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(54) Title: OPTICAL-ELECTRICAL ROTARY JOINT AND METHODS OF USE

(57) **Abstract**: The present invention relates generally to rotatable optical couplings, and more particularly to a manually separable and re-connectable optical-electrical rotary joint. The invention provides a manually separable optical-electrical rotary joint in which an optical signal and electrical signal are transmitted while a downstream component rotates relative to an upstream component, for example, as driven by a motor at the upstream component. Further, the downstream component can be easily manually unplugged from the upstream component.

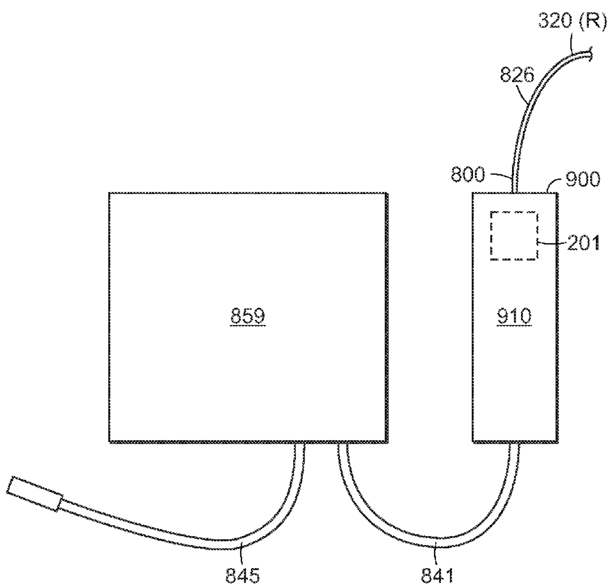

FIG. 1

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OPTICAL-ELECTRICAL ROTARY JOINT AND METHODS OF USE

Cross-reference to Related Application

This application claims priority to U.S. Provisional Application No. 61/529,746, filed August 31, 2011, the contents of which are hereby incorporated by reference in their entirety.

Field of the Invention

The present invention relates generally to an optical rotary joint, and more particularly to a manually connectable and dis-connectable optical-electrical rotary joint.

Background

Optical signals are used in such fields as communication, robotics, medical imaging, and navigational systems. For example, optical coherence tomography (OCT) involves imaging human tissue using optical fibers to carry the image signal. In OCT, an imaging engine uses a fiber optic catheter to send light into a patient's body to collect an image.

Electrical motors move the catheter into place and rotate it at speeds well above 10,000 RPM to collect the image. The rotation and the imaging are coordinated by a microchip in the imaging engine. The optical signal is digitized while electrical signals control the motors.

Where optical and electrical signals are transmitted together, joints present problems. For example, where a downstream component must rotate relative to an upstream instrument, a motor must be provided along the signal line to drive the rotation. Not only does arranging the signal lines around the motor pose logistical problems, the rotation causes problematic vibrations. For example, some optical couplings go out of alignment when rotated at 5,000 RPM.

Further, existing optical couplings are typically not easy to connect and dis-connect. To service or replace one component of an optical system can require replacement of the entire system or significant system down-time. Even a routine event such as sterilizing an imaging catheter can require a medical imaging system to be taken out of service because the catheter is fixed to the imaging engine.

Summary

The invention provides a manually connectable optical-electrical rotary joint across which optical and electrical signals are transmitted while a motor drives rotation of a downstream component. The downstream component can be unplugged from an upstream instrument and easily swapped for another downstream component. Because the rotary joint allows the component to be uncoupled from the instrument, the component can be serviced or replaced while the instrument remains in operation. Further, the rotary joint is designed to operate at rotational speeds in excess of 10,000 RPM without going out of alignment. Since the optical-electrical rotary joint stays in alignment at high speeds and is manually swappable, the invention allows optical-electrical systems to be used more productively with minimal down-time and makes servicing or replacing individual components easier and less costly. For example, OCT systems can use disposable, interchangeable imaging catheters (e.g., sterile, single-use catheters). Thus, the imaging engine of an OCT system can stay in continuous operation while a separate catheter can be used for each image capture operation.

In certain aspects, the invention provides an optical-electrical rotary joint in which an optical line and an electrical conductor in an upstream instrument are coupled to a downstream component to provide optical and electrical transmission while allowing for rotation of the downstream component. The optical signal is transmitted across the junction even during rotation by an arrangement of lenses. Electrical signals can be conducted through one, or a plurality of, conductive lines. Constant electrical contact across a rotating joint may be provided by any suitable mechanism such as slip rings, torroidal springs, contact brushes, pogo pins, conductive bands, or combination thereof. A motor is provided to drive rotation of the downstream component. The motor can be fixed within the instrument, which can be, for example, a medical imaging system. In certain embodiments, the upstream member is provided by a patient interface module (PIM) of an OCT system.

In certain embodiments, the downstream component is provided as a plug, capable of being plugged into a corresponding jack on the upstream instrument. In this way, the upstream and downstream members may be manually separable and joinable. Because the elements can be easily separated and connected, one of the components may be easily removed for cleaning or can even be provided as a sterile, disposable components, such as a medical imaging device.

In related aspects, the invention provides methods for carrying current and light across a rotating joint, suitable for optical systems such as medical imaging systems. The methods includes transmitting light between an upstream instrument and a downstream component, conducting electricity from the instrument to the component, and rotating the component relative to the instrument while transmitting the light and conducting the electricity. Further, any number of distinct electrical signals can be simultaneously conducted (e.g., via different wires).

In some embodiments, methods include manually connecting the component to the instrument, separating them, or both. Rotation of the component can be driven by a motor at the instrument. In certain embodiments, the light is transmitted via an optical path that is coaxial with a drive shaft of the motor.

In some aspects, the invention provides a plug for a rotary joint housing a contact point coupled to an electrical conductor and an end of an optical line. The plug is adapted to be manually inserted into a corresponding jack in an instrument such that the plug member can rotate relative to a corresponding optical conductor and electrical line in the instrument. The optical line can be an optical fiber. A number of electrical contact points and conductors can be included. The plug member may have a male form factor such as, for example, a cylindrical sleeve disposed coaxially with the optical fiber. Use of the plug allows for manual connection and dis-connection of the electoral conductor and optical line to a corresponding line and conductor in in the jack. In certain embodiments, the plug is provided as an end of an optical imaging device such as an imaging catheter in an OCT system. In some aspects, the invention provides a jack for a rotary joint housing a contact point coupled to an electrical conductor and an end of an optical line.

In certain aspects, the invention provides an optical rotary joint. An optical rotary joint according to the invention accommodates an optical path between stationary and rotating optical components in which one component is disposed in the optical path outside one end of a drive shaft and the other component is disposed in the optical path outside the opposite end of the shaft. The optical components preferably are lenses; including concave, convex, double convex, plano-convex, double concave, plano-concave, and prisms. Commonly, one or both of the optical components are a collimator or collimating lens. For example, a stationary collimating lens is disposed in an optical path outside a proximal end of a drive shaft and a rotating collimating lens is disposed outside the distal end of the shaft in the same optical pathway. The optical components may be fixedly or removable attached to the drive shaft. The drive shaft is preferably hollow in order to accommodate the optical path.

In another embodiment, an optical rotary joint comprises an optical path between stationary and rotating components including a drive motor with a drive shaft adapted to accommodate the optical path. A stationary collimating lens is attached to the drive motor and disposed in the optical path outside a proximal end of the hollow drive shaft. A rotating collimating lens is attached to the hollow drive shaft and disposed in the optical path outside a distal end of the hollow drive shaft.

In a further embodiment, an optical rotary joint comprises an optical path between stationary and rotating components including a drive motor slidably held within a receiver and including a hollow drive shaft adapted to accommodate the optical path. A stationary collimating lens is removably attached to the drive motor and disposed in the optical path outside a proximal end of the hollow drive shaft. A rotating collimating lens is rotatably disposed within a first housing such that when the first housing is removably attached to the receiver, the rotating collimating lens is removably attached to the hollow drive shaft and disposed in the optical path outside a distal end of the hollow drive shaft.

The foregoing and other features and advantages are defined by the appended claims. The following detailed description of exemplary embodiments, read in conjunction with the accompanying drawings is merely illustrative rather than limiting, the scope being defined by the appended claims and equivalents thereof.

Brief Description of the Drawings

In the accompanying figures, like elements are identified by like reference numerals among the several preferred embodiments of the present invention.

FIG. 1 shows components of an OCT system including a patient interface module (PIM).

FIG. 2 illustrates a PIM accommodating an optical-electrical rotary joint.

FIGS. 3A-3C illustrates the attachment of the components of an optical-electrical rotary joint housed within a catheter handle and a receiver.

FIGS. 4A and 4B illustrate an optical-electrical rotary joint with slip rings and contact brushes according to certain embodiments.

FIGS. 5A and 5B illustrate an optical electrical rotary joint with ring contacts according to certain embodiments.

FIG. 6 shows an electrical connection made with pogo pins.

FIG. 7 shows an electrical connection provided by cantilevers.

FIG. 8A illustrates a cross-sectional view of an embodiment of an optical rotary joint.

FIG. 8B illustrates a close-up view of section 8B of the proximal end of the optical rotary joint of FIG. 8A.

FIG. 9A is an enlarged cross-sectional view of the optical rotary joint of FIG. 8A.

FIG. 9B is a cross-sectional view along the line 9B—9B of FIG. 9A.

FIG. 9C is a cross-sectional view along the line 9C—9C of FIG. 9A.

FIGS. 10A-10C illustrate a drive shaft assembly in three configurations.

FIG. 11 illustrates an exemplary optical path through an optical rotary joint.

FIG. 12 illustrates the effect of angled lens surfaces on lateral offset of an input beam.

FIG. 13 shows the effect of angled lens surfaces on a change of angle of an input beam.

Detailed Description

The foregoing and other features and advantages of the invention are apparent from the following detailed description of exemplary embodiments, read in conjunction with the accompanying drawings. The detailed description and drawings are merely illustrative of the invention rather than limiting, the scope of the invention being defined by the appended claims and equivalents thereof.

The invention provides an optical-electrical rotary joint A rotary joint of the invention is useful in a rotational optical system in which light and current each carry signals between stationary and rotating optical elements. A rotary joint of the invention comprises a connector that facilitates connection and disconnection of the stationary and rotating optical-electrical components. The rotary joint is useful in any optical system comprising stationary and rotating optical-electrical components. Such systems include an Optical Coherence Tomography ("OCT") system, or may comprise another type of imaging system, including by way of example and not limitation, Intravascular Ultrasound ("IVUS"), spectroscopy, RAMAN, alternative interferometric techniques, therapeutic or diagnostic delivery devices, pressure wires, etc. In the case of an optical imaging system, light sources can be any laser source, broadband source, super-luminescent diode, tunable source, and the like. Communication between proximal and distal ends of any rotational imaging system may be via any suitable medium such as, for example, wires, optics, including fiber optics, lens systems, wireless, RF, etc.

FIG. 1 shows components of a system for OCT including a patient interface module (PIM) 900. An OCT system uses coherent light for imaging materials such as tissue of a patient. An OCT system may include an imaging engine 859 coupled to a workstation (e.g., a computer) via connector 845. Imaging engine 859 is further connected to the patient interface module (PIM) 900 by connection line 841. The mechanics of PIM 900 can be housed in a durable housing 910.

An imaging catheter 826 extends from PIM 900 to an imaging target (e.g., patient). Inside imaging catheter 826 is disposed optical fiber 320. Imaging catheter 826 is connected to PIM 900 at a rotary joint 201 through catheter handle 800, described in more detail herein. As illustrated by FIG. 1, PIM 900 is stationary (S) relative to fiber 320, which rotates (R) (i.e., relative to PIM 900 and housing 910.

FIG. 2 shows imaging catheter 826 connected to PIM 900 through the interaction of catheter handle 800 and receiver 700. As illustrated in FIG. 2, in some embodiments, PIM 900 includes a housing 910 accommodating a central seat 920 adapted to receive components of a rotary joint. For example, the PIM 900 includes a distal aperture 930 adapted to accommodate the receiver 700 removably attached to the catheter handle 800 as described herein with regard to FIGS. 3A-3C. The central seat 920 can also accommodate other components of an optical imaging system, for example a carriage or translatable drive stage 202 to accommodate the motor housing 450 (See FIGS. 3A-4C). The translatable drive stage 202 includes bearing 980 engaging guide rail 970 and lead screw 950 turned by motor 940 and controlled by circuit board 990.

In certain embodiments, motor housing 450 includes a motor to drive rotation of catheter 826. Motor 940 drives translation of drive stage 202, and thus translation of imaging catheter 826. By the combined rotation and translation of this apparatus, a distal end of the imaging catheter may take an image around and along the target tissue.

While imagining catheter 826 is being rotated by a motor mounted at motor housing 450, PIM housing 910 remains stationary (relative to the rotating imaging catheter). Due to the action of rotary joint 201, both optical communication and constant electrical contact are maintained across the junction between the rotating components and the stationary components.

In certain embodiments, rotary joint 201 is manually separable and re-connectable. A re-connectable optical electrical rotary joint can generally be described in terms of an upstream member or “jack” (e.g., housing 910 with receiver 700) and a downstream member or “plug” (e.g., catheter handle 800 including optical fiber 320).

Various mechanisms can provided constant electrical contact for one or more electrical lines across the joint. The electrical lines may include separate contact points for the rotary and connector functions. For example, in some embodiments, the rotary function is provided by a slip ring, and a separable, re-connectable connection is provided by conductive torroidal springs or pogo pins, discussed in greater detail below with reference to FIGS. 4A-7.

In certain embodiments, a single assembly provides rotary and connector functions. For example, a wire-brush slip ring assembly with clearance to support the axial connection motion can be included.

FIGS. 3A-3C illustrates catheter handle 800 coupling to receiver 700 to provide an operational rotary joint. For clarity, electrical lines and connections are not shown in FIGS. 3A-3C, and will be discussed with reference to FIGS. 4A-7 below. Catheter handle 800 may be provided as an end of imagining catheter 826 and receiver 700 may be mounted in PIM 900, as shown in FIG. 2.

As shown in FIGS. 3A-3C, a coupling 300 is provided at an end of imaging catheter 826 housed within catheter handle 800. Within receiver 700, motor housing 450 houses motor 400. Joining catheter handle 800 to receiver 700 (i.e., coupling imaging catheter 826 to PIM 900) positions coupling 300 within motor housing 450 so that rotary joint 201 transmits torque, translational forces, and optical and electrical signals.

To accomplish this, motor 400 is fixedly held within a lumen 410 longitudinally disposed through a motor housing 450 that may include or be attached to a carriage or longitudinally translatable drive stage 202 (see FIGS.10A-10C) that provides longitudinal translation of the hollow drive shaft 500 (and the housing 450) relative to a receiver 700. The coupling 300 is coaxially disposed within catheter handle 800. A rigid shaft 310 rotates freely within a support housing 208 which is supported by a vibration dampening mechanism 810 that is fixedly disposed to an internal surface of catheter handle 800. Connections of the motor 400 to the motor housing 450 and the vibration dampening mechanism 810 to the internal surface may be by connection methods including by way of example and not limitation, a friction fit with or without shims, a weld, an adhesive, etc.

