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(54) **MAGNETIC POSITION SENSOR**

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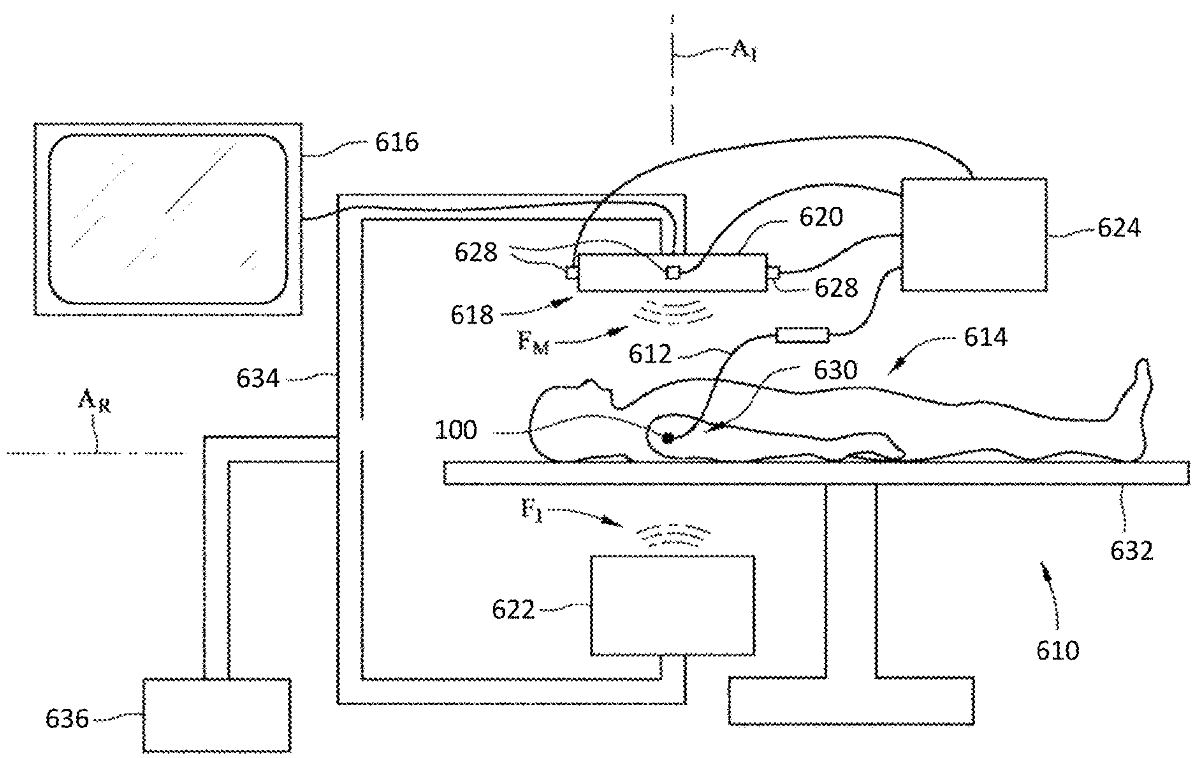
(57) **ABSTRACT**

A magnetic position sensor for tracking a position of a medical device. The magnetic position sensor includes a magnetically permeable core. The magnetically permeable core has a longitudinal axis and a first flat surface extending parallel with the longitudinal axis. A coil including a conductive wire is wrapped around the longitudinal axis of the magnetically permeable core in a plurality of windings.



