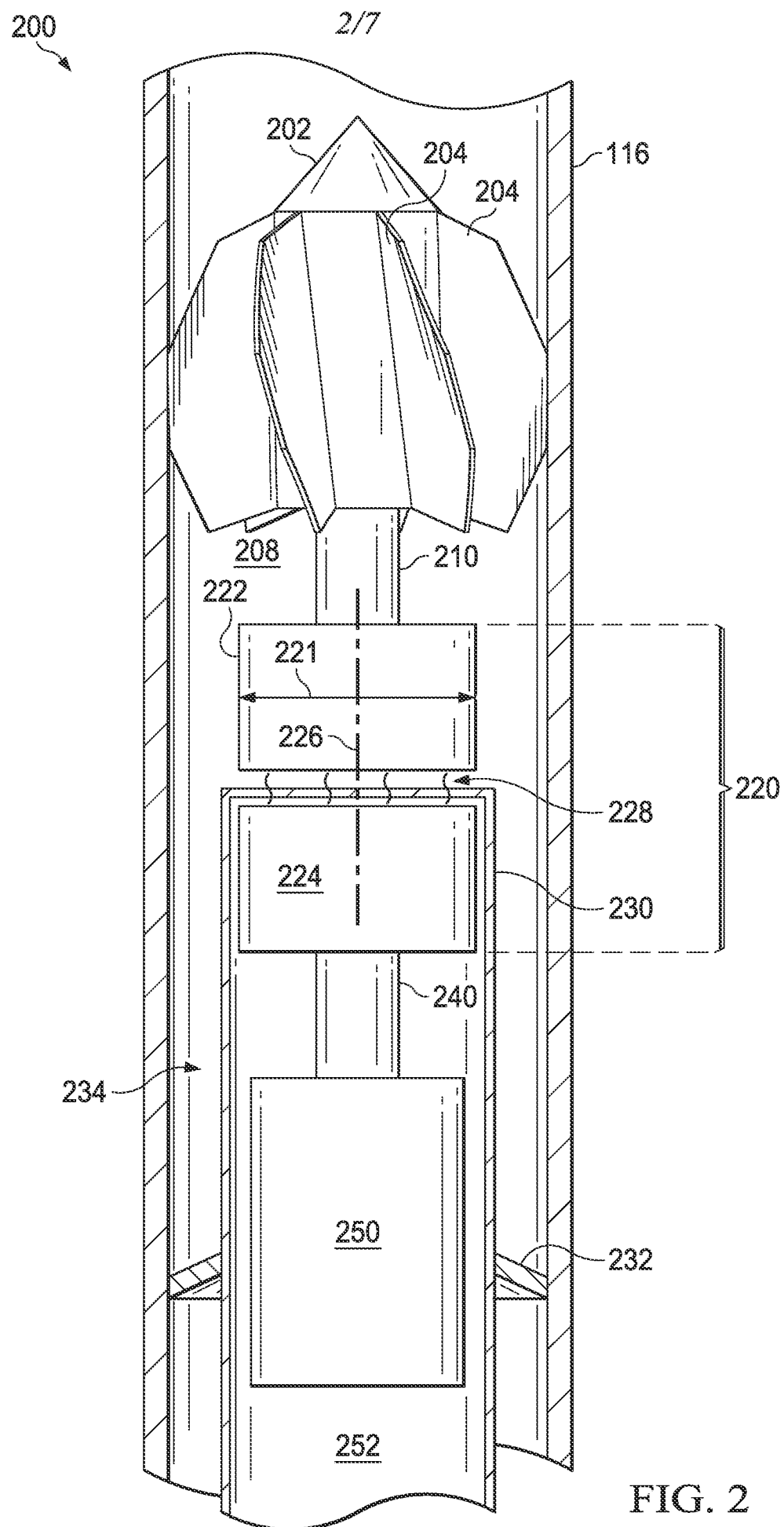


FIG. 2

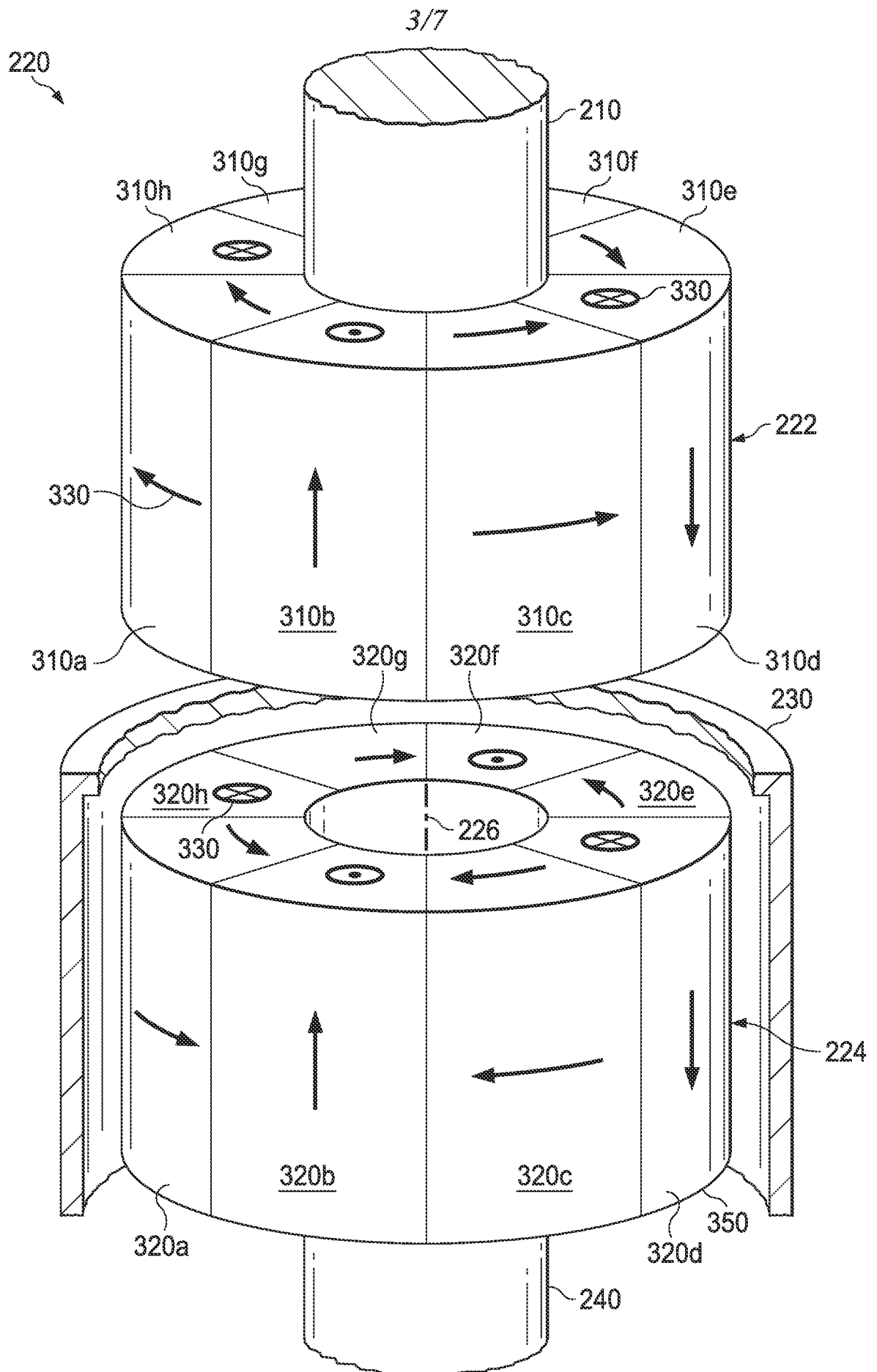


FIG. 3

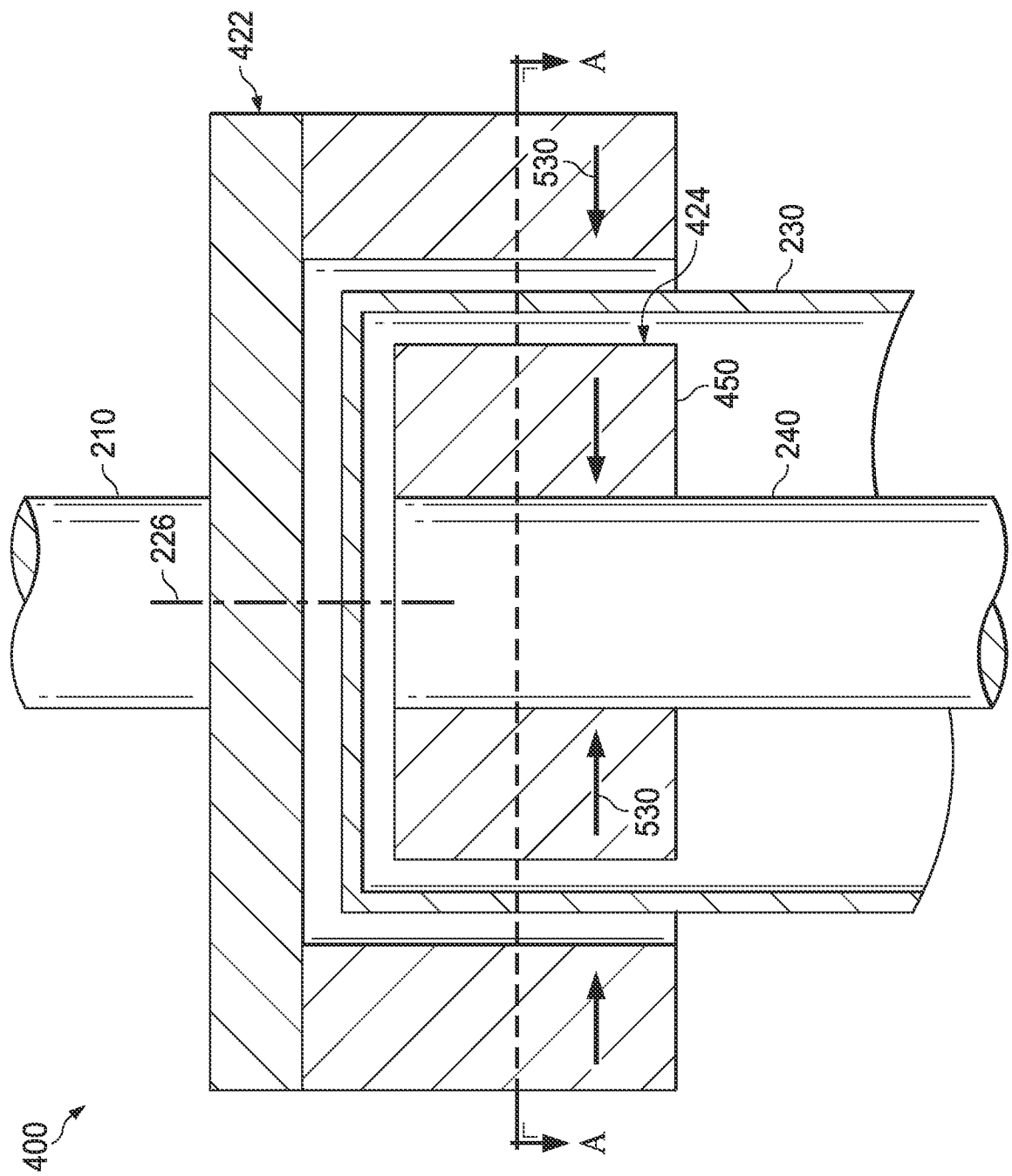


FIG. 4

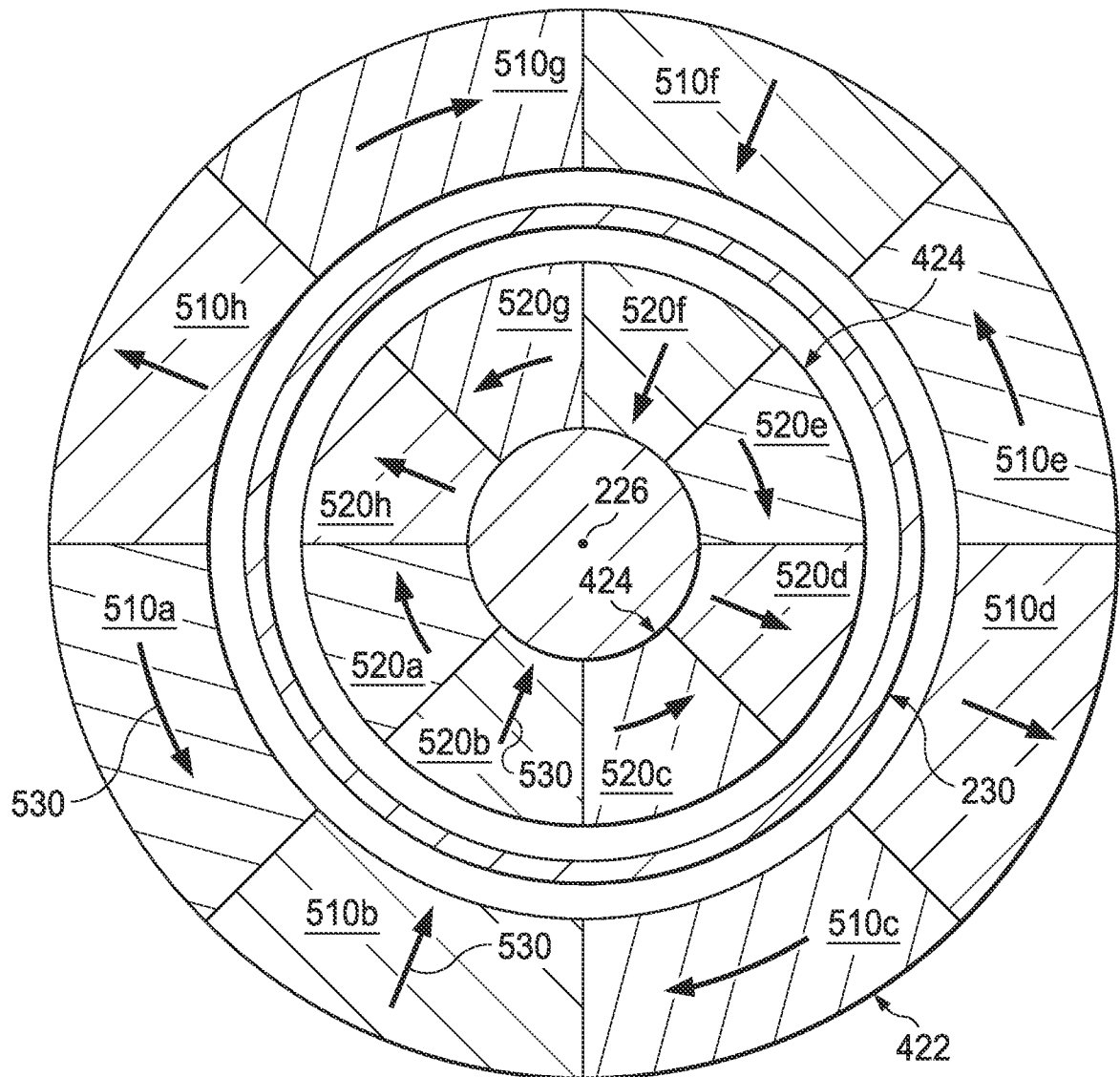


FIG. 5

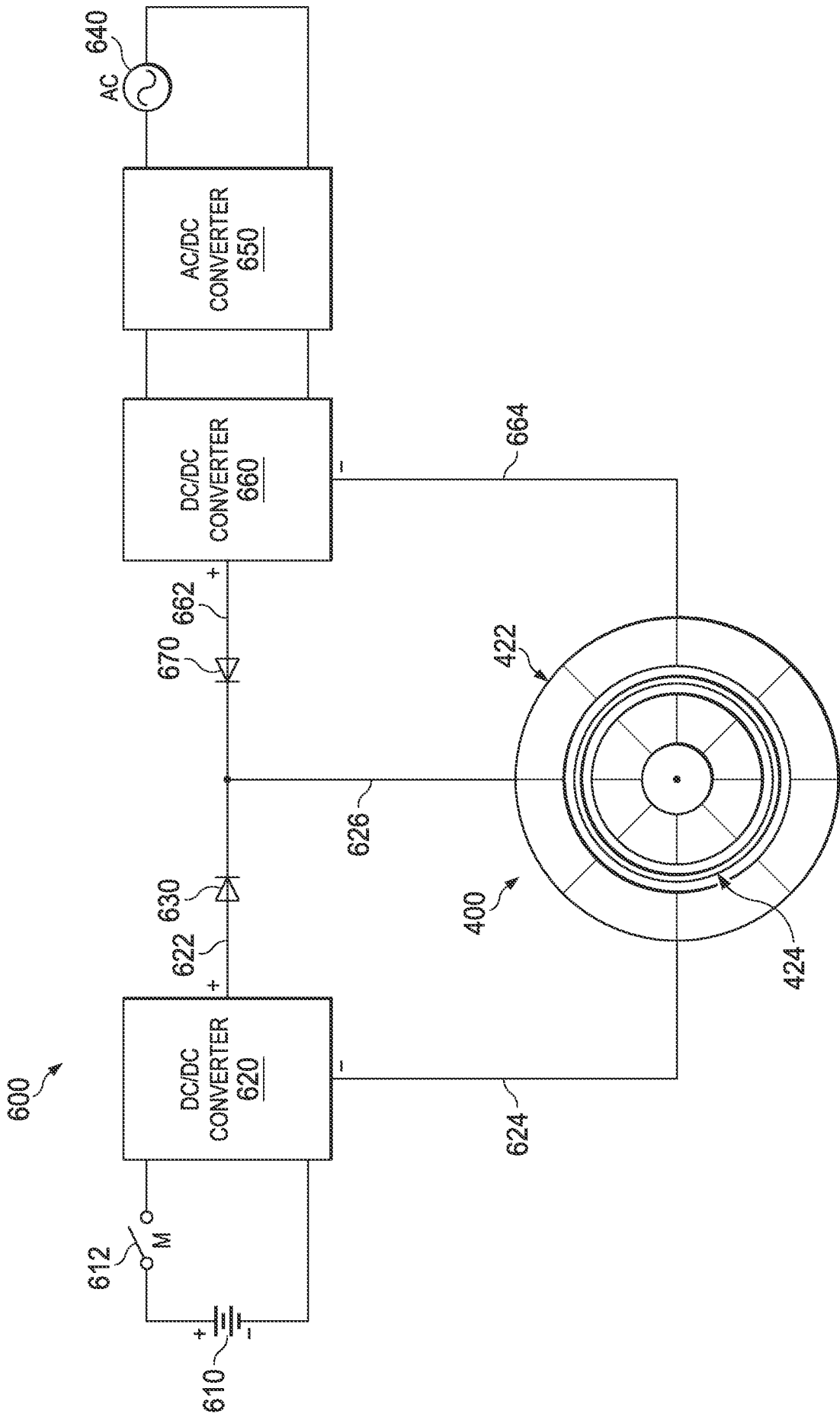


FIG. 6

7/7

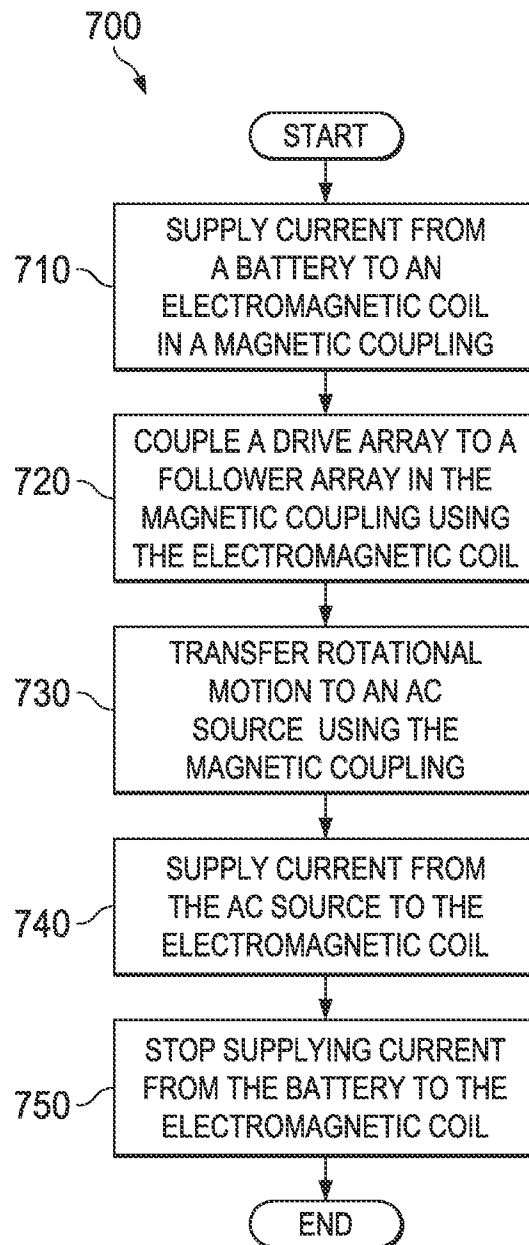


FIG. 7

A. CLASSIFICATION OF SUBJECT MATTER**E21B 17/02(2006.01)i, E21B 17/03(2006.01)i, E21B 41/00(2006.01)i**