Referring to FIG. 3A, the receiver 700 includes a lumen 720 disposed longitudinally therethrough. The motor housing 450 is disposed coaxially within the lumen 720 such that an annular space 730 is defined between the exterior surface of the motor housing and the inner surface of the lumen 720. As illustrated in FIG. 3B, upon initial engagement of the catheter handle 800 and the receiver 700, the catheter handle 800 is accommodated by the annular space 730. Such accommodation creates a preliminary alignment of the coupling 300 with the lumen 410.

A tapered feature 415 may be disposed at a distal end of the lumen 410 and the motor housing 450. As illustrated in FIG. 3C, upon further coaxial engagement of the catheter handle 800 within the annular space 730 of the receiver 700, the coupling 300 is guided by the tapered feature 415 into coaxial accommodation with the lumen 410. In an alternative embodiment, a tapered guide feature may be implemented on the proximal end of the coupling 300 instead of, or in addition to, the tapered feature 415. Such accommodation creates in turn a preliminary coaxial alignment of a distal end hollow drive shaft 500 with the lumen 360.

In certain embodiments, a distal end of the hollow drive shaft 500 includes an externally beveled feature 515 (see, e.g., FIG. 4B). In this embodiment, upon further engagement of the catheter handle 800 and the receiver 700, the lens holder 350 is guided by the beveled feature 515 to engage the lumen 360 and the hollow drive shaft 500. In some embodiments, a guide feature, for example, tapered feature 367 (see FIG. 9A) may be disposed at a proximal end of the lumen 360 instead of, or in addition to, beveled feature 515. The shape of the beveled features 415, 515, or the alternative embodiments may be straight or rounded to suit the intended use.

So aligned, the hollow drive shaft 500 may be removably attached within the lumen 360 (as described herein with regard to FIG. 8A). In an alternative embodiment, the engagement of the lumen 360 and the hollow drive shaft 500 may be effected by motion of the rotary drive motor 400 and associated components instead of, or in addition to, further engagement of the catheter handle 800 and the receiver 700.

Coincident with the removable attachment of the hollow drive shaft 500 within the lumen 360, the catheter handle 800 removably attaches to the receiver 700, by any method of removable attachment. For example, in one embodiment, slots 710 on the interior surface of the receiver 700 accommodate ribs 830 on the exterior surface of catheter handle 800. In this embodiment, as illustrated in FIGS. 3A-3C, the receiver 700 and the catheter handle 800 are oriented such that each rib 830 is disposed at an open end of each slot 710. So oriented, the receiver 700 is rotated relative to the catheter handle 800 so that each rib 830 enters each slot 710. Each rib 830 may further include a radial or longitudinal protrusion (not shown) at an end thereof that serves to snap onto a radial or longitudinal depression (not shown) within any or all of the slots 710. Such a snap fit may facilitate a locking attachment of the catheter handle 800 to the receiver 700, and the snap-locking bumps may be on the proximal face of the locking tab.

With handle 800 mounted in receiver 700 as shown in FIG. 3C, a functional optical-electrical rotary joint is provided, with coupling 300 at the downstream side of the joint and motor 400 at the upstream side of the joint. Further, the joint includes one or more of a contact point between a downstream electrical line and an upstream electrical line. Any suitable electrical contact point may be included. In some embodiments, an optical-electrical rotary joint is provided in which the electrical contact points employ one or more of a slip ring in contact with a contact brush; pogo pin; torroidal spring; ring contact; banded contact; cantilever; or combination thereof.

FIGS. 4A and 4B illustrate an optical-electrical rotary joint 201 with slip rings and contact brushes according to certain embodiments. As shown in FIG. 4A, in one embodiment, an exemplary optical rotary joint 201 comprises a coupling 300 operably coupled to a motor 400 having a hollow drive shaft 500, and a stationary lens holder 600 operably coupled to the proximal end of the hollow drive shaft 500. The hollow drive shaft 500 is rotationally driven by the motor 400. Referring to FIG. 4A, the coupling 300 is fixedly connected to a housing (e.g., rigid shaft 310) of a first optical fiber 320, which housing may also accommodate one or more electrical wires.

For electrical connection, joint 201 includes slip rings 521 in contact with contact brushes 525. As shown in FIG. 4B, slip rings 521 are mounted on an exterior surface of coupling 300 and are in electrically conductive contact with first wires 323. Contact brushes 525 are disposed within motor housing 450 such that when the downstream plug member is inserted into the upstream jack member, each slip ring 521 makes electrical contact with a contact brush 525. Contact brushes 525 are each connected to one of second wires 517 so that when joint 201 is engaged, while stationary as well as while rotating, each of first wires 323 is in constant electrical contact with a corresponding one of second wires 517.

For optical connection, coupling 300 has mounted therein a shaft 310 configured for transmission of light. In one embodiment, shaft 310 is a hollow shaft that accommodates an optical fiber concentrically disposed therethrough. In another embodiment, shaft 310 may be a solid shaft or rod that is longitudinally transmissive to light similar to an optical fiber. Shaft 310 may be manufactured from a material, including by way of example and not limitation, stainless steel, titanium, beryllium, copper, alloys of titanium, beryllium and/or copper, ceramic material such as alumina, light transmissive material such as glass or plastic, and the like. The rigidity of a ceramic material may control vibration of the housing during rotational movement. Connection of the housing to the coupling 300 may be via a connection method including by way of example and not limitation, a frictional fit, a snap fit, crimping, swaging, over-molding, an adhesive, a weld, magnetic connection, and the like. Materials for the coupling 300 may be any metal or plastic, such as poly-ether-ether ketone (PEEK), and the like.

Referring to FIGS. 4A, a first optical fiber 320 is disposed longitudinally through shaft 310 such that a first fiber ferrule 330 fixedly connects over an end of the first optical fiber 320. The first optical fiber 320 may be a single mode optical fiber, multi-mode optical fiber, and the like. The first fiber ferrule 330 can be made from a material that has properties similar to that of the first optical fiber 320. For example, the first fiber ferrule 330 may be made from glass to match coefficient of thermal expansion with the first optical fiber 320. The first optical fiber 320 may be connected to the first fiber ferrule 330 by a connection method including by way of example and not limitation, an adhesive, a weld, splicing, fusion, and the like. Alternatively, the first optical fiber 320 may be manufactured integrally with the first fiber ferrule 330.

The first optical fiber 320 is disposed approximately concentrically or coaxially within the shaft 310 and rotates with shaft 310. A distal end of shaft 310 may extend to a flexible drive cable of imaging catheter 826.

As shown in FIG. 4A, a first collimating lens 340 is disposed in optical communication with a proximal end of the first optical fiber 320, e.g., fixedly attached to the proximal end of the first fiber ferrule 330. The first collimating lens 340 may include an outer circumference or exterior surface that is coterminous with the exterior surface of the first fiber ferrule 330. The first collimating lens 340 may be attached to the first fiber ferrule 330 via a connection method including by way of example and not limitation, a frictional fit, a snap fit, a weld, an adhesive, and the like. The first fiber ferrule 330 facilitates stronger attachment of the first optical fiber 320 to the first collimating lens 340.

In another embodiment, the first fiber ferrule 330 may be disposed within a ferrule sleeve or ring 335 to reinforce attachment of the first fiber ferrule 330 and the first collimating lens 340 (see, e.g., FIG. 9A and related discussion).

In certain embodiments, the first collimating lens 340 is fixedly held by a lens holder 350, for example, by a connection method including by way of example and not limitation, a frictional fit, a snap fit, an adhesive, a split sleeve with a clamping ring, and the like. The lens holder 350 may be manufactured from any material having suitable dimensional stability, suitable dynamic coefficient of friction, and suitable stiffness. Suitable materials for the lens holder 350 include by way of example and not limitation, stainless steel, aluminum, or thermoplastics such as polyetheretherketone (PEEK) or polyoxymethylene (POM), which is sold under the trademark DELRIN by E. I. du Pont de Nemours and Company, USA.

In another embodiment, the lens holder 350 may further be fixedly held to the proximal end of the first fiber ferrule 330. In another embodiment, the lens holder 350 may be further fixedly held to a proximal end of a ferrule sleeve. Connection of the lens holder 350 to fiber ferrule 330 (and/or to an optional ferrule sleeve) may be by a connection method including by way of example and not limitation, a frictional fit, a snap fit, a weld, an adhesive, and the like.

As shown in FIG. 4B, coupling 300 is manually separable from, and re-connectable to, motor housing 450. Accordingly, coupling 300 with catheter handle 800 together provide a "plug" that is separable from, and re-connectable to, a "jack" provided by receiver 700 and motor housing 450.

Referring to FIG. 4B, hollow drive shaft 500 extends from motor 400. A distal portion of the hollow drive shaft 500 is configured to be inserted into lens holder 350 and align with first collimating lens 340 when coupling 300 is coupled to housing 450 (i.e., when the plug is inserted into the jack). Insertion of coupling 300 into housing 450 may result in hollow drive shaft 500 being inserted into a lumen in lens holder 350. Preferably, hollow drive shaft 500 removably attaches within the lumen to facilitate removal and replacement of plug member 513 when in use in the field.

The lumen of lens holder 350 may include internal shoulders, which may facilitate precise alignment between hollow drive shaft 500 and lens holder 350 and/or removable attachment of the hollow drive shaft 500 within the lumen 360. The lumen of lens holder 350 may define a sloped interior portion dimensioned to accommodate the cross-sectional configuration of the drive shaft 500. As discussed below with reference to FIGS. 9A and 9C, lens holder 250 may include a stop for positioning collimating lens 340 and/or hollow drive shaft 500 within lens holder 350. The stop can hold lens 340, shaft 500, or both and prevent the relative motion of the parts.

The coupling 300 accommodates shaft 310, the first fiber ferrule 330, the first collimating lens 340, lens holder 350, and first wire(s) 323 in a way that transfers torque from the hollow drive shaft 500 to coupling 300, but also inhibits vibration of the apparatus from affecting angular alignment of the first collimating lens 340. This may be achieved by a configuration that provides for co-rotation or simultaneous rotation of the first optical fiber 320, the first fiber ferrule 330, collimating lens 340, and wire(s) 323 with the device without rigid or fixed attachment therebetween. The fit-up of drive shaft 500 and lens holder 350 is tightly controlled to provide more axial force and torque than is required to move the catheter core in its sheath and less axial force than would damage the bearings of motor 400. Shoulders within lens holder 350 help control the spring constant and hence grip on the shaft. Elasticity and coefficient of thermal expansion of the lens holder 350 material are both carefully chosen to provide the required range of engagement force and torque over the require range of operating conditions, especially at rotational speeds as high as between about 10,000 and 20,000 RPM.

In certain embodiments, lens holder 350 engages the coupling 300 by having a cross-sectional shape that is not free to rotate within coupling 300 (see, e.g., FIG. 9B). Lens holder 350 and coupling 300 may include any complementary shape that does not allow their relative rotation, such as polygonal, triangular, pentagonal, hexagonal, octagonal, trapezoidal, and the like. Thus, the lens holder 350 is not fixedly held to the coupling 300; however, rotation of the lens holder 350 is coupled to rotation of the coupling 300, which, in turn is coupled to rotation of the housing.

Vibration of shaft 310 may be reduced by decoupling transfer of moments between the lens holder 350 and the coupling 300 in a direction transverse to the longitudinal axis. Such decoupling may be achieved, for example, by a configuration including a plurality of pins presented by an inner surface of coupling 300 to a circumferential groove in an outer surface of the lens holder 350 (see FIGS. 2A and 2C). The pins may be spring loaded and biased inward, or may be press fit through holes in coupling 300. Such a pin-and-groove configuration facilitates longitudinal application of force between the lens holder 350 and the coupling 300 without a fixed or rigid connection therebetween.

The design reduces the effect of vibration of housing on the angular alignment of collimating lens 340.

In some embodiments, roll or rotation is transmitted by the square end of the lens holder 350 engaging the square pocket in the coupling 300. Pitch and yaw, which are the transverse angular alignments to the roll/rotation, are left free. Longitudinal force, “Z”, is transmitted by the pins 375 in groove 380. Transverse forces, “X” and “Y”, are transmitted by the square end/square pocket apposition. In one embodiment, at least 2 pins 375 transmit a longitudinal force while allowing the pitch and yaw motion, as described above. This may be precisely symmetric with respect to pitch and yaw motions or asymmetric with respect to the pitch and yaw motions. Alternatively, the pins 375 could also provide transverse restraint.

The hollow drive shaft 500 is rotationally driven by the motor 400. In one embodiment, the motor 400 is disposed concentrically around the hollow drive shaft 500. Such an arrangement may facilitate a reduction in the number of moving parts and a reduction in size of the optical rotary joint 201. In other embodiments, the motor 400 may include a separate housing 450 and be disposed apart from the hollow drive shaft 500 such that the hollow drive shaft 500 is driven by the motor 400 via, for example, an external gear train, belt, chain, or other mechanism for transfer of torque from the motor 400 to the hollow drive shaft 500 as may be known in the art. An exemplary motor 400 capable of producing rotational speeds in excess of 10,000 RPM, alternatively between about 10,000 and 20,000, is the Maxon DC motor sold by Maxon Precision Motors, Inc. (Fall River, MA).

As shown in FIG. 4A, hollow drive shaft 500 freely rotates proximate to a second collimating lens 610 fixedly held within stationary lens holder 600. The stationary lens holder 600 receives an end of hollow drive shaft 500. The second collimating lens 610 is optically coupled to the optical path within the hollow drive shaft 500. The stationary lens holder 600 may be attached to the motor 400 via a connection method including by way of example and not limitation, a frictional fit, a snap fit, crimping, swaging, overmolding, an adhesive, a weld, a magnetic fit, and the like. A second fiber ferrule 620 is attached to the second collimating lens 610. The second fiber ferrule 620 fixedly connects to a second optical fiber 630, as shown in FIG. 4A, which delivers light to and/or receives light from the second collimating lens 610 from a light source (not shown), such that the light may pass from the second optical fiber 630 to the collimating lens 610. In one embodiment, an end of the second optical fiber 630 is coaxially disposed with the second fiber ferrule 620. The second optical fiber 630 may be a single mode or multi-mode optical fiber. The second fiber ferrule 620 is made from a material that has properties similar to that of the second optical fiber 630. For example, the second fiber ferrule 620 may be made from glass to match coefficient of thermal expansion with the second optical fiber 630. The second optical fiber 630 may be connected to the second fiber ferrule 620 by a connection method including by way of example and not limitation, an adhesive, a weld, splicing, fusion, etc. Alternatively, the second optical fiber 630 may be manufactured integrally with the second fiber ferrule 620.

As shown in FIG. 4A, the second collimating lens 610 is disposed in optical communication with a distal end of the second optical fiber 630. The second collimating lens 610 may be made from an optical material having an internally variable index of refraction and may be the same as or different from the first collimating lens 340. For example, in one embodiment, the second collimating lens 610 is a lens having a radial index gradient such as a gradient index ("GRIN") or self focusing ("SELFOC") lens. In other embodiments, other types of collimating lenses may be used, such as devices that narrows a beam of light or causes the directions of motion to become more aligned in a specific direction (i.e. collimated or parallel) or to cause the spatial cross section of the beam to become smaller.