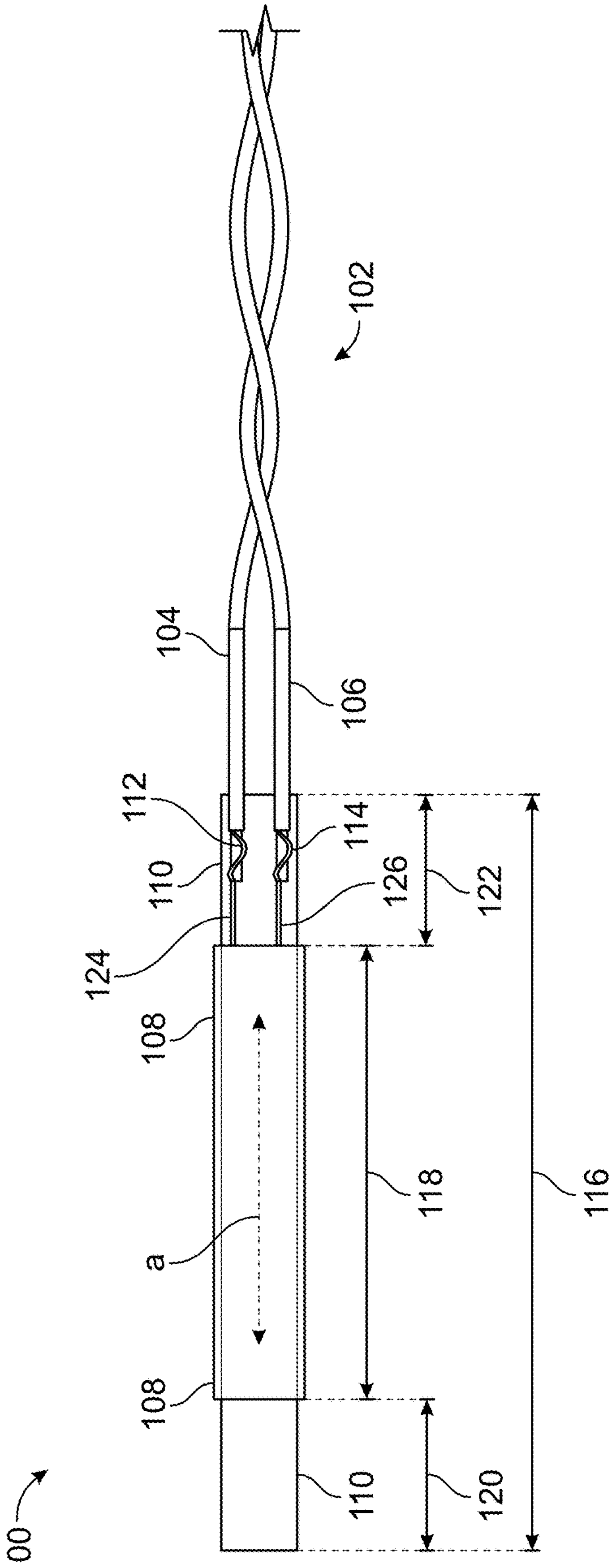


FIG. 1A

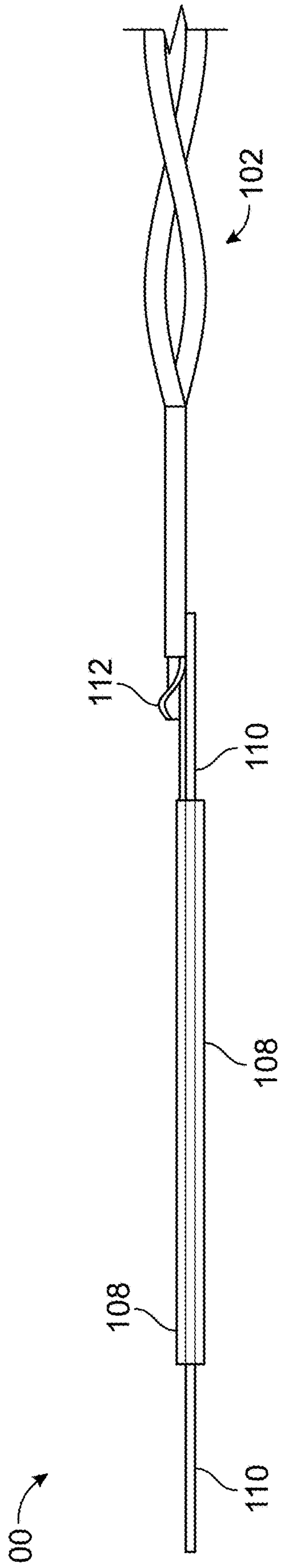


FIG. 1B

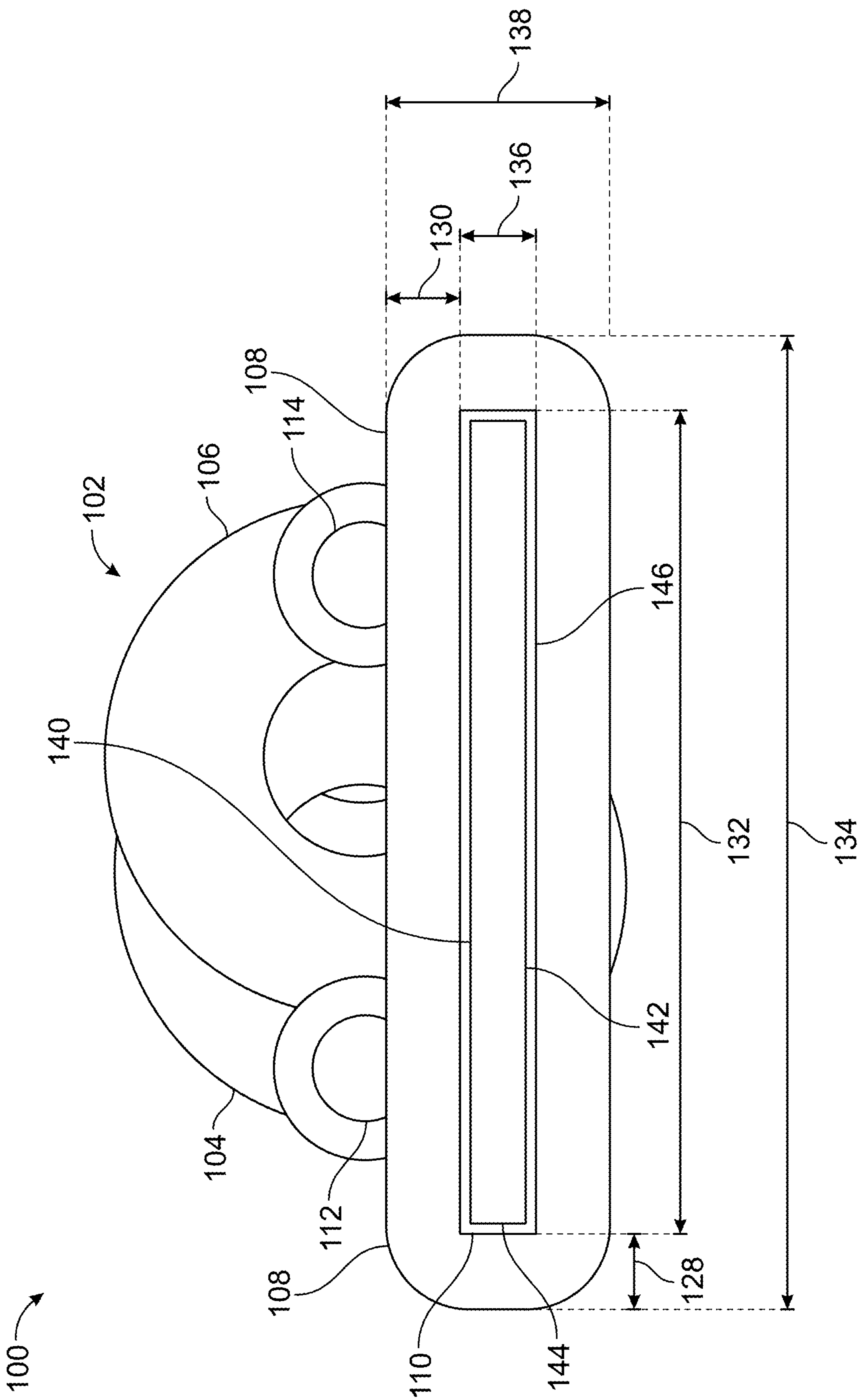

138
136
130
108
114
106
102
146
140
132
134
142
104
112
108
128