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

E21B 17/02; E21B 7/00; E21B 4/02; F03G 3/08; E21B 4/04; E21B 41/00; G01V 1/40; F01D 15/10; E21B 17/03

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: magnetic coupling, magnet, array, barrier, prevent, magnetic field, generator, turbine, downhole**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2008-0047753 A1 (HALL et al.) 28 February 2008 See paragraphs [0002]-[0012], [0030]-[0053]; and figures 1-2, 4, 6, 9, 11.	1-23
Y	US 2010-0224410 A1 (WASSELL et al.) 09 September 2010 See paragraphs [0008], [0031], [0051]-[0054], [0067], [0074]; and figures 1, 4B, 6A-6B.	1-23
A	US 5091725 A (GARD, MICHAEL F.) 25 February 1992 See column 3, line 32 - column 8, line 17; and figures 1-2.	1-23
A	WO 2012-071460 A2 (SAJAN, JOSEPH, JACOB) 31 May 2012 See paragraphs [0050]-[0054]; and figure 1.	1-23
A	US 4732225 A (JURGENS et al.) 22 March 1988 See column 1, line 57 - column 3, line 18; and figures 1-2.	1-23



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

31 August 2016 (31.08.2016)

Date of mailing of the international search report

01 September 2016 (01.09.2016)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea

Facsimile No. +82-42-481-8578

Authorized officer

KIM, Jin Ho

Telephone No. +82-42-481-8699



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2015/064041

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2008-0047753 A1	28/02/2008	US 8033328 B2	11/10/2011
US 2010-0224410 A1	09/09/2010	CA 2754204 A1	10/09/2010
		CA 2754204 C	17/06/2014
		CN 102414471 A	11/04/2012
		CN 102414471 B	17/09/2014
		EP 2404076 A1	11/01/2012
		US 8087476 B2	03/01/2012
		WO 2010-101902 A1	10/09/2010
US 5091725 A	25/02/1992	None	
WO 2012-071460 A2	31/05/2012	CA 2857107 A1	31/05/2012
		US 2012-0126539 A1	24/05/2012
		US 8581429 B2	12/11/2013
		WO 2012-071460 A3	23/08/2012
US 4732225 A	22/03/1988	CA 1262454 A	24/10/1989
		EP 0232891 A2	19/08/1987
		EP 0232891 B1	08/01/1992