In one embodiment, the second collimating lens 610 is fixedly attached to the distal end of the second fiber ferrule 620. The second collimating lens 610 may be attached to the second fiber ferrule 620 via a connection method including by way of example and not limitation, a frictional fit, a snap fit, an adhesive, etc. It is contemplated that the second fiber ferrule 620 facilitates stronger attachment of the second optical fiber 630 to the second collimating lens 610.

In another embodiment, the second collimating lens 610 is fixedly held by the stationary lens holder 600 by a connection method including by way of example and not limitation, a frictional fit, a snap fit, an adhesive, etc. The stationary lens holder 600 may be manufactured from a material including by way of example and not limitation, stainless steel, aluminum, or plastics such as polyetheretherketone (PEEK) or polyoxymethylene (POM).

Electrical contact may be provided by any suitable mechanism. In certain embodiments, for example, as shown in FIGS. 4A and 4B, electrical contact is provided by slip rings and contact brushes. Other electrical contact mechanisms are provided including, for example, ring contacts, pogo pins, and cantilever contacts.

FIGS. 5A and 5B illustrate an optical electrical rotary joint with ring contacts according to certain embodiments. As shown in FIG. 5A, first wires 323 enter a distal end of coupling 300. Each of first wires 323 is in electrical contact with one of banded contacts 649 on an outer surface of lens holder 350. As shown in FIG. 5B, lens holder 350 and coupling 300 cooperate to define a plug member configured to be inserted into a lumen of jack member 529. Within jack member 529, a number of ringed contacts 633 are disposed to each make contact with one of banded contacts 649.

Jack member 529 is fixed to a set of rotating slip rings 641, which rotate relative a set of stationary permanent slip rings 645. As shown in FIG. 5B, R indicates a component that rotates relative to the components marked with an S. Jack member 529 is mounted within motor 400, which drives its rotation. Stationary slip rings 645 are mounted within motor housing 450 and each in contact with one of second wires 517.

As discussed above with reference to FIGS. 4A and 4B, optical communication across rotary joint 203 is provided by an optical path through first collimating lens 340 held by lens holder 350 and second collimating lens 610 mounted through a second fiber ferrule 620.

While rotating (R) components are rotating relative to stationary (S) components, optical communication and constant electrical contact are maintained across rotary joint 203 by the optical path and electrical contacts. Light is transmitted between first optical fiber 320 and second optical fiber 630 while current is transmitted along first wires 323 and second wires 517.

Other electrical contact mechanisms are included within the invention. For example, FIG. 6 shows an electrical connection made with pogo pins. For the sake of clarity, only certain components are shown in FIG. 6. First wires 323 enter coupling 300 and are connected to contact bands 649. Each of the contact bands 649 is in contact with at least one of pogo pins 753 mounted within jack member 529. In some embodiments (pictured), jack member 529 remains stationary relative to coupling 300. In certain embodiments, jack member 529 and coupling 300 are stationary relative to each other and rotate together relative to an upstream motor and associated hardware with electrical connection maintained through slip rings (as illustrated, for example, in FIG. 5A).

In some embodiments, electrical contact is provided through the use of conductive cantilevered tabs in the form of one or more of cantilever 757, as shown in FIG. 7. As shown in FIG. 7, within coupling 300, wires can be connected to one or more band member 649. Each of band member 649 makes electrical contact with one of cantilever 757 provided with jack member 529. In some embodiments (pictured), jack member 529 remains stationary relative to coupling 300. In certain embodiments, jack member 529 and coupling 300 are stationary relative to each other and rotate together relative to an upstream motor and associated hardware with electrical connection maintained through slip rings (as illustrated, for example, in FIG. 10A).

As discussed above, the invention provides a manually separable and re-connectable optical-electrical rotary joint. Through the use of a joint of the invention, a component of an optical-electrical system such as an OCT system can be easily connected to, and separated from, another component. For example, an imaging catheter can be connected to a PIM in an OCT system. Because the optical-electrical rotary joint is easy and quick to connect and affordable to manufacture, an imaging catheter (or other component) can be provided that is disposable or designed for easy removal for sterilization.

Because the patient imaging component (the catheter) can be disconnected from the operating hardware (PIM 900 and imaging engine 859), the operating hardware can be kept in constant operation even when any given imaging component is taken out of service (e.g., for replacement or cleaning).

In some systems, rotational electrical contact is not needed. Accordingly, in some aspects and embodiments, the invention provides an optical rotary joint, such as a fiber-optic rotary joint (FORJ). In certain embodiments, an optical rotary joint such as a FORJ is manually separable and re-connectable.

Generally speaking, an optical rotary joint facilitates alignment and transmission of light between rotating optical components and stationary optical components. As shown in FIG. 8A, in one embodiment, an exemplary optical rotary joint 200 comprises a coupling 300 operably coupled to a motor 400 having a hollow drive shaft 500, and a stationary lens holder 600 operably coupled to the proximal end of the hollow drive shaft 500. The hollow drive shaft 500 is rotationally driven by the motor 400, as indicated by arrow 510. The longitudinal axis 302 of the first is generally shown in the x-axis direction, while the transverse axis is generally shown in the y-axis.

Referring to FIGS. 8A and 9A, the coupling 300 is fixedly connected to a rigid shaft 310 that extends from a distal end 315 of the coupling 300, such that the rigid shaft 310 rotates with the coupling 300. In one embodiment, the rigid shaft 310 is a hollow shaft that accommodates an optical fiber concentrically disposed therethrough. In another embodiment, the rigid shaft 310 may be a solid shaft or rod that is longitudinally transmissive to light similar to an optical fiber. The rigid shaft 310 may be manufactured from a material, including by way of example and not limitation, stainless steel, titanium, beryllium, copper, alloys of titanium, beryllium and/or copper, ceramic material such as alumina, light transmissive material such as glass or plastic, and the like. The rigidity of a ceramic material may control vibration of the rigid shaft 310 during rotational movement. Connection of the rigid shaft 310 to the coupling 300 may be via a connection method including by way of example and not limitation, a frictional fit, a snap fit, crimping, swaging, overmolding, an adhesive, a weld, magnetic connection, and the like. Materials for the coupling 300 may be any metal or plastic, such as polyetheretherketone (PEEK), and the like.

Referring to FIGS. 8A and 9A, a first optical fiber 320 is disposed longitudinally through the rigid shaft 310 such that a first fiber ferrule 330 fixedly connects over a proximal end 325 of the first optical fiber 320. The first optical fiber 320 may be a single mode optical fiber, multi-mode optical fiber, and the like. The first fiber ferrule 330 is made from a material that has properties similar to that of the first optical fiber 320. For example, the first fiber ferrule 330 may be made from glass to match coefficient of thermal expansion with the first optical fiber 320. The first optical fiber 320 may be connected to the first fiber ferrule 330 by a connection method including by way of example and not limitation, an adhesive, a weld, splicing, fusion, and the like. Alternatively, the first optical fiber 320 may be manufactured integrally with the first fiber ferrule 330.

The first optical fiber 320 is disposed approximately concentrically or coaxially within the rigid shaft 310 and rotates with the rigid shaft 310. The rigid shaft 310 connects on a distal end thereof to another portion of a flexible drive cable (not shown) ultimately including an optical probe (not shown) at a distal end of the flexible drive cable. Examples of a flexible drive cable, an imaging system including an optical probe rotating at a distal end of a flexible drive cable, may be found, for example, in Dick et al., U.S. Pub. 2009/0018393; Kemp et al., U.S. Pub. 2009/0046295; and Castella, et al., U.S. Pub. 2009/0043191, all of which are hereby incorporated by reference in their entirety herein.

As shown in FIG. 9A, a first collimating lens 340 is disposed in optical communication with a proximal end of the first optical fiber 320. The first collimating lens 340 may be made from an optical material having an internally variable index of refraction. For example, in one embodiment, the first collimating lens 340 is a lens having a radial index gradient. Such a lens, known in the art as a gradient index ("GRIN") or self-focusing ("SELFOC") lens facilitates the ability to precisely focus light using a simple, compact lens geometry, (NSG Europe, Belgium). In other embodiments, other types of collimating lenses as known in the art may be used.

In one embodiment, the first collimating lens 340 is fixedly attached to the proximal end of the first fiber ferrule 330. The first collimating lens 340 may include an outer circumference or exterior surface that is coterminous with the exterior surface of the first fiber ferrule 330. The first collimating lens 340 may attached to the first fiber ferrule 330 via a connection method including by way of example and not limitation, a frictional fit, a snap fit, a weld, an adhesive, and the like. The first fiber ferrule 330 facilitates stronger attachment of the first optical fiber 320 to the first collimating lens 340.

In another embodiment, referring to FIG. 9A, the first fiber ferrule 330 may be disposed within a ferrule sleeve or ring 335 to reinforce attachment of the first fiber ferrule 330 and the first collimating lens 340. The ferrule sleeve 335 may be circular or polygonal configuration that tightly fits over the exterior surface of the first fiber ferrule 330 and first collimating lens 340. The ferrule sleeve 335 may be manufactured from a material including by way of example and not limitation, metal, stainless steel, poly-methyl-methacrylate (PMMA), other plastic, and the like. The ferrule sleeve 335 may attach over the first fiber ferrule 330 and/or the first collimating lens 340 via a press fit, an adhesive, a snap fit, magnetic fit, or other methods of attachment.

In one embodiment, the first collimating lens 340 is fixedly held by a lens holder 350. In this embodiment, for example referring to FIGS. 8A and 9A, the first collimating lens 340 is disposed within or engaged with a distal end of a lumen 360 disposed longitudinally through the proximal end of the lens holder 350 by a connection method including by way of example and not limitation, a frictional fit, a snap fit, an adhesive, a split sleeve with a clamping ring, and the like. The lens holder 350 may be manufactured from any material having suitable dimensional stability, suitable dynamic coefficient of friction, and suitable stiffness. Suitable materials for the lens holder 350 include by way of example and not limitation, stainless steel, aluminum, or thermoplastics such as polyetheretherketone (PEEK) or polyoxymethylene (POM), which is sold under the trademark DELRIN by E. I. du Pont de Nemours and Company, USA.

In another embodiment, the lens holder 350 may further be fixedly held to the proximal end of the first fiber ferrule 330. In another embodiment, the lens holder 350 may be further fixedly held to a proximal end of the ferrule sleeve 335. In yet a further embodiment, the lens holder 350 may further be fixedly held to the proximal ends of both the first fiber ferrule 330 and the ferrule sleeve 335. Connection of the lens holder 350 to either or both of the fiber ferrule 330 and the ferrule sleeve 335 may be by a connection method including by way of example and not limitation, a frictional fit, a snap fit, a weld, an adhesive, and the like.

Referring to FIG. 8A, a distal portion of the hollow drive shaft 500 longitudinally extends from a distal end 405 of the motor 400. The distal portion of the hollow drive shaft 500 attaches within the lumen 360 that includes an opening on a proximal side of the lens holder 350 such that the hollow drive shaft 500 is longitudinally and coaxially aligned with the first collimating lens 340. Attachment of the hollow drive shaft 500 within the lumen 360 of the lens holder 350 may be by a connection method including by way of example and not limitation, a frictional fit, a snap fit, an adhesive, a weld, and the like. In one embodiment, the hollow drive shaft 500 removably attaches within the lumen 360 to facilitate removal and replacement of the motor 400 when in use in the field.

Referring to FIG. 9A, the lumen 360 is illustrated as having a luminal surface including one or more internal shoulders 370 at the proximal and distal ends of the lumen 360, which may facilitate precise alignment between hollow drive shaft 500 and lens holder 350 and/or removable attachment of the hollow drive shaft 500 within the lumen 360. In one embodiment, the internal shoulders 370 is a sloped inner diameter (ID) of the lumen 360, whereby the distal end of the motor shaft 500 abuts with the internal shoulders 370. In one embodiment, the ID is cylindrical or polygonal as to accommodate the cross-sectional configuration of the drive shaft 500. Preferably, the internal shoulders 370 avoids contact with the middle portion of the shaft 500 for precise alignment. In one embodiment, a stop 375 facilitates precise positioning of first collimating lens 340 and/or hollow drive shaft 500 within lens holder 350. The stop 375 prevents the lens 340 from moving proximally on the distal side of the stop 375 and the stop 375 prevents the motor shaft 500 from moving distally on the proximal side of the stop 375. In one embodiment, the stop 375 is integral with lens holder 350. Alternatively, the stop 375 could be fixedly attached to the distal end of lens holder 350.

The coupling 300 accommodates the rigid shaft 310, the first fiber ferrule 330, the first collimating lens 340, and the lens holder 350 in a way that transfers torque from the hollow drive shaft 500 to the rigid shaft 310, but also inhibits vibration of the rigid shaft 310 from affecting angular alignment of the first collimating lens 340. The accommodation of coupling 300 may be achieved by a configuration that provides for co-rotation or simultaneous rotation of the first optical fiber 320, the first fiber ferrule 330, and the first collimating lens 340 with the rigid shaft 310 without rigid or fixed attachment therebetween. The fit-up of shaft 500 and lens holder 350 is tightly controlled to provide more axial force and torque than is required to move the catheter core in its sheath and less axial force than would damage the bearings of motor 400. Shoulders 370 help control the spring constant and hence grip on the shaft. Elasticity and coefficient of thermal expansion of the lens holder 350 material are both carefully chosen to provide the required range of engagement force and torque over the require range of operating conditions, especially at rotational speeds as high as between about 10,000 and 20,000 RPM.

For example, referring to FIGS. 9A-9C, in one embodiment, the lens holder 350 engages the coupling 300 by having at least a proximal end 355 including a cross-sectional shape that is not free to rotate within the distal end of a bore 365 of the coupling 300. Such a shape is illustrated in FIG. 9B as a square or rectangular cross-section; however, the cross-sectional shape of at least the proximal end 355 of the lens holder 350 and the distal end of the bore 365 may be any complementary shape that does not allow rotation of at least the proximal end 355 of the lens holder 350 within the bore 365, such as polygonal, triangular, pentagonal, hexagonal, octagonal, trapezoidal, and the like. Thus, the lens holder 350 is not fixedly held to the coupling 300; however, rotation of the lens holder 350 is coupled to rotation of the coupling 300, which, in turn is coupled to rotation of the rigid shaft 310.

The effects of vibration of the rigid shaft 310 may be reduced by decoupling transfer of moments between the lens holder 350 and the coupling 300 in a direction transverse to the longitudinal axis. Such decoupling may be achieved, for example, by a configuration including a plurality of pins 375 that are accommodated within one or more circumferential grooves 380 disposed in an outer surface of the lens holder 350, as illustrated in FIGS. 9A and 9C. The plurality of pins 375 may be spring loaded and biased inward, or may be press fit through corresponding holes (not shown) disposed radially through the coupling 300. Such a configuration including the plurality of pins 375 disposed in the one or more circumferential grooves 380 facilitates longitudinal application of force between the lens holder 350 and the coupling 300 without a fixed or rigid connection therebetween.