110
144
100

FIG. 1C

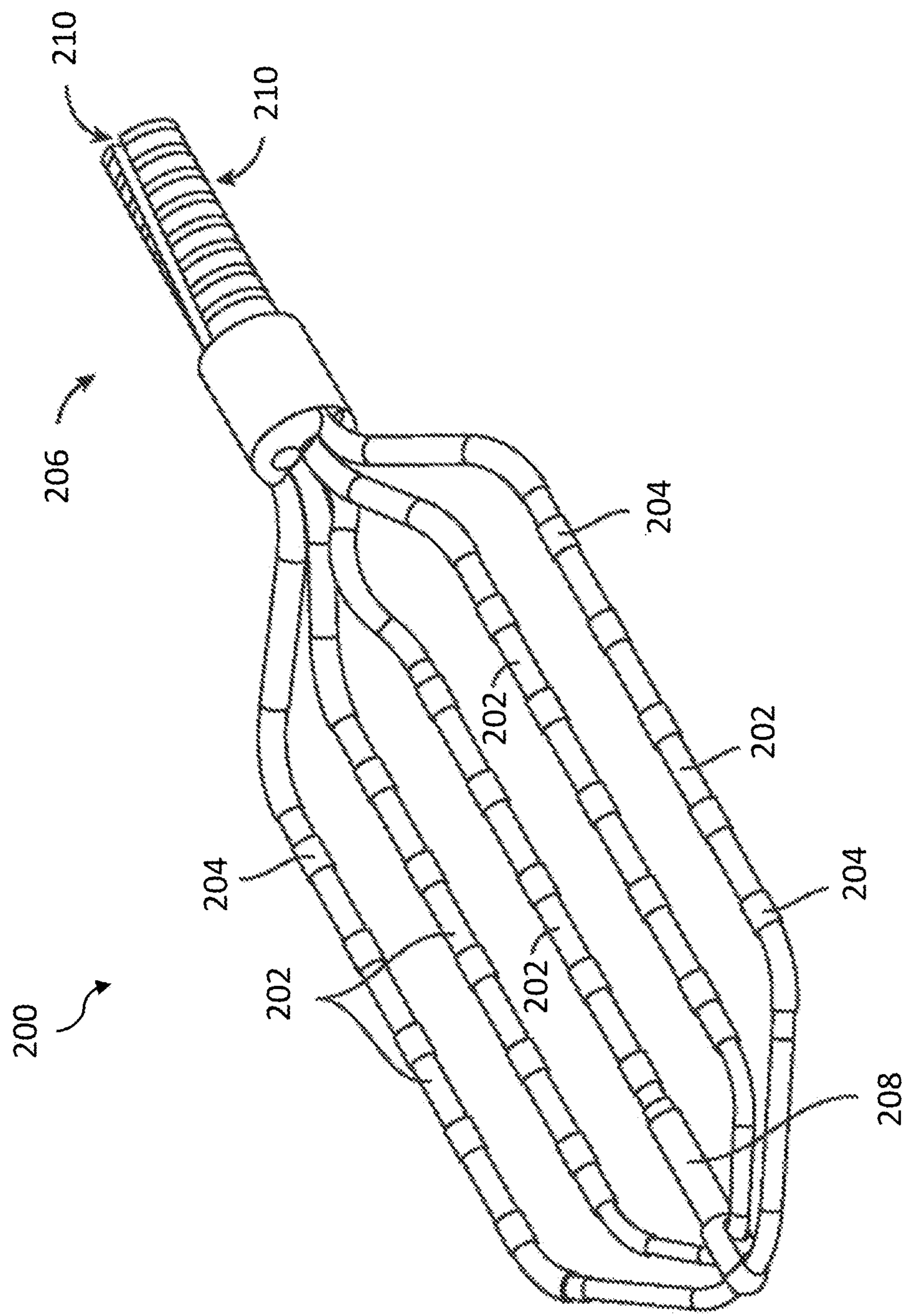


FIG. 2

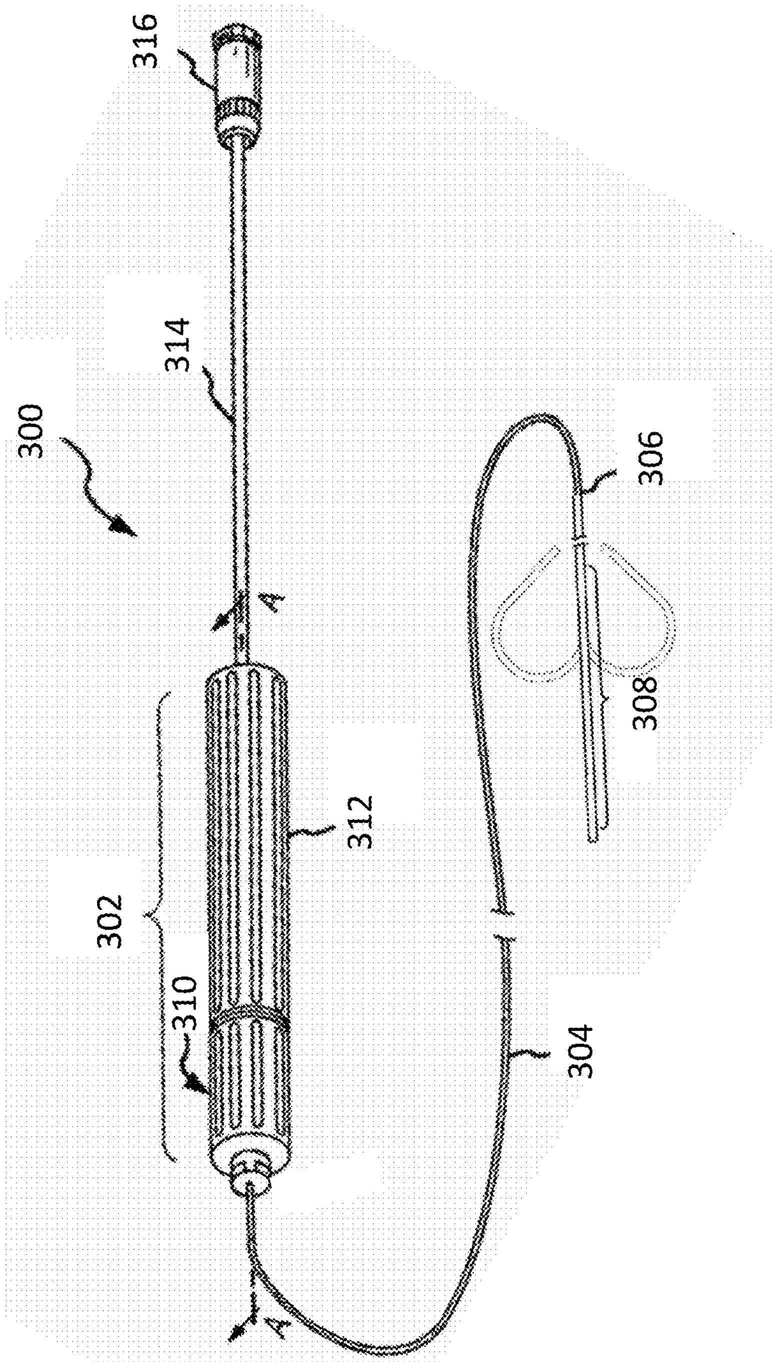


FIG. 3

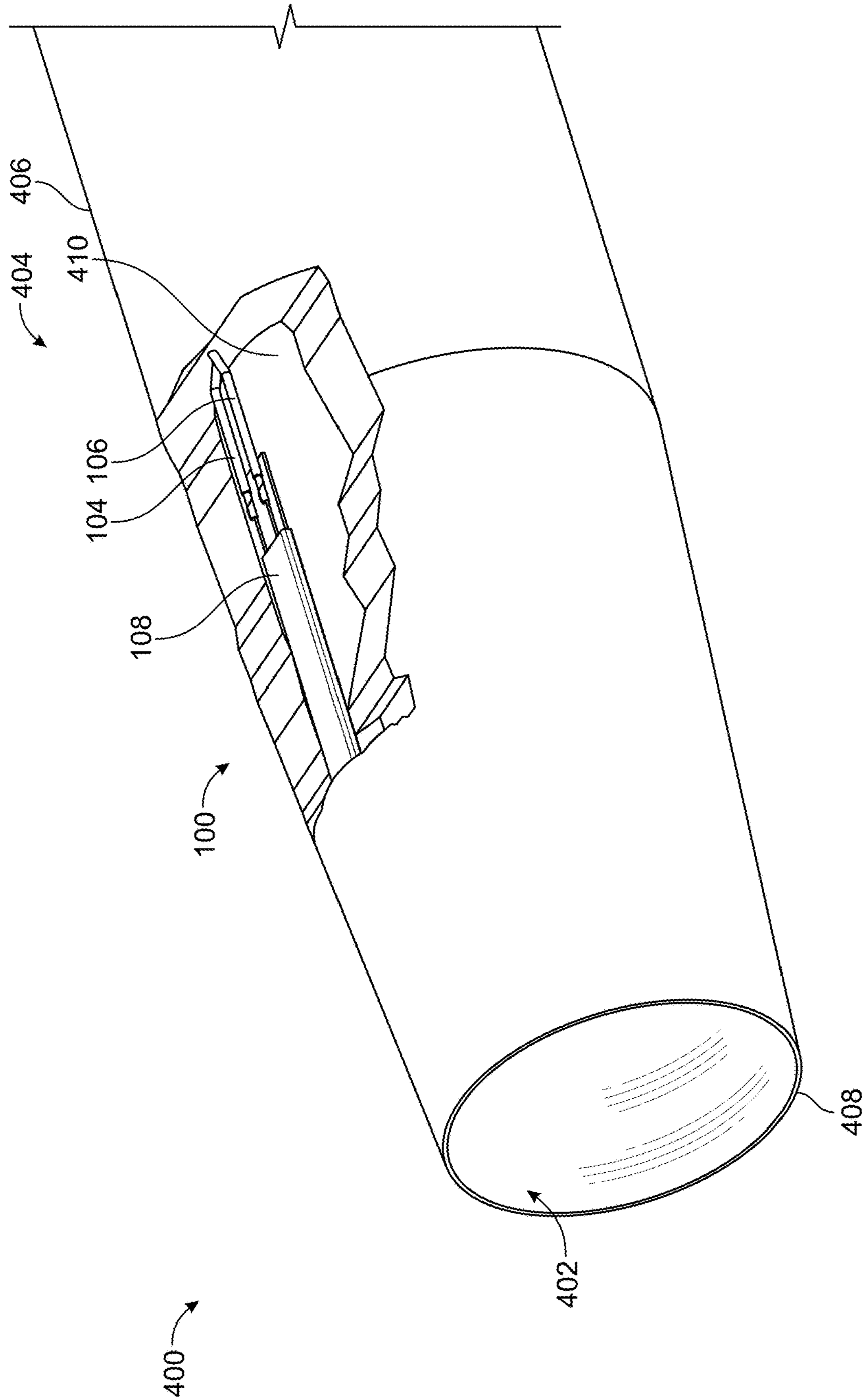
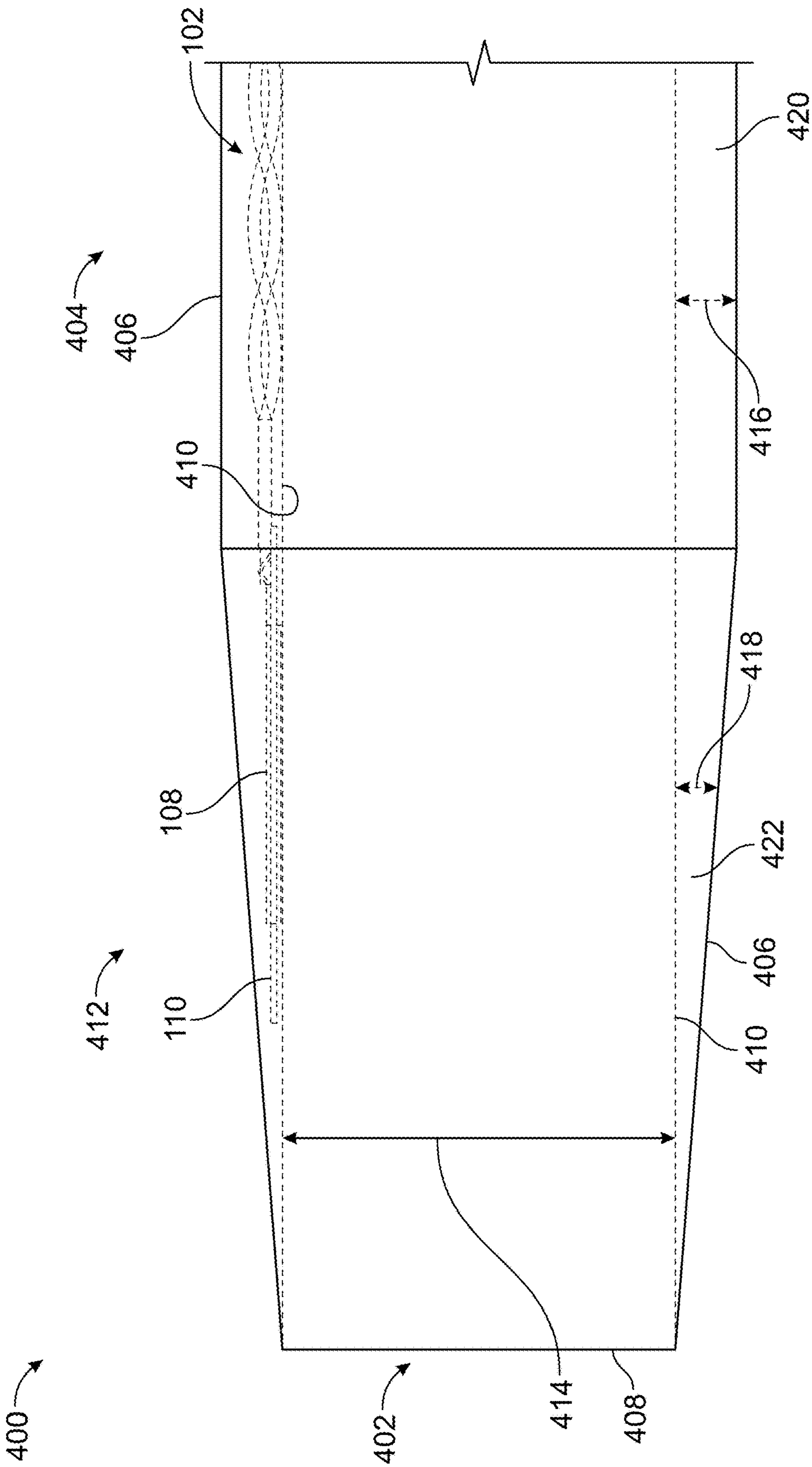