The design reduces the effect of vibration of rigid shaft 310 on the angular alignment of collimating lens 340. With respect to the 6 degrees of freedom between the fixed and rotating portions of the joint, roll or rotation is transmitted by the square end of the lens holder 350 engaging the square pocket in the coupling 300. Pitch and yaw, which are the transverse angular alignments to the roll/rotation, are left free. Longitudinal force, "Z", is transmitted by the pins 375 in groove 380. Transverse forces, "X" and "Y", are transmitted by the square end/square pocket apposition. In one embodiment, at least 2 pins 375 transmit a longitudinal force while allowing the pitch and yaw motion, as described above. This may be precisely symmetric with respect to pitch and yaw motions or asymmetric with respect to the pitch and yaw motions. Alternatively, the pins 375 could also provide transverse restraint.

The hollow drive shaft 500 is rotationally driven by the motor 400, as indicated by arrow 510 in FIG. 8A. In one embodiment, the motor 400 is disposed concentrically around the hollow drive shaft 500. Such an arrangement may facilitate a reduction in the number of moving parts and a reduction in size of the optical rotary joint 200. In other embodiments, the motor 400 may include a separate housing 450, as shown in FIG. 3A, and be disposed apart from the hollow drive shaft 500 such that the hollow drive shaft 500 is driven by the motor 400 via, for example, an external gear train, belt, chain, or other mechanism for transfer of torque from the motor 400 to the hollow drive shaft 500 as may be known in the art. An exemplary motor 400 capable of producing rotational speeds in excess of 10,000 RPM, alternatively between about 10,000 and 20,000, is available from Maxon Precision Motors, Inc. (Fall River, MA).

As shown in FIGS. 8A and 8B, a proximal end 520 of the hollow drive shaft 500 freely rotates proximate to a second collimating lens 610 fixedly held within the proximal end of the stationary lens holder 600. The stationary lens holder 600 includes a distal lumen 602 to receive the proximal end 520 of the hollow drive shaft 500 and freely rotate within the distal lumen 602. The second collimating lens 610 in the proximal end 610 is optically coupled to the optical path within the hollow drive shaft 500. The stationary lens holder 600 may be attached to the motor 400 via a connection method including by way of example and not limitation, a frictional fit, a snap fit, crimping, swaging, overmolding, an adhesive, a weld, a magnetic fit, and the like. A second fiber ferrule 620 is attached to a proximal end of the second collimating lens 610. The second fiber ferrule 620 fixedly connects over a distal end of a second optical fiber 630, as shown in FIG. 11, which delivers light to and/or receives light from the second collimating lens 610 from a light source (not shown), such that the light may pass from the second optical fiber 630 to the collimating lens 610. In one embodiment, the distal end of the second optical fiber 630 is coaxially disposed with the second fiber ferrule 620. The second optical fiber 630 may be a single mode or multi-mode optical fiber. The second fiber ferrule 620 is made from a material that has properties similar to that of the second optical fiber 630. For example, the second fiber ferrule 620 may be made from glass to match coefficient of thermal expansion with the second optical fiber 630. The second optical fiber 630 may be connected to the second fiber ferrule 620 by a connection method including by way of example and not limitation, an adhesive, a weld, splicing, fusion, etc. Alternatively, the second optical fiber 630 may be manufactured integrally with the second fiber ferrule 620.

As shown in FIG. 8B, the second collimating lens 610 is disposed in optical communication with a distal end of the second optical fiber 630. The second collimating lens 610 may be made from an optical material having an internally variable index of refraction and may be the same as or different from the first collimating lens 340 described hereinabove with regard to FIGS. 8A and 9A. For example, in one embodiment, the second collimating lens 610 is a lens having a radial index gradient such as a gradient index ("GRIN") or self-focusing ("SELFOC") lens. In other embodiments, other types of collimating lenses may be used, such as devices that narrows a beam of light or causes the directions of motion to become more aligned in a specific direction (i.e. collimated or parallel) or to cause the spatial cross section of the beam to become smaller.

In one embodiment, the second collimating lens 610 is fixedly attached to the distal end of the second fiber ferrule 620. The second collimating lens 610 may be attached to the second fiber ferrule 620 via a connection method including by way of example and not limitation, a frictional fit, a snap fit, an adhesive, etc. It is contemplated that the second fiber ferrule 620 facilitates stronger attachment of the second optical fiber 630 to the second collimating lens 610.

In another embodiment, the second collimating lens 610 is fixedly held by the stationary lens holder 600 by a connection method including by way of example and not limitation, a frictional fit, a snap fit, an adhesive, etc. The stationary lens holder 600 may be manufactured from a material including by way of example and not limitation, stainless steel, aluminum, or plastics such as polyetheretherketone (PEEK) or polyoxymethylene (POM).

As discussed above, the invention provides optical-electrical rotary joints and optical rotary joints for use with optical systems. A joint can have two lenses disposed therein for creating and aligning a light path through the joint. Further, in certain embodiments, joints of the invention include features to aid in the precise alignment of optical components.

For example, in some embodiments, stationary lens holder 600 includes deformable region 609 that is selectively deformed to align the second ferrule 620, the second fiber 630, and the second collimating lens 610 relative to the hollow drive shaft 500. As shown in FIG. 8B, an annular groove 603 can be provided that is disposed at an outer surface 606 of the stationary lens holder 600 resulting in a region 609 having reduced wall thickness. In this embodiment, alignment of the second ferrule 620, second fiber 630, and second collimating lens 610 is accomplished by deformation of the region 609 having reduced wall thickness. Deformation applied to the region 609 effectively adjusts the alignment of the second ferrule 620, second fiber 630, and second collimating lens 610 relative to the hollow drive shaft 500.

In one embodiment, a plurality of adjusters 612 may be provided disposed longitudinally through the stationary lens holder 600 and disposed across the annular groove 603, as illustrated in FIG. 8B. Suitable adjusters 612 may include, for example, screws, bolts, threaded rods, or other devices as known in the art. One or more of the adjusters 612 may be manipulated to deform the reduced diameter portion 603 of lens holder 600. The plurality of adjusters 612 may include any number of adjusters 612 as desired or appropriate to achieve the desired alignment.

In one embodiment the plurality of adjusters 612 may remain in place after alignment. Such arrangement may have the benefit of facilitating field adjustment of alignment if misalignment occurs. In another embodiment, the region 609 is permanently deformed to or near an optimal alignment and the plurality of adjusters 612 are removed. Such permanent deformation may be accomplished, for example, via application of heat during alignment via the plurality of adjusters 612 followed by removal of the heat to allow the region 609 to cool prior to removal of the plurality of adjusters 612.

In a further embodiment, an external device may be used to deform the region 609. For example, heat may be applied to the stationary lens holder 600 via a heated sleeve or other device (not shown) placed thereover. After heating the stationary lens holder 600 and manipulating the sleeve or other device (not shown) to selectively deform the region 609 as desired, the heat may be removed while leaving the sleeve or other device (not shown) in place to allow the region 609 to cool, thus permanently deforming the region 609 as desired. Other arrangements as known in the art may be applied to accomplish the desired deformation of the region 609.

In a further embodiment, combinations of alignment methods may be used, including for example and without limitation alignment and attachment of second fiber 630 and second ferrule 620 to second collimating lens 610 by means of UV-cured adhesive followed by alignment by means of deformation of lens holder 600 in region 609.

As discussed with reference to FIGS. 4A-7, optical-electrical rotary joints are provided that can be manually separated and re-coupled. An optical-electrical rotary joint allows optical communication and continuous electrical contact from an upstream side of a coupling to a downstream side of the coupling while the two sides of the coupling my rotate relative to one another. Further, as discussed with reference to FIGS. 8A-9B, the invention provides optical rotary joints that allow optical communication across a coupling while downstream components rotate relative to upstream components.

In a further aspect, the invention provides for optical and optical-electrical joints in which a downstream component (such as an imaging catheter in an OCT system) translates relative to an upstream component. In general, translation of a component refers to motion of the component in a direction that is substantially parallel to an axis of an optical path (e.g., optical path 711 in FIG. 4A) or substantially parallel to an axis of rotation in a rotary joint.

For example, FIG. 3A illustrates a support housing 208 disposed within catheter handle 800 as well as rigid shaft 310 and coupling 300. With coupling 300 coupled to motor 400, rigid shaft 310 can be translated relative to support housing 208. FIGS. 10A-10C illustrate a drive shaft assembly for translating rigid shaft 310 relative to support housing 208.

Referring to FIGS. 10A-10C, in one embodiment, portions of rotary joint 201, described above, may be utilized as part of a drive shaft assembly 50 that operationally connects the motor 400 to a flexible drive cable 120. The drive shaft assembly 50 may include the longitudinal translation mechanism or axially translatable drive stage 202 for longitudinal translation of the flexible drive cable 120 during rotation thereof. The axially translatable drive stage 202 may include a lead screw driven by a stepping motor or other mechanism for precise control of translation velocity and position of the motor 400. Thus, the flexible drive cable 120 may be translated longitudinally, as indicated by arrow 126 to provide a catheter “pull back”.

As shown in FIGS. 10A-10C, in one embodiment, the drive shaft assembly 50 includes the stiffener or section of rigid shaft 310 that is sized to be self-supporting at the desired rotational speed and “pull-back” distance. A support housing 208 is coaxially disposed within the vibration dampening mechanism 810, and the support housing 208 includes a lumen 206, which is sized to accommodate at least a portion the rigid shaft 310. A distal end of the rigid shaft 310 is operably connected to a proximal end of a semi-rigid shaft 210. The semi-rigid shaft 210 is small enough to fit in the same lumen as a flex shaft 120 and flexible enough not to take a permanent set with some bending of the catheter sheath, but stiff enough to operate (transmit torque and axial force) within lumen 206 without failing. The semi-rigid shaft 210 may comprise nitinol, i.e. nickel titanium alloy, or another material such as stainless steel, tantalum, gold, platinum, titanium, copper, nickel, vanadium, zinc metal alloys thereof, copper-zinc-aluminum alloy, and combinations thereof. A proximal end of the flexible drive cable 120 is operably coupled to a distal end of the semi-rigid shaft 210.

Still referring to FIGS. 10A-10C, in one embodiment, the vibration dampening mechanism 810, for example, is an elastomeric vibration dampener 810, which may be disposed concentrically around the support housing 208 and between the support housing 208 and an external housing 800, for example, the catheter handle 800 disposed at a proximal end of a catheter sheath 100. The vibration dampening mechanism 810 may include one or more layers 216 of an elastomer or other mechanically compressible material and may thereby provide a mechanism to dampen high speed rotational vibrations on the proximal end of the drive shaft assembly 50. For example, the vibration dampening mechanism 810 may include a first layer, a second layer, and a third layer of an elastomer of varying degrees of compressibility to dampen the high speed rotational vibrations.

By dampening high speed rotational vibrations, the vibration dampening mechanism 810 inhibits catastrophic failure of the drive shaft assembly 50 when axially translated or “pulled back” by the translatable drive stage 202 during rotation at speeds in excess of 10,000 rpm, alternatively between about 5,000 and 25,000 rpm. Without the vibration dampening mechanism 810, the semi-rigid shaft 210 is limited in amplitude of vibration by the support housing 208; however, in the presence of the vibration dampening mechanism 810, the semi-rigid shaft 210 may additionally be inhibited from excessive vibration amplitude. Thus, the vibration dampening mechanism 810 facilitates a longer range of translation or "pull back" for a given configuration of the rigid shaft 310, the support housing 208, and the semi-rigid shaft 210. The vibrational dampening mechanism 810 may provide dampening further inhibiting the rotational vibrations from being translated to the distal end of the drive shaft assembly 50. Such dampening may also be beneficial for maintaining alignment of optics and therefore maintaining signal integrity along an optical path through the support housing 208.

Referring to FIGS. 10A-10C, operation of the drive shaft assembly 50 may begin, for example, in the configuration illustrated in FIG. 10C, wherein the stiffener or rigid shaft 310 is accommodated substantially coaxially within the lumen 206 of the support housing 208, which is fixedly attached to the external housing 800 via the vibration dampening mechanism 810. In this configuration, the semi-rigid shaft 210 is supported within the catheter sheath 100. In all of the configurations to be described below with regard to FIGS. 10A-10C, the flexible drive cable 120 is supported by the catheter sheath 100. In this configuration, the semi-rigid shaft 210 is supported within the catheter sheath 100.

In one embodiment, the catheter sheath 100 may include the external housing 800 disposed on a proximal end thereof, as illustrated by regions enclosed by dashed lines 218 in FIGS. 10A-10C. The flexible drive cable 120 and the semi-rigid shaft 210 are operably coupled with the distal end of the stiffener or rigid shaft 310. The stiffener or rigid shaft 310 is sufficiently rigid and/or has a sufficient diameter to be self-supporting in free space; however, in this configuration the rigid shaft 310 is further supported against large amplitude wobbling or flopping at rotational speeds in excess of 10,000 rpm (alternatively, between about 5,000 and 25,000 rpm) by an inner wall of the support housing 208. Such support of the flexible drive cable 120, the semi-rigid shaft 210, and the stiffener or rigid shaft 310 facilitates maintenance of a uniform rotational speed thereof.

FIG. 10B represents the drive shaft assembly 50 configured such that the flexible drive cable 120 and the semi-rigid shaft 210 are translated proximally relative to the configuration illustrated in FIG. 10C (or distally relative to the configuration illustrated in FIG. 10A). In this configuration, the flexible drive cable 120 remains supported within the catheter sheath 100 and operably coupled with the semi-rigid shaft 210 on the proximal end of the catheter sheath 100. The semi-rigid shaft 210 is supported on a distal end by the catheter sheath 100 and on a proximal end by connection to the stiffener or rigid shaft 310. In this configuration the semi-rigid shaft 210 is supported against large amplitude wobbling or flopping at rotational speeds in excess of 10,000 rpm (alternatively, between about 5,000 and 25,000 rpm) by an inner wall of the lumen 206 of the support housing 208. As noted with regard to FIG. 10C, the stiffener or rigid shaft 310 is sufficiently rigid and/or has a sufficient diameter to be self-supporting in free space. However, in this configuration the stiffener or rigid shaft 310 is further supported by being partially within the proximal end of the support housing 208, and is therefore further supported against large amplitude wobbling or flopping at rotational speeds in excess of 10,000 rpm (alternatively, between about 5,000 and 25,000 rpm) by the inner wall of the support housing 208. The proximal end of the stiffener or rigid shaft 310 extends from the proximal end of the lumen 206 and is operably coupled with the drive motor 400 via the coupling 300. Such support of the flexible drive cable 120, the semi-rigid shaft 210, and the stiffener or rigid shaft 310 facilitates maintenance of a uniform rotational speed thereof.