FIG. 4A



102
404
406
410
420
416
108
412
110
418
422
406
410
400
402
414
408

FIG. 4B

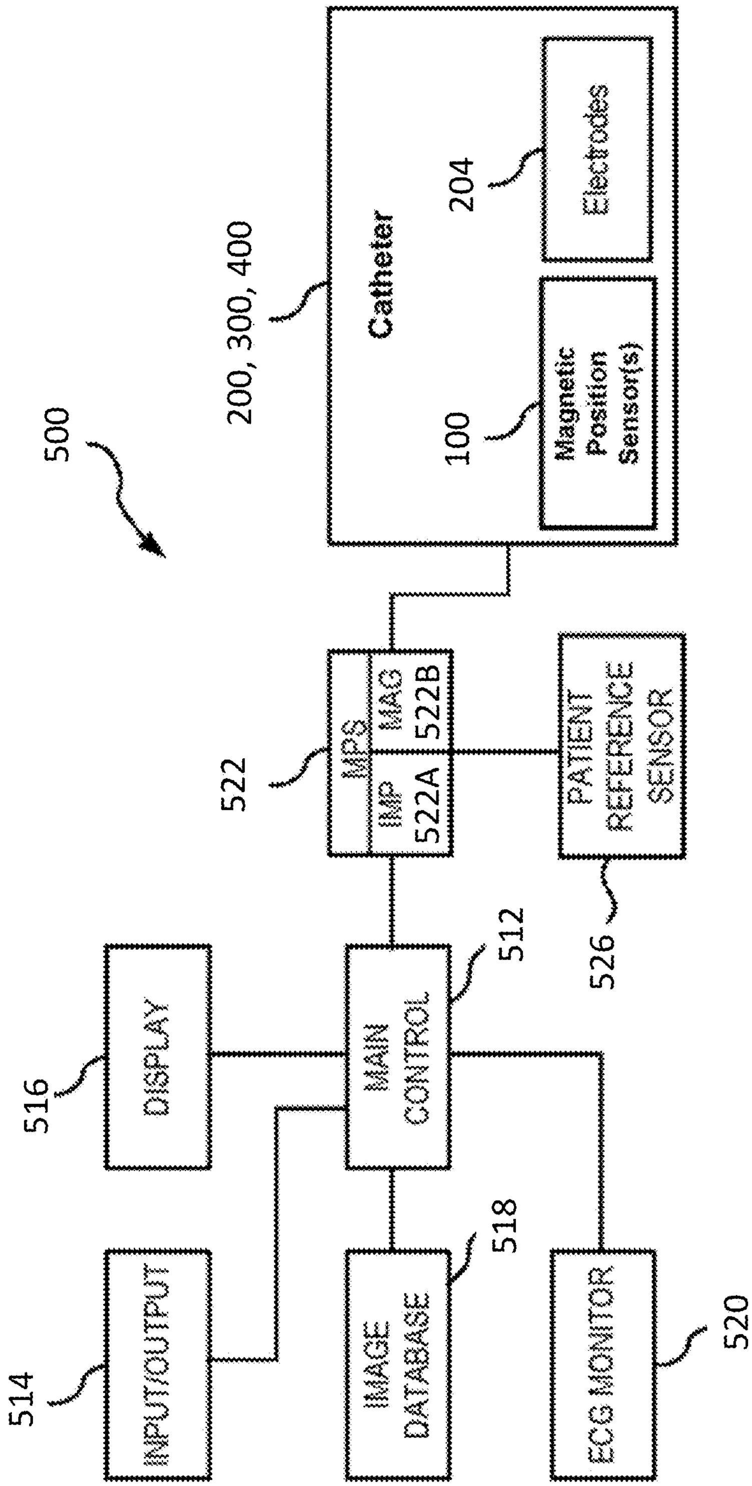

500
200, 300, 400
Catheter
100
Magnetic Position Sensor(s)
204
Electrodes
522
MPS
IMP
522A
MAG
522B
PATIENT REFERENCE SENSOR
526
MAIN CONTROL
512
DISPLAY
516
INPUT/OUTPUT
514
IMAGE DATABASE
518
ECG MONITOR
520

FIG. 5

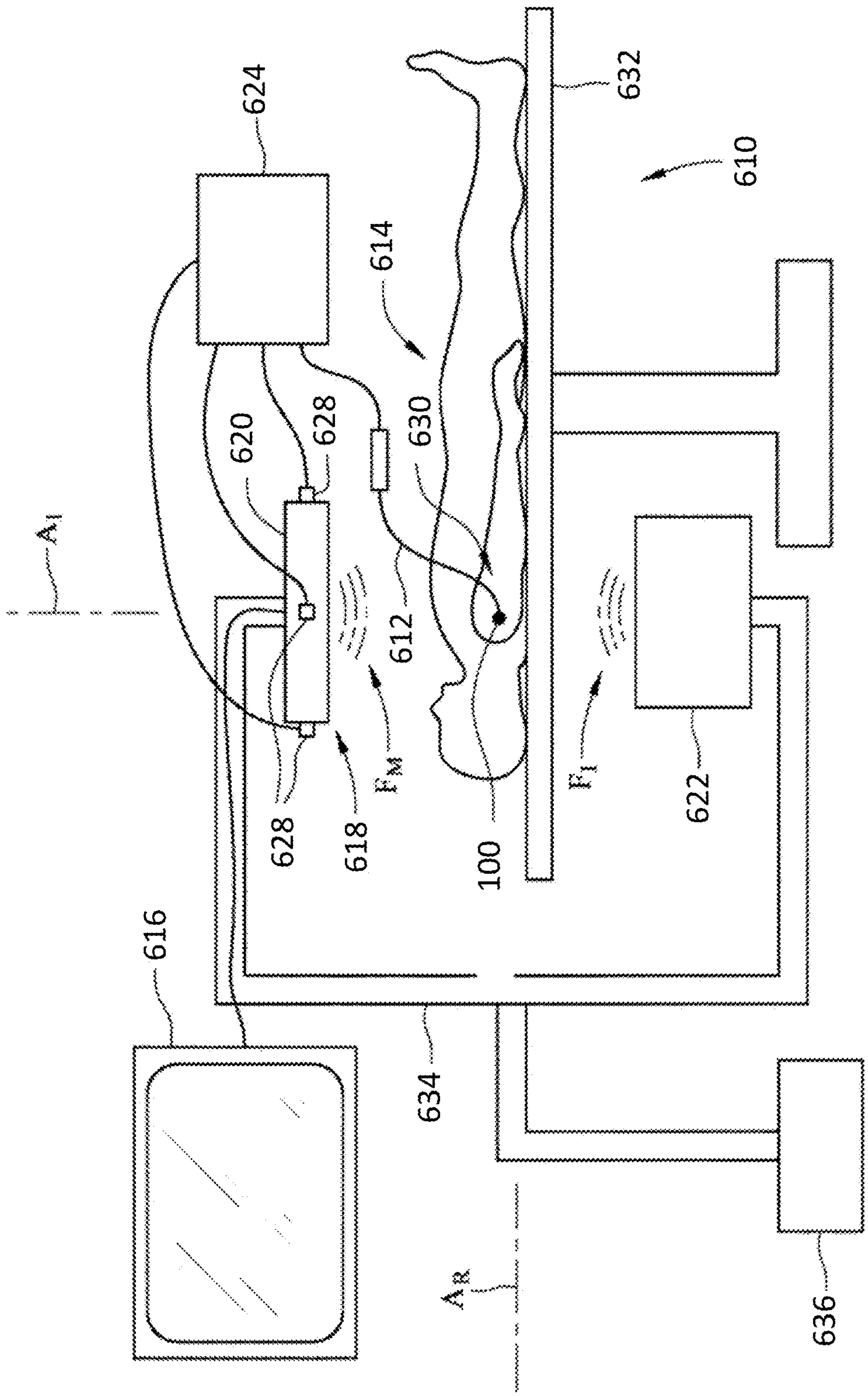

624
632
610
614
620
628
630
A_I
612
F_M
F_I
622
628
618
100
616
634
A_R
636

FIG. 6

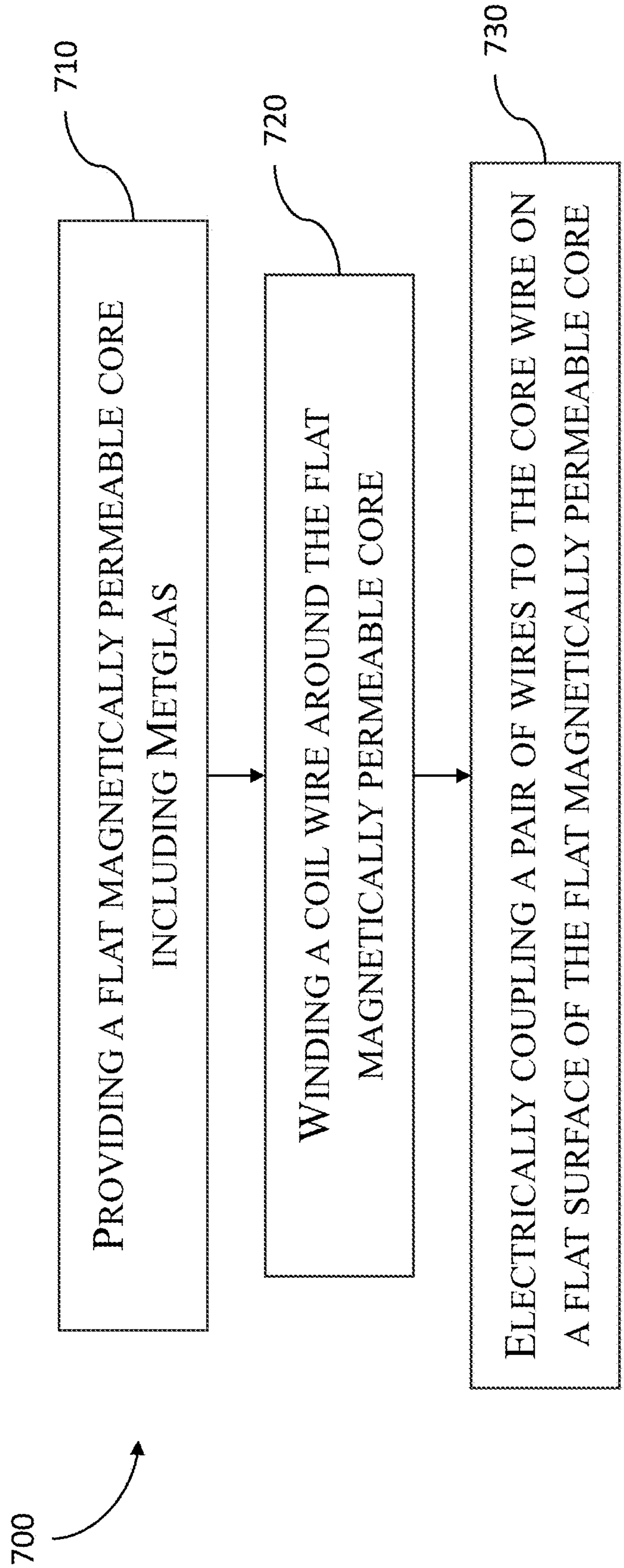

700
710
PROVIDING A FLAT MAGNETICALLY PERMEABLE CORE INCLUDING METGLAS
720
WINDING A COIL WIRE AROUND THE FLAT MAGNETICALLY PERMEABLE CORE
730
ELECTRICALLY COUPLING A PAIR OF WIRES TO THE CORE WIRE ON A FLAT SURFACE OF THE FLAT MAGNETICALLY PERMEABLE CORE

FIG. 7

MAGNETIC POSITION SENSOR

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims benefit of priority to U.S. Provisional Patent Application No. 63/553,414 filed on Feb. 14, 2024, the entire disclosure of which is hereby incorporated by reference.

BACKGROUND

[0002] The present disclosure relates generally to a magnetic position sensors for tracking a position and/or an orientation of a medical device. In general, medical positioning systems are used to track a position and/or an orientation of a medical device within a patient. Exemplary medical devices used with medical positioning systems include catheters, introducers, guide wires, etc. Such medical devices may include an elongate flexible shaft and various diagnostic and/or therapeutic elements that are used to perform various diagnosis or treatment procedures including mapping and/or ablation on anatomy (e.g., cardiac tissue).