Referring once again to FIG. 10A, in this configuration the stiffener or rigid shaft 310 has been translated proximally relative to the configuration illustrated in FIG. 10B so as to be substantially external to the proximal end of the lumen 206 of the support housing 208. The semi-rigid shaft 210 is now disposed substantially within the support housing 208; however, the flexible drive cable 120 remains within the catheter sheath 100 and operably coupled to the metal semi-rigid shaft 210 at the distal end of the support housing 208. Thus, the flexible drive cable 120 remains supported within the catheter sheath 100. Accordingly, an optical rotary joint or an optical-electrical rotary joint may include a mechanism to provide translation of a downstream component relative to an upstream component.

Optical rotary joints (optionally with electrical rotary joint components) transmit light between an upstream portion and a downstream portion. Light may be transmitted by any method known in the art including, for example, conversion to an electrical signal for transmission over an electrical coupling or transmission through a solid medium such as glass or a gain medium. In certain embodiments, light is transmitted from an upstream component to a downstream component through free space (i.e., air, a gas, or a vacuum). In some embodiments, light is transmitted through free space coaxially with, and down the center of, hollow drive shaft 500 of motor 400.

Light transmission through the hollow drive shaft 500 is achieved without any optical components disposed therein. Referring to FIG. 11, an optical path 1000 may be represented as a beam of light 1010 traced through the optical rotary joint 200 between the first optical fiber 320 and the second optical fiber 630. A window at the distal tip in the hollow drive shaft 500 may be implemented for keeping out contamination.

Describing the optical path 1000 from left to right in FIG. 11, the first optical fiber 320 and the first collimating lens 340 are optically aligned to pass a signal longitudinally therebetween. First fiber ferrule 330 facilitates a mechanical connection between the first optical fiber 320 and the first collimating lens 340, but is not essential and may be absent or replaced by other elements in other embodiments. Similarly, the second collimating lens 610 and the second optical fiber 630 are optically aligned to pass a signal longitudinally therebetween. Second fiber ferrule 620 facilitates a mechanical connection between the second collimating lens 610 and the second optical fiber 630, but may be absent or replaced by other elements in other embodiments.

In one embodiment, this alignment is via physical connection, as described hereinabove with regard to FIGS. 1A and 2A. Other embodiments may include a physical gap between, for example, the first collimating lens 340 and the first optical fiber 320. The coupling 300, the rigid shaft 310, the first optical fiber 320, the first fiber ferrule 330, the first collimating lens 340, and the lens holder 350 rotate together as a unit driven by the hollow drive shaft 500.

Referring to FIG. 11, following the beam 1010 from left to right, the beam 1010 passes through the first optical fiber 320 into the first collimator lens 340. The beam 1010 is expanded and collimated by the first collimator lens 340 and freely passes through the hollow drive shaft 500. After passing through the hollow drive shaft 500, the beam 1010, collimated as a result of passing through the first collimator lens 340, enters the second collimator lens 610, which contracts the beam 1010 as illustrated. The contracted beam 1010 passes from the second collimator lens 610 into the second optical fiber 630. Alternatively, the light may pass from the second optical fiber 630 to the collimator lens 610.

In one embodiment, the first and second fibers 320, 630 and ferrules 330, 620 include angled surfaces 1020, 1030, respectively. Similarly, the first and second collimator lenses 340, 610 may include angled surfaces 1040, 1050, respectively, adjacently disposed to the angled surfaces 1020, 1030, respectively. The first and second collimator lenses 340, 610 may further include angled surfaces 1060, 1070, respectively, disposed opposite from the angled surfaces 1040, 1050, respectively. As known in the art, the angled surfaces 1020, 1030, 1040, 1050, 1060, and 1070 help to inhibit back reflection of the beam 1010.

A light beam crossing an interface between material surfaces disposed at a non-orthogonal angle relative to the light beam and having dissimilar indices of refraction will be refracted. When utilizing a lens having a lens having a radial index gradient, an offset of a beam upon entry to the lens may result in an offset of the beam upon exit from the lens. For example, referring to FIG. 12, a lateral offset 1100 of the beam 1010 upon entry into a collimator lens, for example, the first collimator lens 340 having the angled surfaces 1040 and 1060, may result in a change in the output angle 1110 at which the beam 1010 exits the collimator lens 340. Similarly, referring to FIG. 13, a change of input angle 1120 of the beam 1010 upon entry into a collimator lens, for example, the first collimator lens 340 having the angled surfaces 1040 and 1060, may result in a change in the output lateral offset 1130 at which the beam 1010 exits the collimator lens 340. Therefore, it may be difficult to manufacture optical assemblies with adequate angular and radial alignment for good performance.

However, an alignment method may be used to compensate for such angular and radial offsets. For example, in one embodiment of such an alignment method, manufacturing errors of angular and lateral alignment between collimating lenses 340, 610 can be eliminated or reduced to acceptable levels by alignment of first and second fibers 320, 630 in ferrules 330, 620 with respect to their collimating lenses 340, 610, as described above. Referring to FIG. 11, in one embodiment, optically transparent adhesive is used to join first ferrule 330, first fiber 320, and first collimating lens 340, the alignment being carried out before the adhesive is cured with UV light. Similarly optically transparent adhesive may be used to join second ferrule 620, second fiber 630, and second collimating lens 610, the alignment being carried out before the adhesive is cured with UV light.

As discussed and shown herein, a mechanically simple, compact, optical-electrical rotary joint that reliably operates to transmit light and current between stationary and rotating components with low losses and excellent signal integrity at rotational speeds in excess of 10,000 RPM (alternatively, between about 5,000 and 25,000 rpm) is presented. The optical-electrical rotary joint includes a concentrically driven hollow drive shaft through which light is transmitted without any optical components disposed therein. Electrical contact mechanisms are provided to conduct current in one or more conductive lines across the joint. The light, the current, or both can carry a signal (i.e., encoded information). Further, mechanisms are presented that allow for translation of a downstream component of an optical-electrical rotary joint relative to an upstream component. The invention further provides optical rotary joints such as, for example, a fiber optic rotary joint or FORJ.

The simple design of the hollow drive shaft facilitates ease of replacement of a faulty motor in the field and reduces the cost and complexity of the optical rotary joint. The manually operable coupling mechanism and re-connectable optical and electrical connections disclosed herein allow for components on either side of a joint to be removed and replaced or treated separately. Thus, the invention allows for an optical-electrical system in which a component is replaceable or disposable while another component is persistent. In some embodiments, an OCT system is provided with a PIM coupled to an imaging engine to operate with a disposable or replaceable imaging catheter.

It will be appreciated by those skilled in the art that changes could be made to the embodiments described hereinabove without departing from the broad concepts disclosed therein. It is understood, therefore, that this disclosure is not limited to the particular embodiments disclosed, but it is intended to cover modifications that may include a combination of features illustrated in one or more embodiments with features illustrated in any other embodiments. Various modifications, equivalent processes, as well as numerous structures to which the present disclosure may be applicable will be readily apparent to those of skill in the art to which the present disclosure is directed upon review of the present specification. Accordingly, this description is to be construed as illustrative only and is presented for the purpose of enabling those skilled in the art to make and use the optical rotary joint described herein and to teach the best mode of carrying out the same.

CLAIMS

What is claimed is:

1. An optical electrical rotary joint comprising:

an upstream member comprising an optical line and an electrical conductor; and

a downstream member rotatably coupled to the upstream member and comprising:

a downstream conductor in constant electrical contact with the upstream electrical conductor, and

a downstream optical line in optical communication with the optical line.

2. The joint of claim 1, further comprising a motor to drive rotation of the downstream member.

3. The joint of claim 2, wherein the motor is stationary relative to the upstream member.

4. The joint of claim 1, further comprising a plurality of upstream and downstream electrical conductors, each in constant contact with its respective other.

5. The joint of claim 1, wherein the upstream and downstream members are manually separable and joinable.

6. The joint of claim 5, wherein the constant contact is maintained by one selected from the list consisting of slip ring, torroidal spring, pogo pin, and cantilever.

7. The joint of claim 1, wherein the upstream member comprises a jack on an imaging apparatus and the downstream member comprises a plug on a catheter.

8. The joint of claim 7, wherein the catheter is disposable.

9. A method for carrying current and light across a rotating joint, the method comprising:

transmitting light between an upstream instrument and a downstream component;

conducting electricity from the instrument to the component; and

rotating the component relative to the instrument while transmitting the light and conducting the electricity.

10. The method of claim 9, further comprising conducting a plurality of distinct electrical signals simultaneously through a plurality of conductors.

11. The method of claim 9, further comprising manually coupling the component to the instrument.

12. The method of claim 9, wherein the component is manually separable from the instrument.

13. The method of claim 9, further comprising driving the rotation with a motor that remains stationary relative to the component.

14. The method of claim 13, wherein the component comprises an optical line disposed coaxially with a drive shaft of the motor.

15. The method of claim 9, wherein the transmitted light comprises a signal representing an image of tissue.

16. A plug for a rotary joint, the plug comprising:

a contact point coupled to an electrical line, and

an end of an optical conductor,

wherein the contact point and the end are housed in a plug member that is configured to be manually inserted into a corresponding jack in an instrument such that the plug member can rotate relative to a corresponding optical conductor and electrical line in the instrument.

17. The plug of claim 16, wherein the plug member is a male form factor adapted to be manually coupled to the jack.

18. The plug of claim 16, wherein the contact point comprises a metal ring.

19. The plug of claim 16, further wherein the plug member is manually connectable and dis-connectable with the jack.

20. The plug of claim 16, wherein the optical conductor comprises an optical fiber.

21. The plug of claim 20, wherein the plug member comprises a cylindrical sleeve disposed coaxially with the optical fiber.

22. The plug of claim 16, further comprising a plurality of electrical contact points, each disposed substantially at a terminus of one of a plurality of electrical conductors.

23. The plug of claim 16, further wherein the plug is coupled to an imaging catheter.

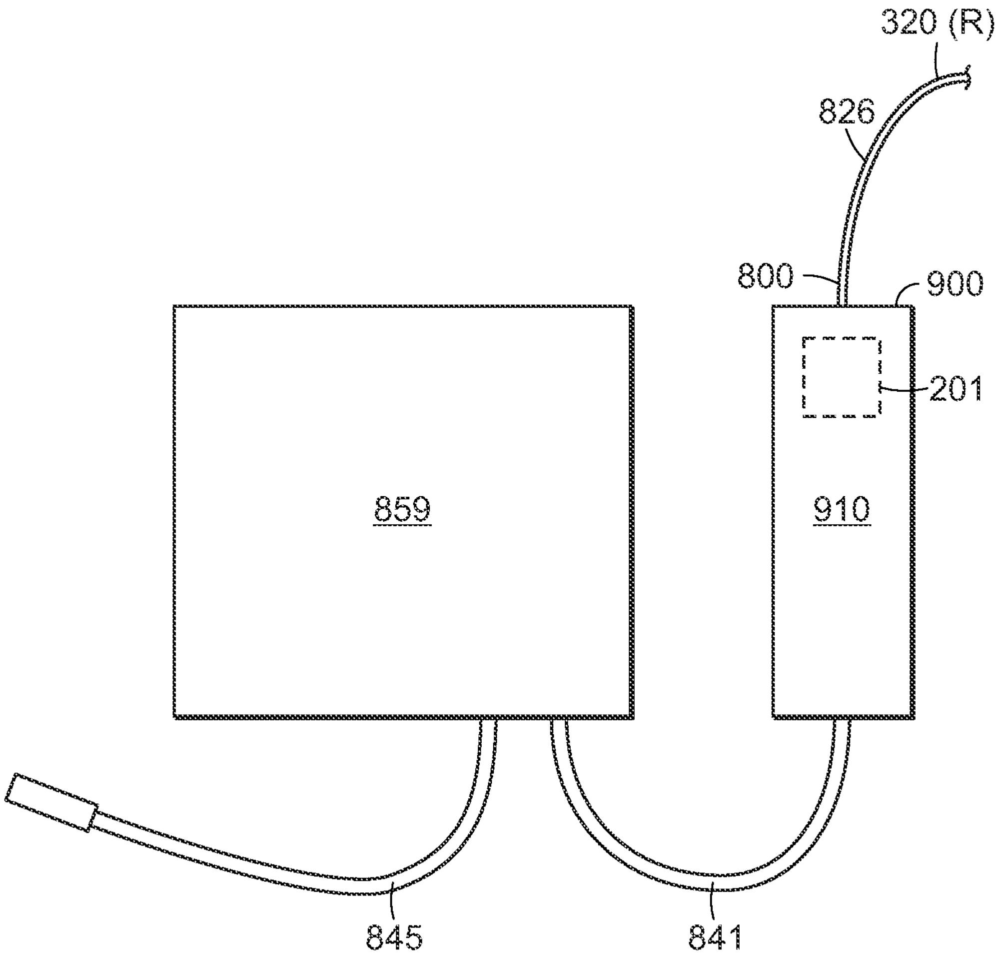


FIG. 1

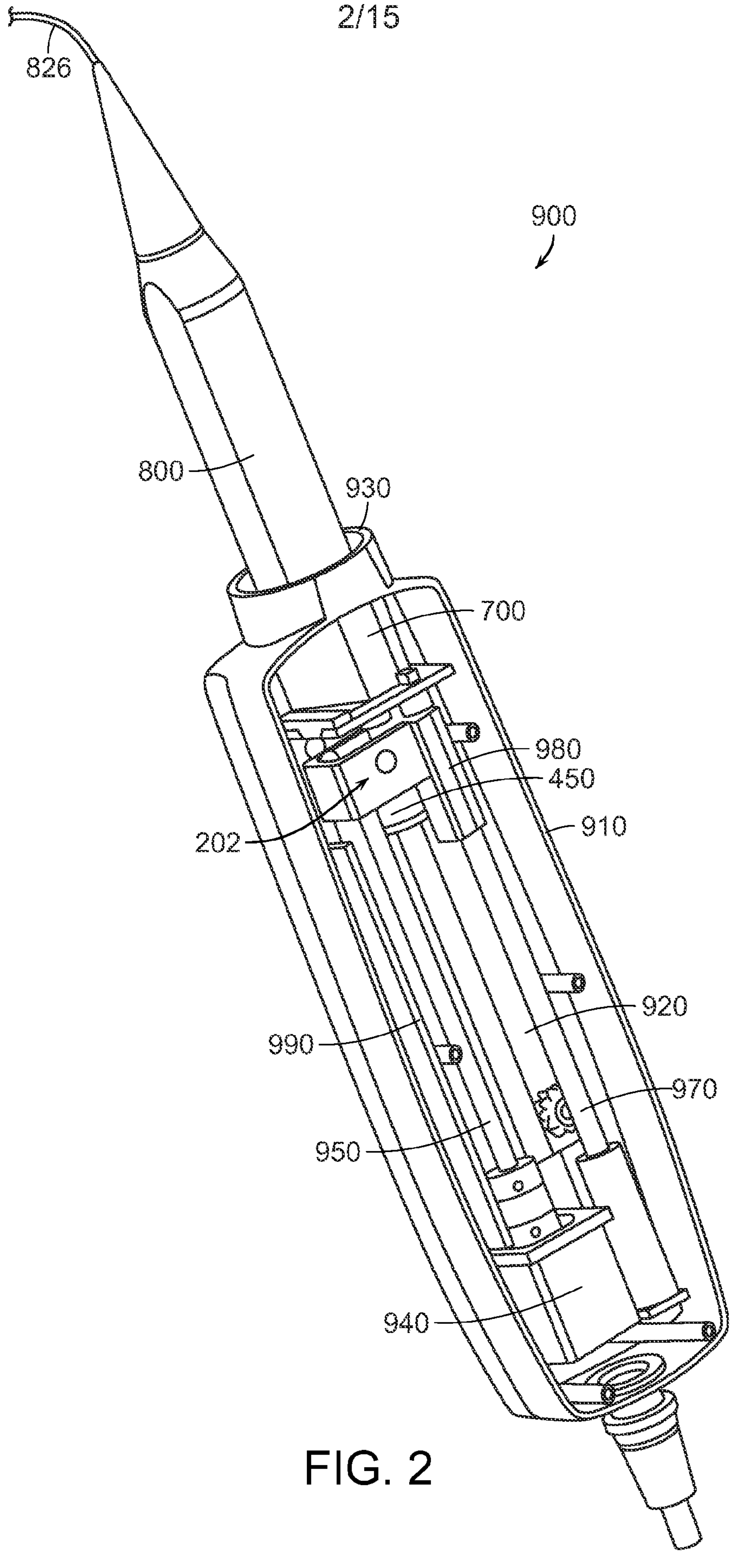
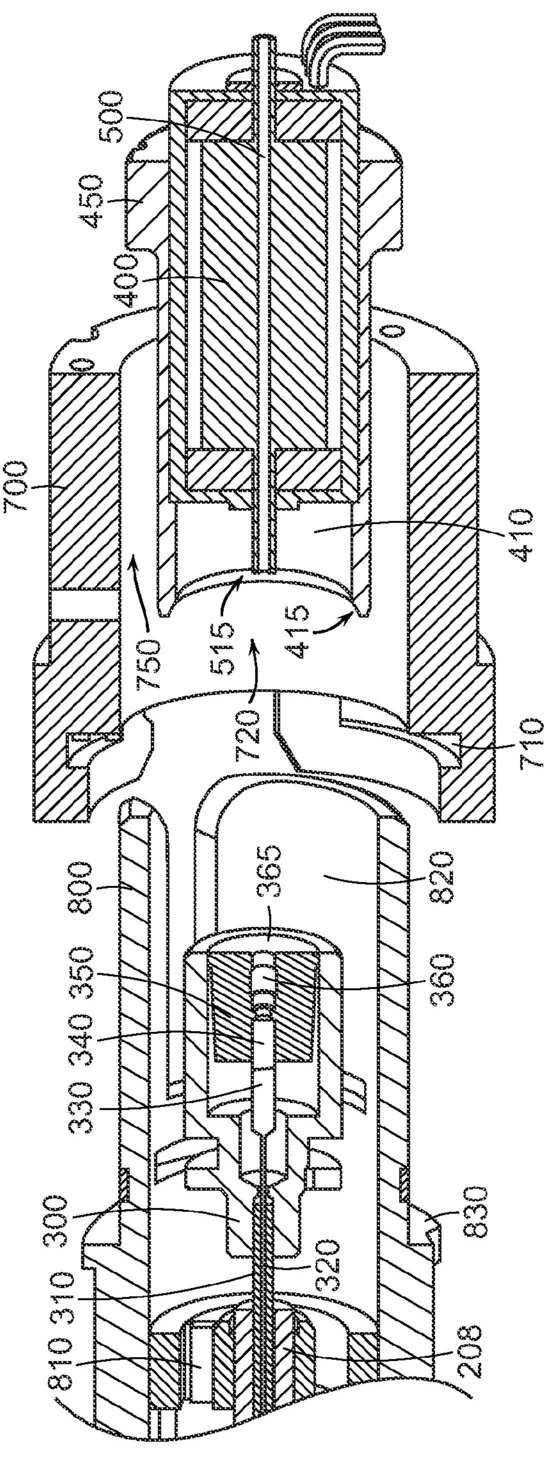


FIG. 2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810 310
208

FIG. 3A

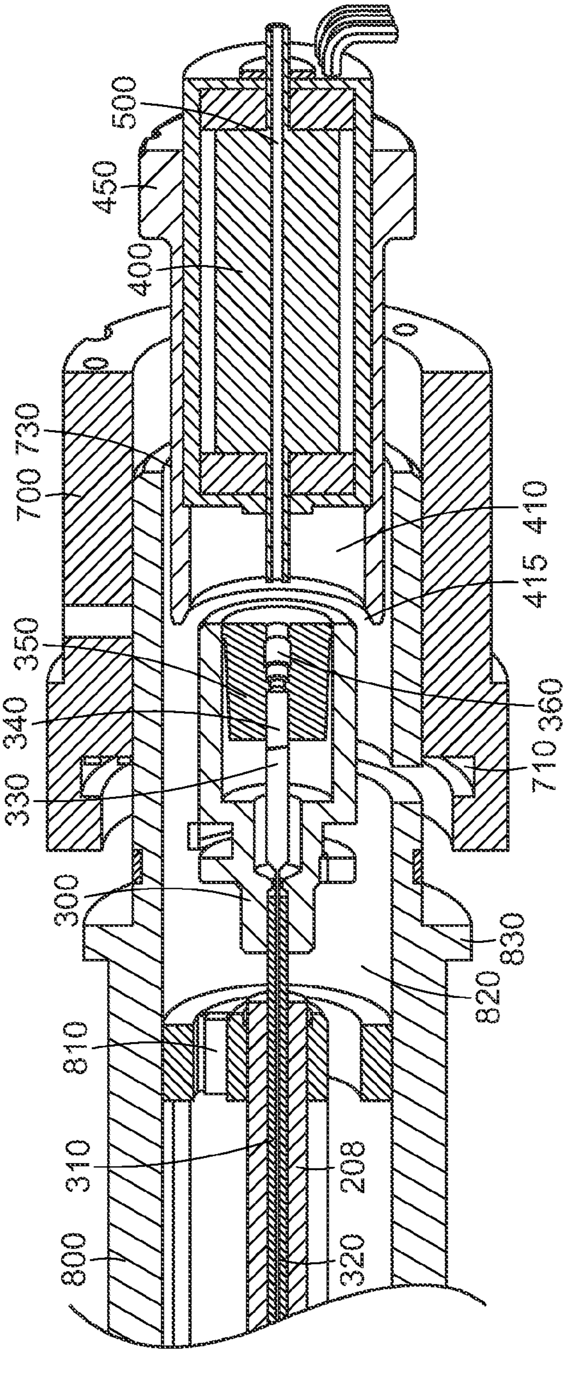
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FIG. 3B

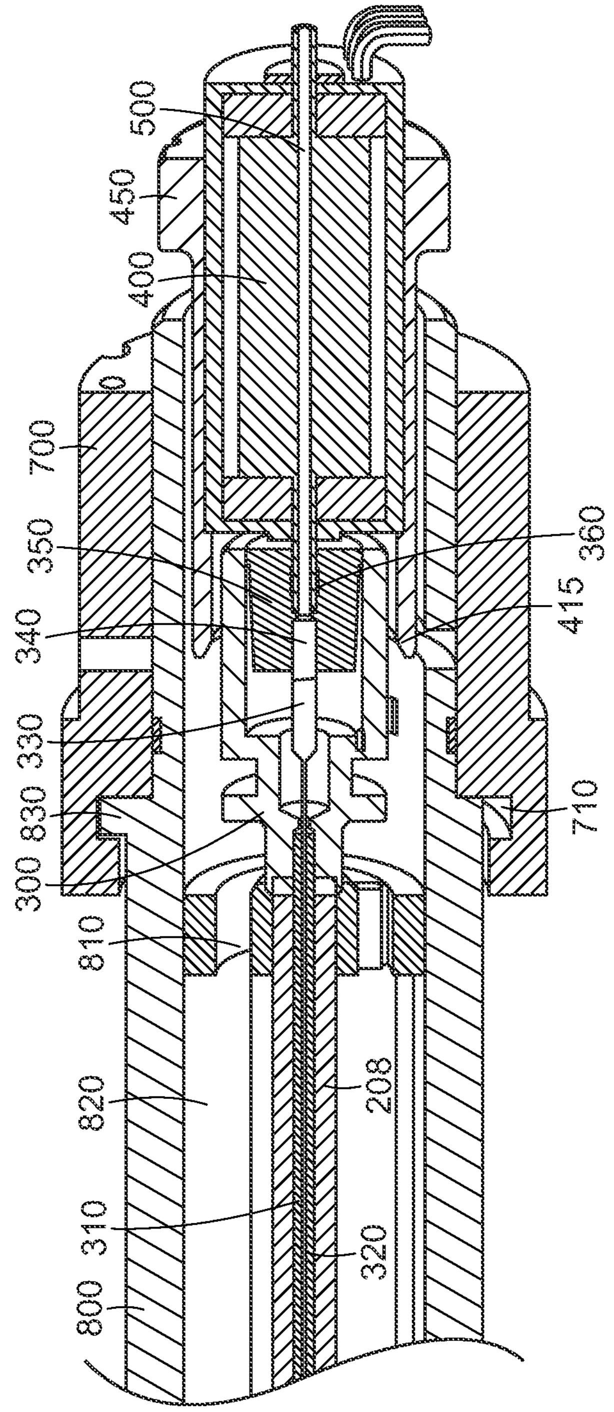
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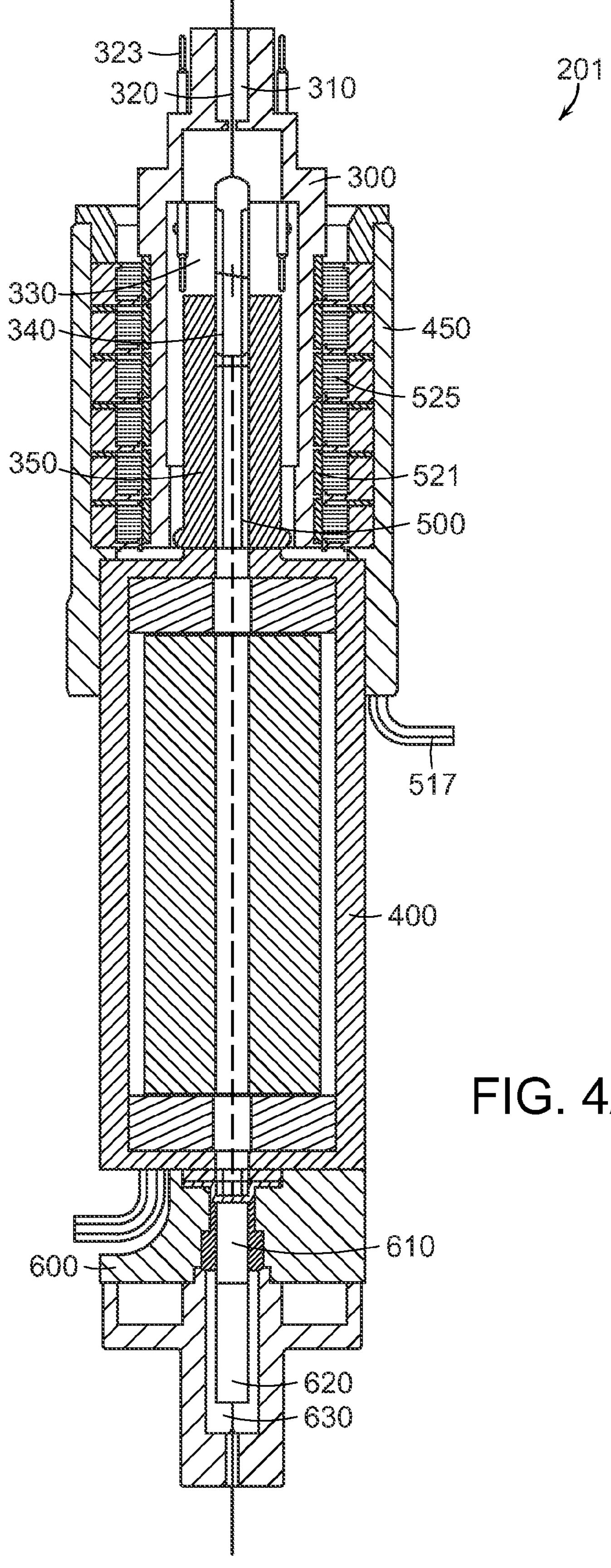
FIG. 3C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517
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610
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630