SUMMARY

[0003] According to some embodiments, a magnetic position sensor for tracking a position of a medical device. The magnetic position sensor includes a magnetically permeable core. The magnetically permeable core has a longitudinal axis and a first flat surface extending parallel with the longitudinal axis. A coil including a conductive wire is wrapped around the longitudinal axis of the magnetically permeable core in a plurality of windings.

[0004] A method of assembling a magnetic position sensor. The method includes forming a magnetically permeable core from one or more Metglas layers. The magnetically permeable core includes a longitudinal axis and a first flat surface extending parallel with the longitudinal axis. A conductive wire is wound around the longitudinal axis of the magnetically permeable core to form a coil. A pair of wires is electrically coupled to the conductive wire.

[0005] A medical device. The medical device includes an elongate shaft including a side wall. The medical device includes a magnetic position sensor. The magnetic position sensor includes a magnetically permeable core including a longitudinal axis and a first flat surface extending parallel with the longitudinal axis. A coil including a conductive wire is wrapped around the longitudinal axis of the magnetically permeable core in a plurality of windings. The magnetic position sensor is located in the side wall of the elongate shaft.

BRIEF DESCRIPTION OF DRAWINGS

[0006] This written disclosure describes illustrative embodiments that are non-limiting and non-exhaustive. Reference is made to illustrative embodiments that are depicted in the figures, in which:

[0007] FIG. **1**A is a top view of a flat magnetic position sensor, according to some embodiments.

[0008] FIG. **1**B is a side view of a flat magnetic position sensor, according to some embodiments.

[0009] FIG. **1**C is a front view of a flat magnetic position sensor, according to some embodiment.

[0010] FIG. **2** is a high-density grid electrode assembly of an example medical catheter that can include one or more flat magnetic position sensor(s), according to some embodiments.

[0011] FIG. **3** is an exemplary medical catheter that can include one or more flat magnetic position sensor(s), according to some embodiments.

[0012] FIG. **4**A is an isometric view of an introducer catheter with a portion of the catheter wall cut away for viewing purposes, according to some embodiments.

[0013] FIG. **4**B is a cross-sectional side view of an introducer catheter with a flat magnetic sensor located in the catheter wall, according to some embodiments.

[0014] FIG. **5** is a medical device localization system that can be employed with a medical device that includes one or more flat magnetic position sensor(s), according to some embodiments.

[0015] FIG. **6** is a medical localization system that can be employed with a medical device that includes one or more flat magnetic position sensor(s), according to some embodiments.

[0016] FIG. **7** illustrates a flow chart of a method for assembling a flat magnetic position sensor, according to some embodiments.

DETAILED DESCRIPTION

[0017] This disclosure relates to devices, systems, and methods for tracking a position and/or an orientation of a medical device with a flat magnetic sensor. The flat magnetic sensor includes a magnetically permeable core having at least one flat (or substantially flat) surface. The flat magnetic sensor may be optimized for space optimization (i.e., efficient utilization of volume) within the medical device. For example, catheters or other intravascular devices have small cross sectional profiles to navigate through vasculature, and therefore, the components/features within the medical device may be arranged to optimize the limited volume provided by the medical device. In some cases, the flat magnetic sensor may be beneficial when the medical device has limited space in one direction (i.e., the height direction of the flat magnetic sensor) and ample space in an orthogonal direction (i.e., the width direction of the flat magnetic sensor). The flat magnetic sensor can be placed within a distal feature of a diagnostic and/or therapeutic delivery catheter. For example, the flat magnetic sensor can be embedded within a wall (e.g., an interior support wall or a side wall) of an electrophysiology mapping catheter to measure a generated magnetic field to determine position and/or orientation of the flat magnetic sensor. In some embodiments, the flat magnetic sensor is positioned within an introducer or introducer catheter, for instance, within a wall of the introducer catheter (e.g., the Agilis™ NXT Steerable Introducers, commercially available from Abbott Laboratories or as seen generally by reference to U.S. Pat. No. 7,914,515 entitled "Catheter and introducer catheter having torque transfer layer and method of manufacture" to Heideman et al.).

[0018] The flat magnetic sensor may be sensitive to magnetic fields orthogonal to the one or more flat surfaces of the flat magnetically permeable core. For example, if a flat surface of the flat magnetically preamble core is orthogonal to an emitted magnetic field, the flat surface can receive the magnetic field through the flat surface and concentrate the magnetic field through the coil. Because the flat surface of the flat magnetically permeable core has a large width to height ratio (as compared to a cylindrical core which is 1:1), the flat magnetically permeable core is more sensitive to the magnetic field per unit of volume (i.e., cross-sectional area of cylindrical core is $d^2/4$ whereas cross sectional area of a thin, flat rectangular core is d×h, wherein d is width and h is height).

[0019] The flat magnetically preamble core may be formed of Metglas (a thin amorphous metal alloy ribbon produced by using rapid solidification process of approximately 1,000,000° C./s). Metglas has a maximum relative permeability of approximately 1,000,000 (μ/μ_0), making it the highest known magnetically permeable material (far greater than standard magnetically permeable cores such as nickel-iron soft ferromagnetic alloy, mu-metal having a maximum relative permeability of approximately 50,000 to 100,000).

[0020] FIG. **1A** illustrates a top view of a flat magnetic position sensor **100**, according to some embodiments. In some embodiments, the flat magnetic position sensor **100** is connected to a pair of connection wires **102** including a first connection wire **104** and a second connection wire **106**. In some embodiments, the flat magnetic position sensor **100** includes a coil **108** wound around a magnetically permeable core **110**, a first connection joint **112** and a second connection joint **114**, and a first core wire **124** and a second core wire **126**. The magnetically permeable core **110** includes a core length **116**, a core extension distance **120**, and a proximal end distance **122**. The coil **108** includes a coil length **118**.

[0021] The pair of connection wires **102** including the first wire **104** and the second wire **106** may be in a twisted pair configuration. For example, in many embodiments, the pair of connection wires **102** are intertwisted in a range of 10 to 30 turns per inch length, and in some embodiments, the pair of connection wires **102** are intertwisted in a range of 18 to 20 turns per inch length. The pair of connection wires **102** is configured to transmit electrical signals generated by the flat magnetic position sensor **100** in response to a magnetic field generated by a magnetic positioning system (not shown). In some embodiments, the ends of the pair of connection wires **102** are stripped and tinned to improve connection with the first connection joint **112** and the second connection joint **114**.

[0022] The pair of connection wires **102** including the first wire **104** and the second wire **106** are electrically coupled to the first coil wire **124** and the second coil wire **126** at the first connection joint **112** and the second connection joint **114**, respectively. In some embodiments, the first connection joint **112** and the second connection joint **114** (collectively referred to as the connection joints **112**, **114**) each include solder, and in some embodiments, the solder completely encapsulates each of the first wire **104** and the second wire **106** at the connection joints **112**, **114**. In some embodiments, the first coil wire **124** and the second coil wire **126** each include a service loop (i.e., excess coil wire in loop). Each of the first coil wire **124** and the second coil wire **126** overlap with the first wire **104** and second wire **106**, respectively. In some embodiments, a conductor of the first coil wire **124** contacts a conductor of the first wire **104** and/or solder in-contact with the first wire **104** and a conductor of the second coil wire **126** contacts a conductor of the second wire **106** and/or solder in-contact with the second wire **106**. In some embodiments, there is a gap between the connection joints **112**, **114** and the coil **108** and/or a gap between the first and second wire **104**, **106** and the coil **108**. In some embodiments, the connection joints **112**, **114** include a weld strain relief to prevent disconnection of the first and second wires **104**, **106**. The weld strain relief includes an adhesive layer and/or a wire

[0023] The coil **108** includes a conductive wire wound or wrapped around a longitudinal axis a of the magnetically permeable core **110**. For example, the coil includes a 53 AWG wire with **128** turns (or windings) per layer, with **256** turns total (2 layers, a first layer winding toward the distal end and a second layer winding back toward the proximal end), according to some embodiments. The coil **108** may generate a sensor output voltage of between 1-22 mV, and in some embodiments, may generate a sensor output voltage of between 5-8 mV when tested at 9kH. In some embodiments, the coil **108** may be coated with a layer of UV cure adhesive after the coil **108** is wound around the magnetically permeable core **110**.

[0024] The magnetically permeable core **110** includes a core length **116** extending along the longitudinal axis a. The coil length **118** is less than the core length **116**, and in some embodiments, the magnetically permeable core **110** includes a core extension distance **120** and a proximal end distance **122**. In some embodiments, the coil length **118** is less than 83% of the core length **116**. For example, in the embodiment illustrated in FIGS. **1A-C**, the coil length **118** is approximately 60% of the core length **116** (e.g., the coil length is 0.090" and the core length is 0.150"). The reduced longitudinal length of the coil **108** may be especially beneficial in a magnetic position sensor with a relatively small outer diameter (e.g., on the order of 1 French (0.33 millimeters) or less) in which small diameter wire (e.g., 58 AWG) is used to form the coil in order to keep the electrical resistance of the coil **108** below a suitable limit. The extension of the magnetically permeable core **110** beyond the coil **108** serves to concentrate magnetic field through the coil **108**, which increases the resulting voltage induced in the coil **108**. For example, magnetic field lines that interact with the extension (the core extension distance **120**) are directed into the coil **108** to increase the voltage response (e.g., intensify the sensitivity) of the coil **108**, thereby boosting the signal to noise ratio of the flat magnetic sensor **100**.