FIG. 4A

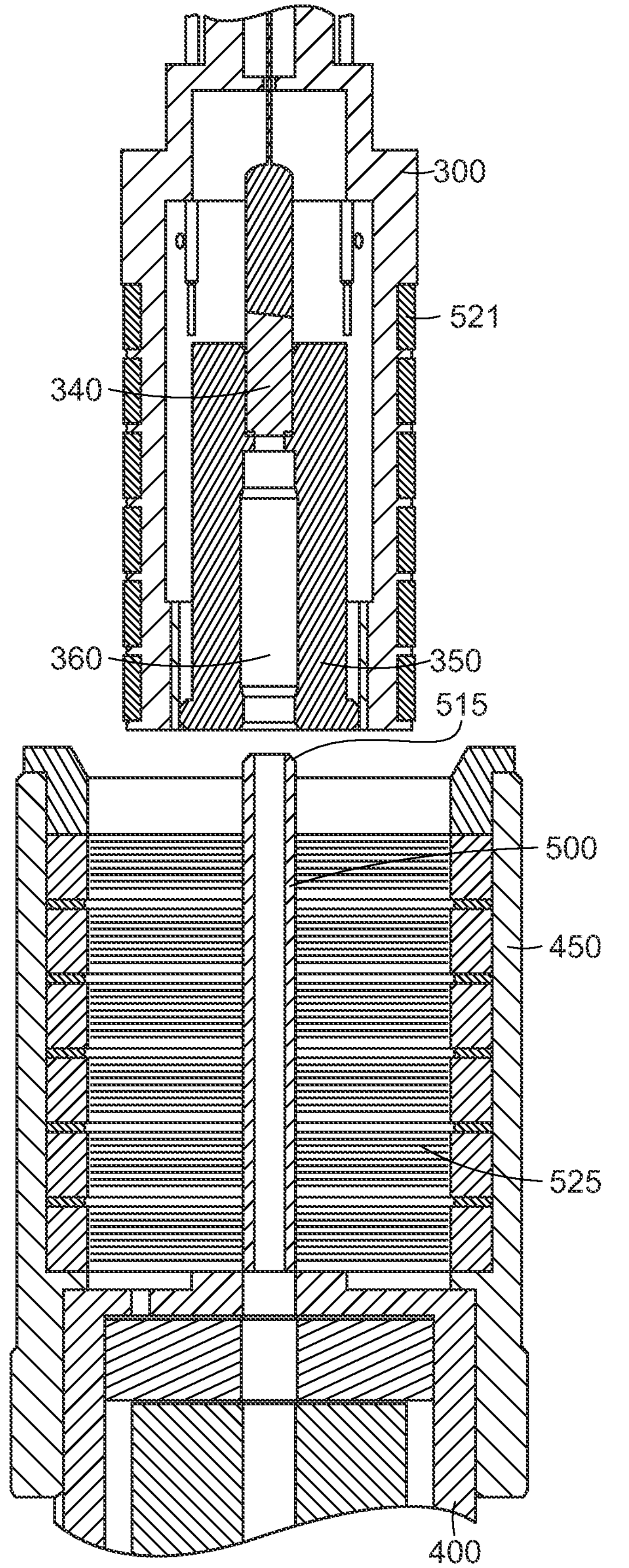

FIG. 4B

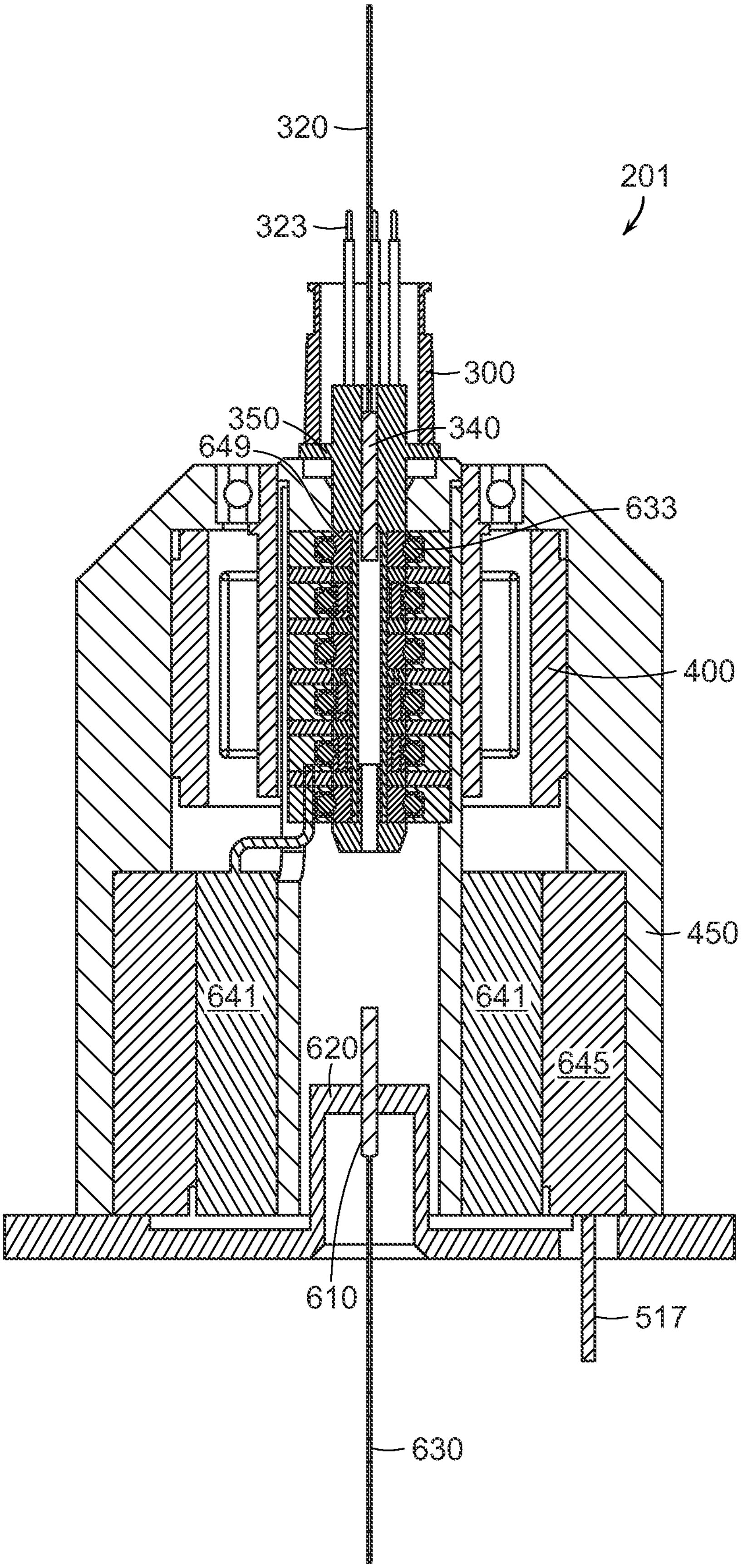
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FIG. 5A

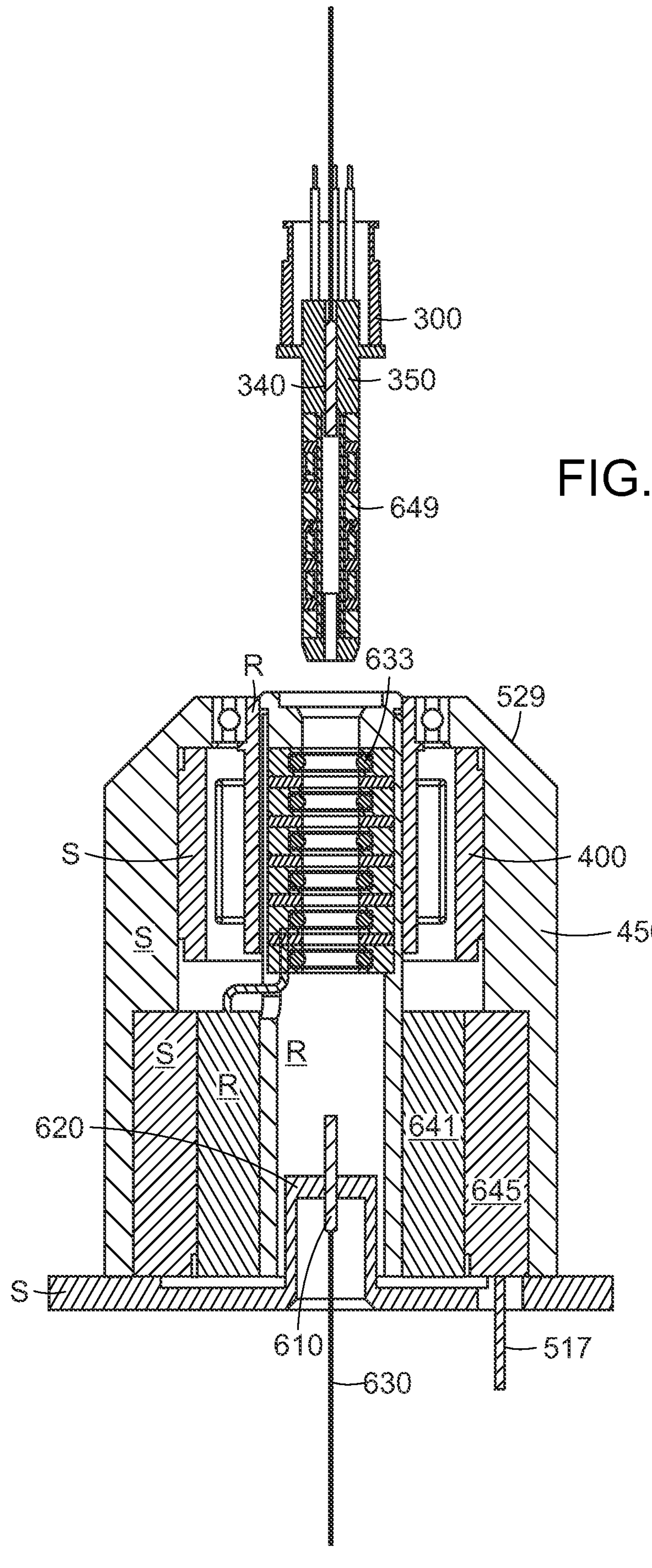


FIG. 5B

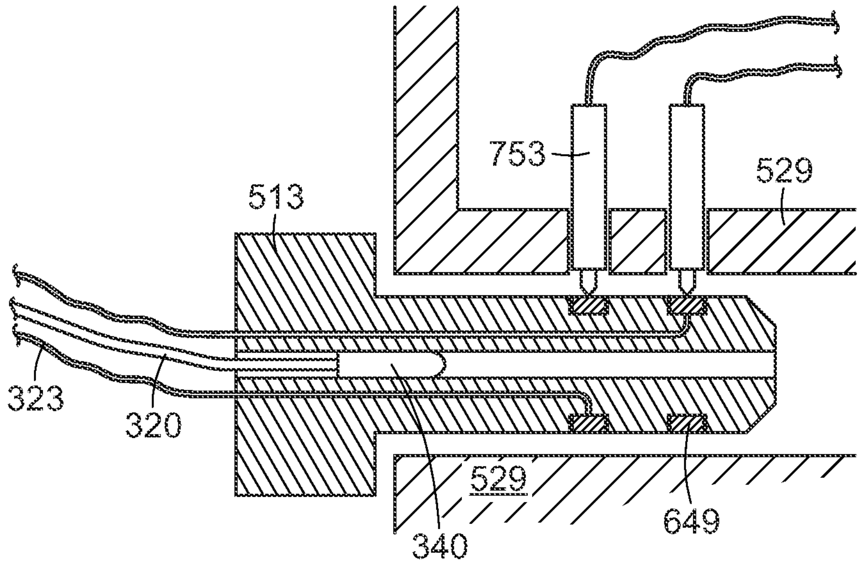


FIG. 6

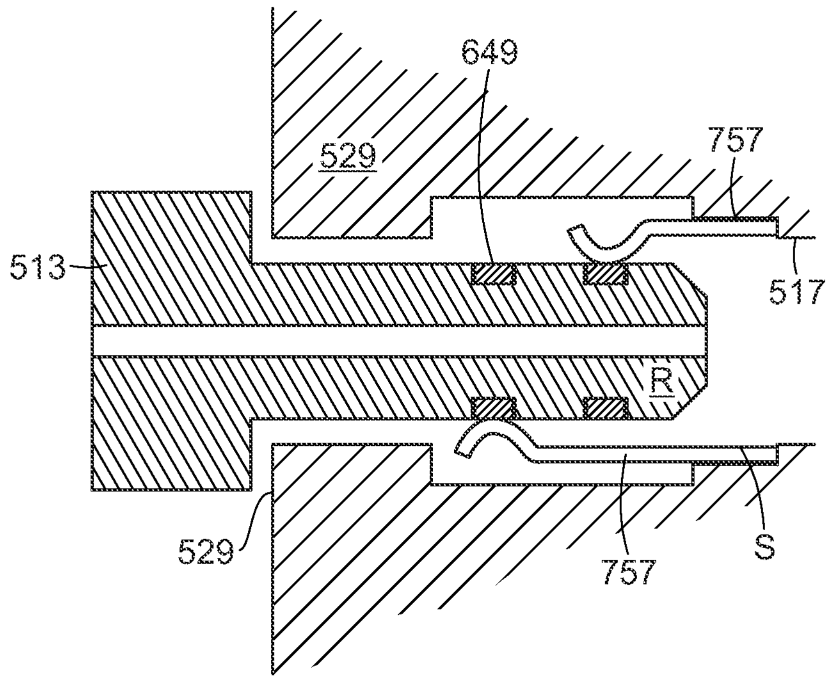
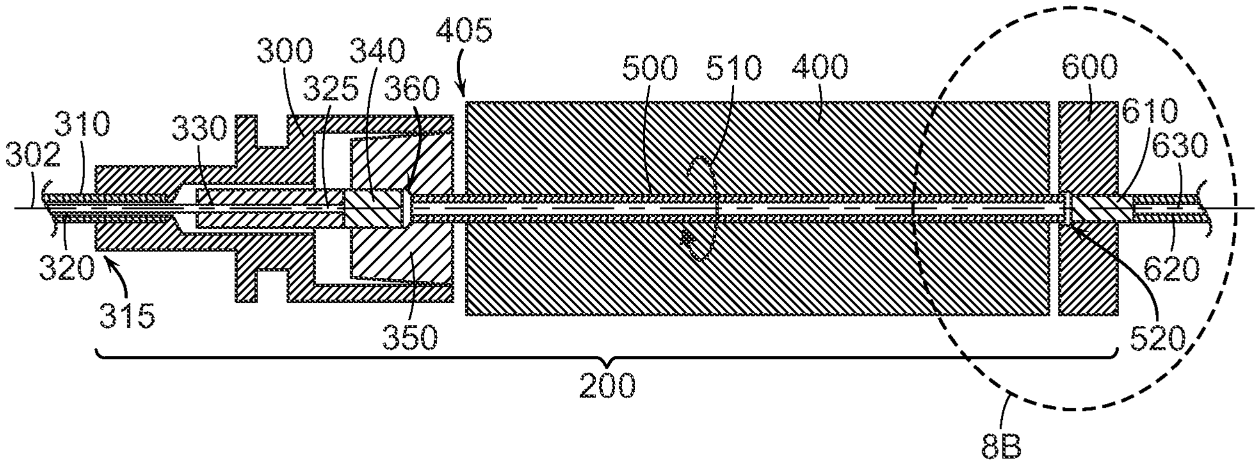


FIG. 7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200
8B

FIG. 8A

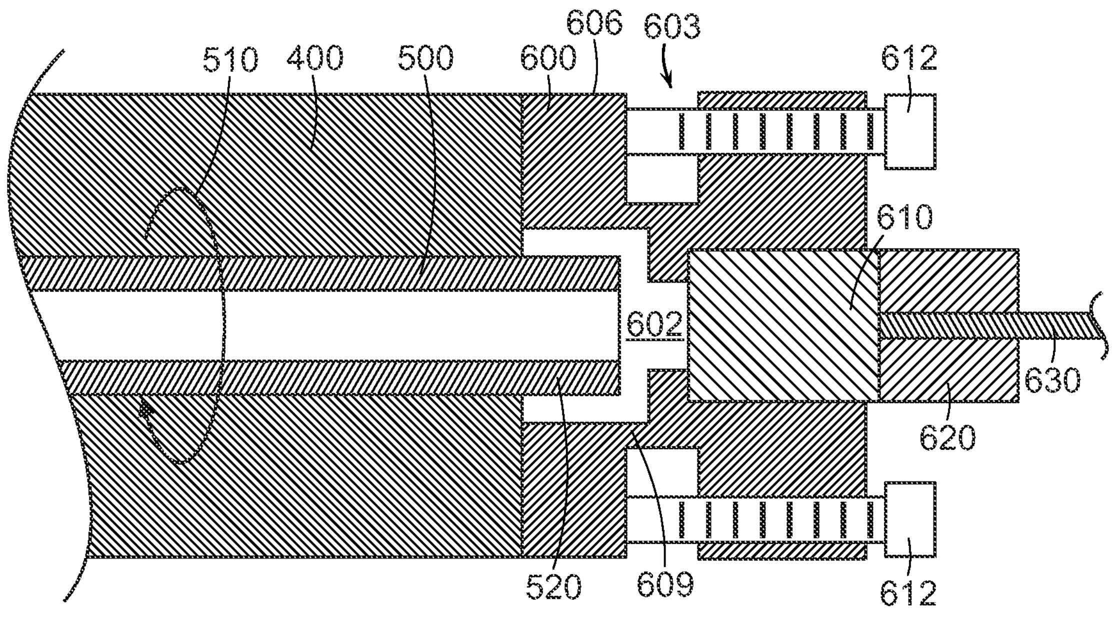
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FIG. 8B