[0025] In some embodiments, the core extension distance **120** to coil length **118** ratio is between 1:2 and 1:10, and in some embodiments, the core extension distance **120** to coil length **118** ratio is between 1:3 and 1:7. For example, in the embodiment shown in FIGS. **1A-C**, the core extension distance **120** to coil length **118** ratio is approximately 1:3 (e.g., the core extension distance is 0.030" and the coil length is 0.090"). In some embodiments, the proximal end distance **122** to coil length **118** ratio is between 1:2 and 1:10, and in some embodiments, the proximal end distance **122** to coil length **118** ratio is between 1:3 and 1:7. For example, in the embodiment shown in FIGS. **1A-C**, the proximal end distance **122** to coil length **118** ratio is approximately 1:3 (e.g., the proximal end distance is 0.030" and the coil length is 0.090"). In some embodiments, the coil **108** is centered on the magnetically permeably core **110** such that the core extension distance **120** is approximately equal to the proximal end distance **122**. In some embodiments, the magnetically permeable core **110** does not extend beyond the coil **108** (e.g., the magnetically permeable core **110** extends an equal distance to the coil **108**), and in some embodiments, the coil **108** may extend further than the magnetically permeable core **110**.

[0026] FIG. **1**B illustrates a side view of the flat magnetic position sensor **100**, according to some embodiments. In some embodiments, the connection joints **112**, **114** are secured to a top surface of the magnetically permeable core **110**.

[0027] FIG. **1**C illustrates a front view of the flat magnetic position sensor **100**, according to some embodiments. In some embodiments, the magnetically permeable core **110** includes a first flat surface **140** and a second flat surface **142** parallel to the first flat surface **140**. In some embodiments, the magnetically permeable core **110** includes one or more third flat surfaces **144** positioned between the first flat surface **140** and the second flat surface **142**, for example, forming a rectangular cross sectional profile. Other cross sectional profiles are contemplated, including a substantially flat ellipse, an oval, a rectangle with rounded edges, etc.). In some embodiments, the proximal end of the magnetically permeable core **110** supports the first connection joint **112** and the second connection joint **114**. In some embodiments, the magnetically permeable core **110** is coated with a polyethylene terephthalate (PET) layer **146**.

[0028] The magnetically permeable core **110** includes a height **136** and a width **132**. In some embodiments, the magnetically permeable core **110** is a substantially thin and flat shape including a height to width ratio (i.e., the height **136** over the width **132**) less than 1:1. In some embodiments the height to width ratio of the magnetically permeable core **110** is between 1:4 and 1:50, in some embodiments the height to width ratio of the magnetically permeable core **110** is between 1:6 and 1:35, and in some embodiments the height to width ratio of the magnetically permeable core **110** is between 1:8 and 1:25. In some embodiments, including the example illustrated in FIG. **1**C, the height to width ratio of the magnetically permeable core **110** is preferably between 1:11 and 1:20 (e.g., the height is 0.0010"±0.0002" and the width is 0.015"±0.001").

[0029] The coil **108** includes a height **138** and a width **134**. In some embodiments, the coil **108** includes a coil thickness **128**, **130** dependent upon one or more of the thickness of the coil wire, the number of windings, and/or the number of winding layers. For example, some embodiments the coil wire is 53 AWG with **128** turns (or windings) per layer, with 2 total layers (a first layer winding toward the distal end and a second layer winding back toward the proximal end), resulting in the coil thickness **128**, **130** approximately equal to 0.0015". In some embodiments the height to width ratio of the coil **108** is between 1:2 and 1:30, in some embodiments the height to width ratio of the coil **108** is between 1:3 and 1:20, and in some embodiments the height to width ratio of the coil **108** is between 1:4 and 1:12. In some embodiments, including the example illustrated in FIG. **1**C, the height to width ratio of the coil **108** is between 1:4 and 1:5 (e.g., the height is 0.004" and the width is 0.018"=0.001").

[0030] In some embodiments, the magnetically permeable core **110** includes and/or is formed from a Metglas material (a thin amorphous metal alloy ribbon produced by using rapid solidification process of approximately 1,000,000° C./s). Metglas has a maximum relative permeability of approximately 1,000,000 ($\mu/\mu 0$), making it one of the highest known magnetically permeable material (far greater than standard magnetically permeable cores such as nickel-iron soft ferromagnetic alloy, mu-metal having a maximum relative permeability of approximately 50,000 to 100,000). The rapid solidification process used to create Metglas creates thin ribbons of Metglas which are difficult (or impossible) to form into cylindrical structures. Metglas is typically manufactured as a thin sheet. In some embodiments, one or more layers of Metglas are stacked and pressed to form the flat magnetically permeable core **110**. The flat magnetically permeable core **110** including Metglas enhances the signal to noise ratio of the flat magnetic sensor **100** and thereby enhances the reliability and accuracy of the magnetic positioning system.

[0031] In some embodiments, the flat magnetic sensor **100** provides a higher sensitivity detection of rotation than a cylindrical magnetic sensor. For example, in a standard cylindrical magnetic sensor, rotation of the sensor (i.e., radial rotation with the longitudinal axis of the cylinder magnetic sensor orthogonal to the magnetic field) may not be detected, as the voltage induced on the coil remains approximately constant. In contrast, the flat magnetic sensor is not a uniform shape about the longitudinal axis and therefore rotation of the sensor is detectable. In some embodiments, the flat magnetic sensor **100** expresses position and orientation data with six degrees-of-freedom (six DOF) as a 3D position (e.g., X, Y, Z coordinates) and 3D orientation (e.g., roll, pitch, and yaw).

[0032] In some embodiments, the flat magnetic sensor **100** may be sensitive to magnetic fields orthogonal to the one or more flat surfaces **140**, **142** of the flat magnetically permeable core **110**. For example, if a flat surface of the flat magnetically permeable core is orthogonal to an emitted magnetic field, the flat surface can receive the magnetic field through the flat surface and concentrate the magnetic field through the coil. Because the flat surface of the flat magnetically permeable core has a large width to height ratio (as compared to a cylindrical core which is 1:1), the flat magnetically permeable core is more sensitive to the magnetic field per unit of volume (i.e., cross-sectional area of cylindrical core is $d^2/4$ whereas cross sectional area of a thin, flat rectangular core is d×h, wherein d is width and h is height).

[0033] FIG. **2** illustrates high-density grid electrode assembly **200** of an example medical catheter that can include one or more instances of the flat magnetic position sensor **100**. The electrode assembly **200** includes five flexible splines **202** and spaced apart electrodes **204**. Each of the flexible splines **202** supports five of the electrodes **204**. The electrode assembly **200** is configured to self-expand from a collapsed delivery configuration wherein the flexible splines **202** are constrained within a lumen of an introducer catheter to the expanded configuration shown in FIG. **2**. The flexible splines **202** have a bending compliance that accommodates conforming the splines **202** to a tissue surface, such as an interior surface of a heart to place each of the electrodes **204** in contact with the tissue surface for using the electrodes **204** to perform a diagnostic and/or therapeutic medical procedure on the tissue. The electrode assembly **200** is mounted to the distal end of an elongate catheter shaft assembly **206**. As described herein, the flat magnetic position sensor **100** can have a small cross sectional profile that accommodates installation of the magnetic position sensor **200** within any one or more of the flexible splines **202**. For example, an instance of the flat magnetic position sensor **100** can be installed within a distal end portion **208** of the central flexible spline **202**. An instance of the flat magnetic position sensor **100** can be installed within a lumen of any of the flexible splines **202** at a suitable longitudinal location, such as, for example, between adjacent instances of the electrodes **204**. One or two instances of the flat magnetic position sensor **100** can be installed in slots **210** in the distal end of the elongate catheter shaft assembly **206**. The instances of the flat magnetic position sensor **100** included in the electrode assembly **200** can be used to generate signals indicative of the position and/or orientation of the corresponding locations of the electrode assembly **200** within a patient using a medical positioning system as described herein.

[0034] FIG. **3** illustrates an exemplary medical catheter **300** that can include one or more instances of the flat magnetic position sensor **100**. The catheter **300** includes a handle assembly **302** and an elongated shaft assembly **304**. The shaft assembly **304** includes a flexible shaft **306** and a steerable section **308**. The handle assembly **302** is drivingly coupled with the steerable section **308** and operable to selectively bend the steerable section **308** in two directions. As described herein, the flat magnetic position sensor **100** can have a small cross sectional profile that accommodates installation of the flat magnetic position sensor **100** within and/or distal to the steerable section **308**. The instances of the flat magnetic position sensor **100** included in the catheter **300** can be used to generate signals indicative of the position and/or orientation of corresponding locations of the catheter **300** within a patient using a medical positioning system as described herein.

[0035] FIG. **4**A is an isometric view of an exemplary introducer catheter **400**, according to some embodiments. The introducer catheter **400** includes an elongate shaft **404** with a lumen **402** extending therethrough, an outer wall **406** and an inner wall **410** defining a catheter side wall therebetween, and a distal end **408**. In some embodiments, the introducer catheter **400** is steerable and configured to deliver a medical instrument through the lumen **102** (e.g., the Agilis™ N×T Steerable Introducers, commercially available from Abbott Laboratories or as seen generally by reference to U.S. Pat. No. 7,914,515 entitled "Catheter and introducer catheter having torque transfer layer and method of manufacture" to Heideman et al.).

[0036] FIG. **4**B is a cross-sectional view of the introducer catheter **400**, according to some embodiments. The introducer catheter **400** includes a tapered distal portion **412** wherein the outer wall **406** converges toward the inner wall **410**. In some embodiments, a lumen diameter **414** remains approximately constant within the tapered distal portion. A first wall **420** of the elongate shaft **404** (i.e., the wall between the inner wall **410** and the outer wall **406** on the elongate shaft **404**) has a first wall thickness **416**. A distal portion wall **422** of the tapered distal portion **412** (i.e., the wall between the inner wall **410** and the outer wall **406** on the tapered distal portion **412**) has a second wall thickness **418**. The second wall thickness **418** gradually reduces toward the distal end **408**.

[0037] In some embodiments, the flat magnetic sensor **100** is positioned between the inner wall **410** and the outer wall **406**. For example, the flat magnetic sensor **100** is disposed within the first wall **420** of the elongate shaft **404** and/or within the distal portion wall **422** of the tapered distal portion **412**. The pair of wires **102** are positioned between the inner wall **410** and the outer wall **406**. The substantially flat and thin profile of the flat magnetic sensor **100** provides space optimization (i.e., efficient utilization of volume) within the catheter **400**. For example, the wall thicknesses **416**, **418** may be much too small for a conventional cylindrical magnetic sensor (i.e., there is limited space in the dimension between the inner wall **410** and the outer wall **406**). However, there is ample space in the orthogonal direction (i.e., along the circumference of the catheter **400**). Therefore, the flat magnetic sensor **100** is beneficial, as it has a narrow profile to fit within the thin walls **420**, **422**, and a wide profile along the circumference of the catheter **400** to enhance detection of magnetic fields.

[0038] FIG. **5** is a diagrammatic view of a medical device localization system **500** that can be used in conjunction with the flat magnetic position sensor(s) **100**. The system **500** includes a main electronic control unit **512** (e.g., a processor) having various input/output mechanisms **514**, a display **516**, an optional image database **518**, an electrocardiogram (ECG) monitor **520**, a localization system, such as a medical positioning system **522**, and a catheter **200**, **300**, **400**. As described herein, in some embodiments the catheter **200**, **300**, **400** includes the electrodes **204** and one or more of the flat magnetic position sensors **100**.

[0039] The input/output mechanisms **514** may include conventional apparatus for interfacing with a computer-based control unit including, for example, one or more of a keyboard, a mouse, a tablet, a foot pedal, a switch and/or the like. The display **516** may also comprise conventional apparatus, such as a computer monitor.

[0040] Various embodiments described herein may find use in navigation applications that use real-time and/or pre-acquired images of a region of interest. Therefore, the system **500** may optionally include the image database **518** to store image information relating to the patient's body. Image information may include, for example, a region of interest surrounding a destination site for the catheter **200**, **300**, **400** and/or multiple regions of interest along a navigation path contemplated to be traversed by the catheter **200**, **300**, **400**. The data in the image database **518** may include known image types including (1) one or more two-dimensional still images acquired at respective, individual times in the past; (2) a plurality of related two-dimensional images obtained in real-time from an image acquisition device (e.g., fluoroscopic images from an x-ray imaging apparatus), wherein the image database **418** acts as a buffer (live fluoroscopy); and/or (3) a sequence of related two-dimensional images defining a cine-loop wherein each image in the sequence has at least an ECG timing parameter associated therewith, adequate to allow playback of the sequence in accordance with acquired real-time ECG signals obtained from the ECG monitor **520**. It should be understood that the foregoing embodiments are examples only and not limiting in nature. For example, the image database **518** may also include three-dimensional image data as well. It should be further understood that the images may be acquired through any imaging modality, now known or hereafter developed, for example X-ray, ultra-sound, computerized tomography, nuclear magnetic resonance or the like.

[0041] The ECG monitor **520** is configured to continuously detect an electrical timing signal of the heart organ through the use of a plurality of ECG electrodes (not shown), which may be externally affixed to the outside of a patient's body. The timing signal generally corresponds to a particular phase of the cardiac cycle, among other things. Generally, the ECG signal(s) may be used by the control unit

512 for ECG synchronized play-back of a previously captured sequence of images (cine loop) stored in the database **518**. The ECG monitor **520** and ECG-electrodes may both include conventional components.

[0042] Another medical positioning system sensor, namely, a patient reference sensor (PRS) **526** (if provided in the system **500**) can be configured to provide a positional reference of the patient's body so as to allow motion compensation for patient body movements, such as respiration-induced movements. Such motion compensation is described in greater detail in U.S. patent application Ser. No. 12/650,932, entitled "Compensation of Motion in a Moving Organ Using an Internal Position Reference Sensor", hereby incorporated by reference in its entirety as though fully set forth herein. The PRS **526** may be attached to the patient's manubrium sternum or other location. The PRS **526** can be configured to detect one or more characteristics of the magnetic field in which it is disposed, wherein medical positioning system **522** determines a location reading (e.g., a P&O reading) indicative of the PRS's position and orientation in the magnetic reference coordinate system.

[0043] The medical positioning system **522** is configured to serve as the localization system and therefore to determine position (localization) data with respect to the one or more flat magnetic position sensors **100** and/or the electrodes **204** and output a respective location reading. In an embodiment, the medical positioning system **522** may include a first medical positioning system or an electrical impedance-based medical positioning system **522**A that determines locations of the electrodes **204** in a first coordinate system, and a second medical positioning system or magnetic field-based medical positioning system **522**B that determines location(s) of the flat magnetic position sensor(s) **100** in a second coordinate system. In an embodiment, the location readings may each include at least one or both of a position and an orientation (P&O) relative to a reference coordinate system (e.g., magnetic based coordinate system or impedance based coordinate system). In some embodiments, the P&O may be expressed with five degrees-of-freedom (five DOF) as a three-dimensional (3D) position (e.g., a coordinate in three perpendicular axes X, Y and Z) and two-dimensional (2D) orientation (e.g., a pitch and yaw) of the flat magnetic position sensor(s) **100** in a magnetic field relative to a magnetic field generator(s) or transmitter(s) and/or the electrodes **204** in an applied electrical field relative to an electrical field generator (e.g., a set of electrode patches). In some embodiments, the P&O may be expressed with six degrees-of-freedom (six DOF) as a 3D position (e.g., X, Y, Z coordinates) and 3D orientation (e.g., roll, pitch, and yaw).

[0044] The impedance based medical positioning system **522**A determines locations of the electrodes **204** based on capturing and processing signals received from the electrodes **204** and external electrode patches while the electrodes **204** are disposed in a controlled electrical field (e.g., potential field) generated by the electrode patches, for example. The MPS system **522**A may include various visualization, mapping and navigation components as known in the art, including, for example, an EnSite™ X EP System commercially available from Abbott Laboratories or as seen generally by reference to U.S. Pat. No. 7,263,397 entitled "Method and Apparatus for Catheter Navigation and Location and Mapping in the Heart" to Hauck et al., or U.S. Pat. Publication No. 2007/0060833 A1 to Hauck entitled "Method of Scaling Navigation Signals to Account for Impedance Drift in Tissue", both owned by the common assignee of the present invention, and both hereby incorporated by reference in their entireties.

[0045] The magnetic-based medical positioning system **522**B determines locations (e.g., P&O) of the flat magnetic position sensor(s) **100** in a magnetic coordinate system based on capturing and processing signals received from the flat magnetic position sensor(s) **100** while the flat magnetic position sensor **100** is disposed in a controlled low-strength alternating current (AC) magnetic (e.g., magnetic) field. The changing or AC magnetic field may induce a current in the coil(s) **108** when the coil(s) **108** are in the magnetic field. The flat magnetic position sensor(s) **100** is thus configured to detect one or more characteristics (e.g., flux) of the magnetic field(s) in which it is disposed and generate a signal indicative of those characteristics, which is further processed by medical positioning system **522**B to obtain a respective P&O for the flat magnetic position sensor(s) **100** relative to, for example, a magnetic field generator.

[0046] FIG. **6** illustrates another example medical positioning system **610** that can be employed in conjunction with a medical device **612** that includes one or more instances of the flat magnetic position sensor **100** to determine the position and/or orientations of the flat magnetic position sensor(s) **100** within a patient **614** and thereby corresponding location(s) and/or orientations of the medical device **612** within the patient **614**. While the medical device **612** is described in the following description as including one magnetic position sensor, the medical device **612** can include more than one instance of the flat magnetic position sensor **100** (e.g., 2, 3, 4, 5, or more instances of the flat magnetic position sensor **100**) and the system **610** can be process output from any suitable number of the flat magnetic position sensors **100** to determine the position and/orientation of the flat magnetic position sensors **100**. In some embodiments, the system **610** includes a display **616** and is configured to generate and display a model of an internal tissue surface of the patient **614** on the display **616** based on the determined positions and/or orientations of the flat magnetic position sensors **100**. The system **610** includes a moving imager **618**, which includes an intensifier **620** and an emitter **622**, and a magnetic positioning system (MPS) **624**, which includes field generators **628**. In some embodiments, the combination of the medical device **612** and the system **610** is configured to generate electrophysiology map information and cardiac mechanical activation data pertaining to the tissue model generated by medical imaging system **610** and display the map information and the activation data on the display **616** to facilitate diagnosis and treatment of the patient **614**. As described herein, the flat magnetic position sensor **100** may have an improved signal to noise ratio that enhances the accuracy and reliability of the determination of the location and/or orientation of the flat magnetic position sensor **100** by the system **610**.

[0047] The moving imager **618** acquires an image of a region of interest **630** while the patient **514** lies on an operation table **632**. The intensifier **620** and the emitter **622** are mounted on a C-arm **634**, which is positioned relative to the patient **614** using a moving mechanism **636**. In one embodiment, the moving imager **618** includes a fluoroscopic or X-ray type imaging system that generates a two-dimensional (2D) image of the heart of the patient **614**.

[0048] The magnetic positioning system (MPS) **624** includes magnetic field generators **628**. The MPS **624** determines the position and orientation of the flat magnetic position sensor **100** of the medical device **612** in a coordinate system based on output from the flat magnetic positioning sensor **100** while disposed in magnetic field(s) generated by the magnetic field generators **628**.

[0049] The C-arm **634** positions the intensifier **620** above the patient **614** and the emitter **622** underneath operation table **632**. The emitter **622** generates, and intensifier **620** receives, an imaging field FI, e.g., a radiation field, that generates a 2D image of the area of interest **630** on the display **616**. The intensifier **620** and the emitter **622** of the moving imager **618** are connected by the C-arm **634** so as to be disposed at opposites sides of patient **614** along an imaging axis AI, which extends vertically with reference to FIG. **6** in the described embodiment. The moving mechanism **636** rotates the C-arm **634** about a rotation axis AR, which extends horizontally with reference to FIG. **6** in the described embodiment. The moving mechanism **636** or an additional moving mechanism may be used to move the C-arm **634** into other orientations. For example, the C-arm **634** can be rotated about an axis (not shown) extending into the plane of FIG. **6** such that imaging axis A_I is rotatable in the plane of FIG. **6**. As such, the moving imager **618** can be associated with a three-dimensional imaging coordinate system having an x-axis (X_p), a y-axis (Y_p), and a z-axis (Z_p).

[0050] The magnetic positioning system (MPS) **624** is positioned to allow the medical device **612** and the field generators **628** to interact with the MPS **624** through the use of appropriate wired and/or wireless technology. The medical device **612** is inserted into the vasculature of the patient **614** such that flat magnetic position sensor **100** is located within the area of interest **630**. The field generators **628** are mounted to the intensifier **620** so as to be capable of generating a magnetic field (F_M) in the area of interest **630** coextensive with the imaging field FI. The MPS **624** is able to detect the position and orientation of the flat magnetic position sensor **100** within the magnetic field (F_M).

[0051] FIG. **7** illustrates a method **700** of assembling a flat magnetic position sensor, according to some embodiments. The method **700** includes step **710**, providing a flat magnetically permeable core **110** including Metglas. The method **700** includes step **720**, winding a coil wire **124**, **126** around the flat magnetically permeable core **110**. The method **700** includes step **730**, electrically coupling a pair of wires **102** to the core wire **124**, **126** on a flat surface **140** of the flat magnetically permeable core **110**.

[0052] While the invention has been described with reference to an exemplary embodiment(s), it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment(s) disclosed, but that the invention will include all embodiments falling within the scope of the appended claims.

Discussion of Possible Embodiments

[0053] The following are non-exclusive descriptions of possible embodiments of the present invention.

[0054] In some aspects, the techniques described herein relate to a magnetic position sensor for tracking a position of a medical device, the magnetic position sensor including: a magnetically permeable core including a longitudinal axis and a first flat surface extending parallel with the longitudinal axis; and a coil including a conductive wire wrapped around the longitudinal axis of the magnetically permeable core in a plurality of windings.

[0055] In some aspects, the techniques described herein relate to a magnetic position sensor, further including: a pair of wires electrically coupled to the conductive wire on the first flat surface of the magnetically permeable core.

[0056] In some aspects, the techniques described herein relate to a magnetic position sensor, wherein one or more layers of Metglas are stacked to the magnetically permeable core.

[0057] In some aspects, the techniques described herein relate to a magnetic position sensor, wherein the one or more layers of Metglas include a plurality of Metglas ribbons.

[0058] In some aspects, the techniques described herein relate to a magnetic position sensor, wherein the magnetically permeable core includes a second flat surface extending parallel to the longitudinal axis.

[0059] In some aspects, the techniques described herein relate to a magnetic position sensor, wherein the magnetically permeable core includes a core width and a core height, wherein a ratio of core height to core width is within a range of 1:4 and 1:50.

[0060] In some aspects, the techniques described herein relate to a magnetic position sensor, wherein the magnetically permeable core extends distal to a distal end of the coil by a core extension distance.

[0061] In some aspects, the techniques described herein relate to a magnetic position sensor, wherein a ratio of the core extension distance to a coil length of the coil is within a range of 1:2 and 1:10.

[0062] In some aspects, the techniques described herein relate to a magnetic position sensor, wherein the magnetically permeable core extends proximal to a proximal end of the coil.

[0063] In some aspects, the techniques described herein relate to a magnetic position sensor, wherein the plurality of windings of the coil extend a coil length along the longitudinal axis and the magnetically permeable core extends a core length along the longitudinal axis, wherein the coil length is less than 83% of the core length.

[0064] In some aspects, the techniques described herein relate to a method of assembling a magnetic position sensor, the method including: forming a magnetically permeable core from one or more Metglas layers, the magnetically permeable core including a longitudinal axis and a first flat surface extending parallel with the longitudinal axis; winding a conductive wire around the longitudinal axis of the magnetically permeable core to form a coil; and electrically coupling a pair of wires to the conductive wire.

[0065] In some aspects, the techniques described herein relate to a method, wherein the pair of wires are electrically coupled to the conductive wire on the first flat surface of the magnetically permeable core.

[0066] In some aspects, the techniques described herein relate to a method, wherein the magnetically permeable core includes a second flat surface extending parallel to the longitudinal axis.

[0067] In some aspects, the techniques described herein relate to a method, wherein the first flat surface of the magnetically permeable core defines a first plane and wherein the second flat surface of the magnetically permeable core defines a second plane, wherein the first plane is parallel to the second plane.

[0068] In some aspects, the techniques described herein relate to a method, wherein the magnetically permeable core is formed via stacking a plurality of Metglas ribbons.

[0069] In some aspects, the techniques described herein relate to a method, wherein the magnetically permeable core includes a core width and a core height, wherein a ratio of core height to core width is within a range of 1:6 and 1:35.

[0070] In some aspects, the techniques described herein relate to a method, wherein a distal portion of the magnetically permeable core extends distal to a distal end of the coil by a core extension distance, wherein the distal portion includes a flat distal surface parallel to the longitudinal axis of the magnetically permeable core.

[0071] In some aspects, the techniques described herein relate to a medical device, including: an elongate shaft including a side wall; and a magnetic position sensor, including: a magnetically permeable core including a longitudinal axis and a first flat surface extending parallel with the longitudinal axis, and a coil including a conductive wire wrapped around the longitudinal axis of the magnetically permeable core in a plurality of windings, wherein the magnetic position sensor is located in the side wall of the elongate shaft.

[0072] In some aspects, the techniques described herein relate to a medical device, wherein the longitudinal axis and the first flat surface are oriented parallel to the elongate shaft.

[0073] In some aspects, the techniques described herein relate to a medical device, wherein the first flat surface is oriented to face radially outward relative to the elongate shaft, wherein a pair of wires is electrically coupled to the conductive wire on the first flat surface of the magnetically permeable core.

What is claimed is:

1. A magnetic position sensor for tracking a position of a medical device, the magnetic position sensor comprising:

a magnetically permeable core including a longitudinal axis and a first flat surface extending parallel with the longitudinal axis; and

a coil including a conductive wire wrapped around the longitudinal axis of the magnetically permeable core in a plurality of windings.

2. The magnetic position sensor of claim **1**, further comprising:

a pair of wires electrically coupled to the conductive wire on the first flat surface of the magnetically permeable core.

3. The magnetic position sensor of claim **1**, wherein one or more layers of Metglas are stacked together to form the magnetically permeable core.

4. The magnetic position sensor of claim **3**, wherein the one or more layers of Metglas include a plurality of Metglas ribbons.

5. The magnetic position sensor of claim **1**, wherein the magnetically permeable core includes a second flat surface extending parallel to the longitudinal axis.

6. The magnetic position sensor of claim **5**, wherein the magnetically permeable core includes a core width and a core height, wherein a ratio of core height to core width is within a range of 1:4 and 1:50.

7. The magnetic position sensor of claim **1**, wherein the magnetically permeable core extends distal to a distal end of the coil by a core extension distance.

8. The magnetic position sensor of claim **7**, wherein a ratio of the core extension distance to a coil length of the coil is within a range of 1:2 and 1:10.

9. The magnetic position sensor of claim **1**, wherein the magnetically permeable core extends proximal to a proximal end of the coil.

10. The magnetic position sensor of claim **1**, wherein the plurality of windings of the coil extend a coil length along the longitudinal axis and the magnetically permeable core extends a core length along the longitudinal axis, wherein the coil length is less than 83% of the core length.

11. A method of assembling a magnetic position sensor, the method comprising:

forming a magnetically permeable core from one or more Metglas layers, the magnetically permeable core including a longitudinal axis and a first flat surface extending parallel with the longitudinal axis;

winding a conductive wire around the longitudinal axis of the magnetically permeable core to form a coil; and

electrically coupling a pair of wires to the conductive wire.

12. The method of claim **11**, wherein the pair of wires are electrically coupled to the conductive wire on the first flat surface of the magnetically permeable core.

13. The method of claim **11**, wherein the magnetically permeable core includes a second flat surface extending parallel to the longitudinal axis.

14. The method of claim **13**, wherein the first flat surface of the magnetically permeable core defines a first plane and wherein the second flat surface of the magnetically permeable core defines a second plane, wherein the first plane is parallel to the second plane.

15. The method of claim **11**, wherein the magnetically permeable core is formed via stacking a plurality of Metglas ribbons.

16. The method of claim **11**, wherein the magnetically permeable core includes a core width and a core height, wherein a ratio of core height to core width is within a range of 1:6 and 1:35.

17. The method of claim **11**, wherein a distal portion of the magnetically permeable core extends distal to a distal end of the coil by a core extension distance, wherein the distal portion includes a flat distal surface parallel to the longitudinal axis of the magnetically permeable core.

18. A medical device, comprising:

an elongate shaft including a side wall; and

a magnetic position sensor, including:

a magnetically permeable core including a longitudinal axis and a first flat surface extending parallel with the longitudinal axis, and

a coil including a conductive wire wrapped around the longitudinal axis of the magnetically permeable core in a plurality of windings, wherein the magnetic position sensor is located in the side wall of the elongate shaft.

19. The medical device of claim **18**, wherein the longitudinal axis and the first flat surface are oriented parallel to the elongate shaft.

20. The medical device of claim **18**, wherein the first flat surface is oriented to face radially outward relative to the elongate shaft, wherein a pair of wires is electrically coupled to the conductive wire on the first flat surface of the magnetically permeable core.

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