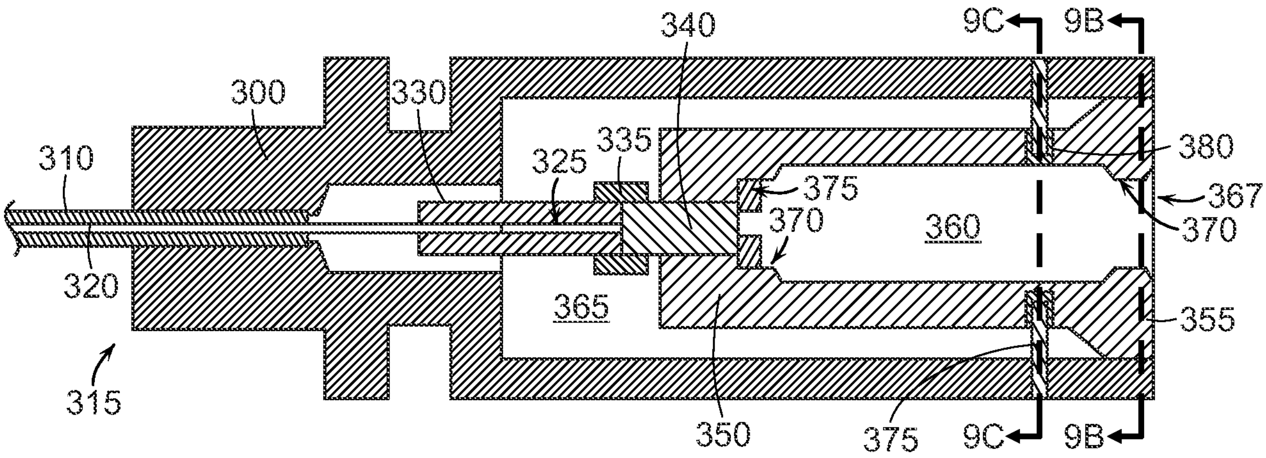


FIG. 9A

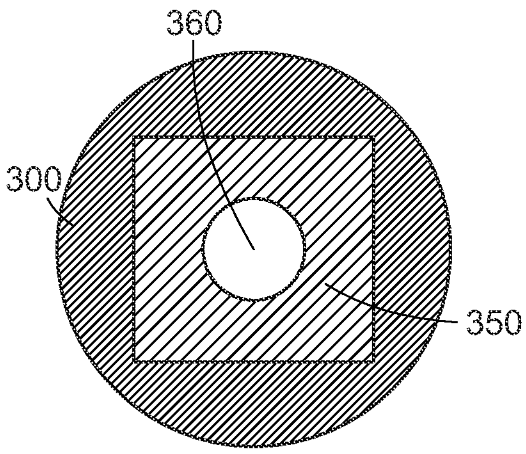


FIG. 9B

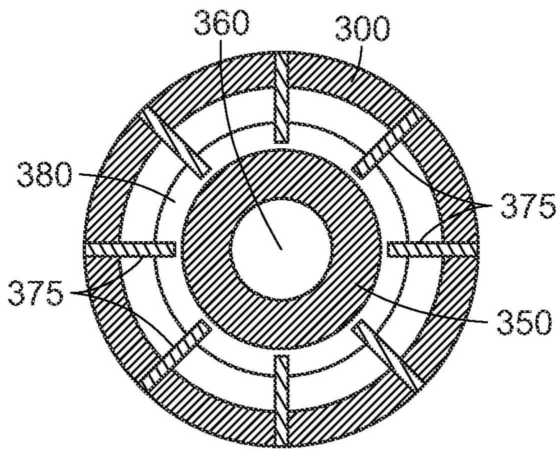
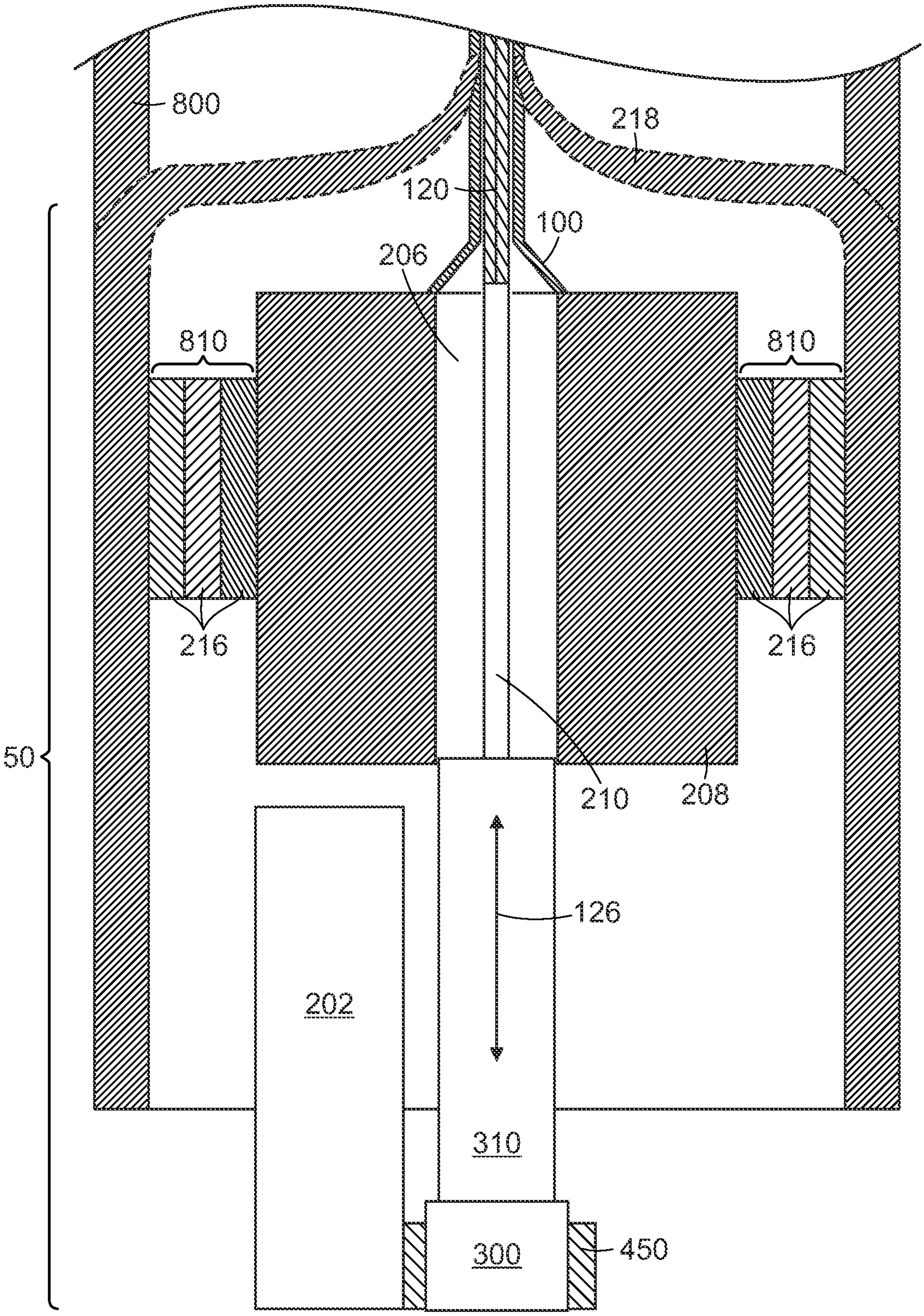


FIG. 9C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450

FIG. 10A

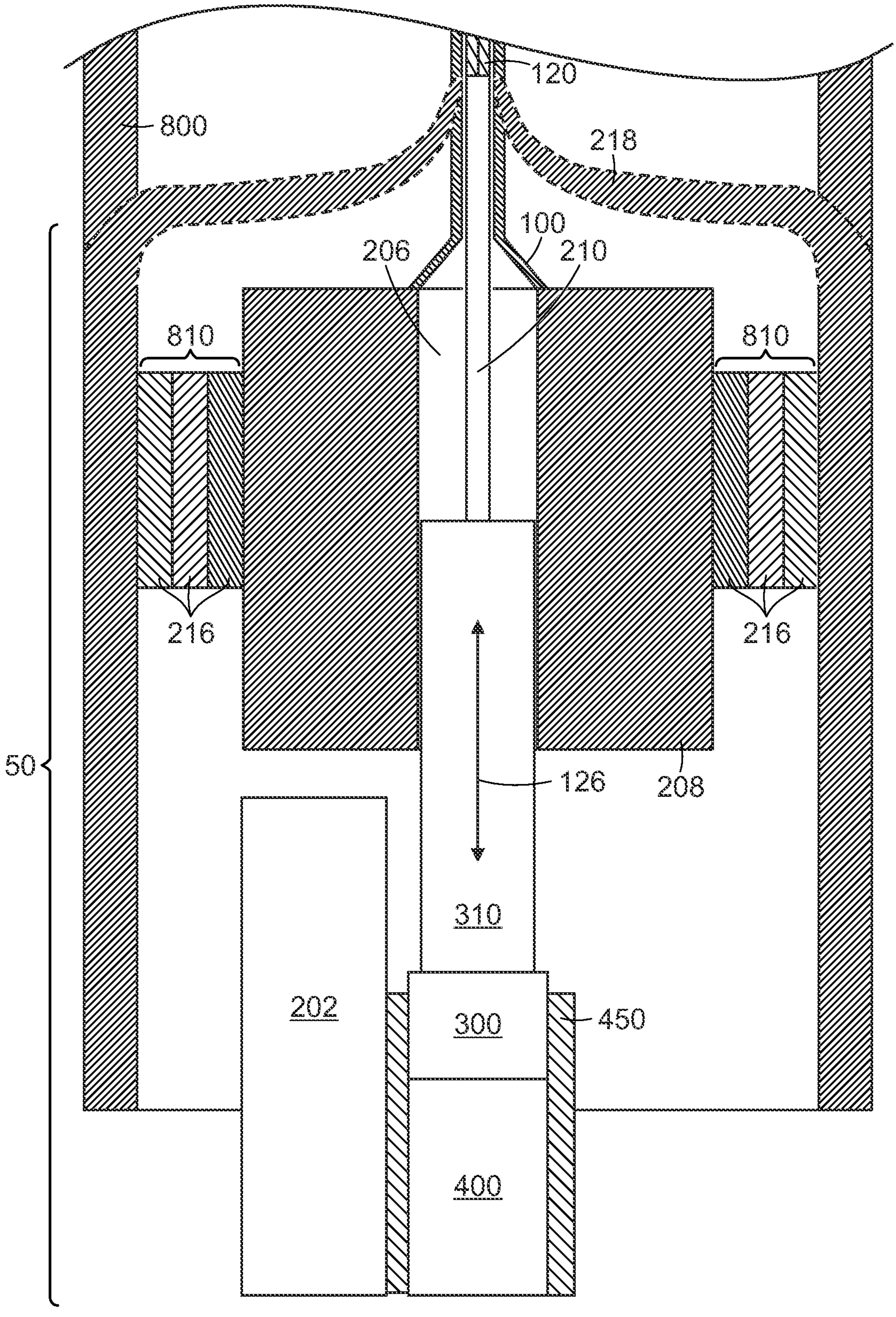
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FIG. 10B

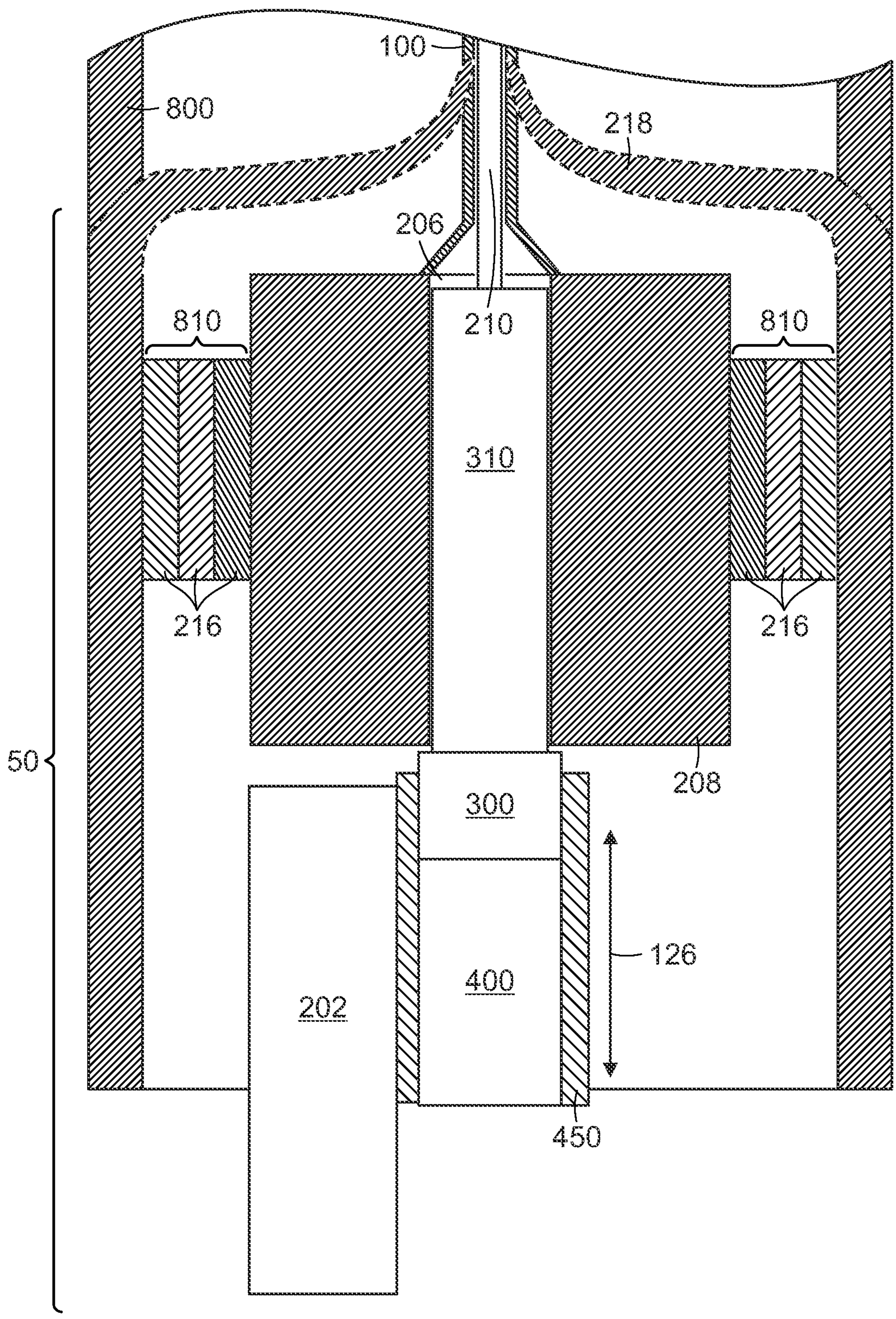
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FIG. 10C

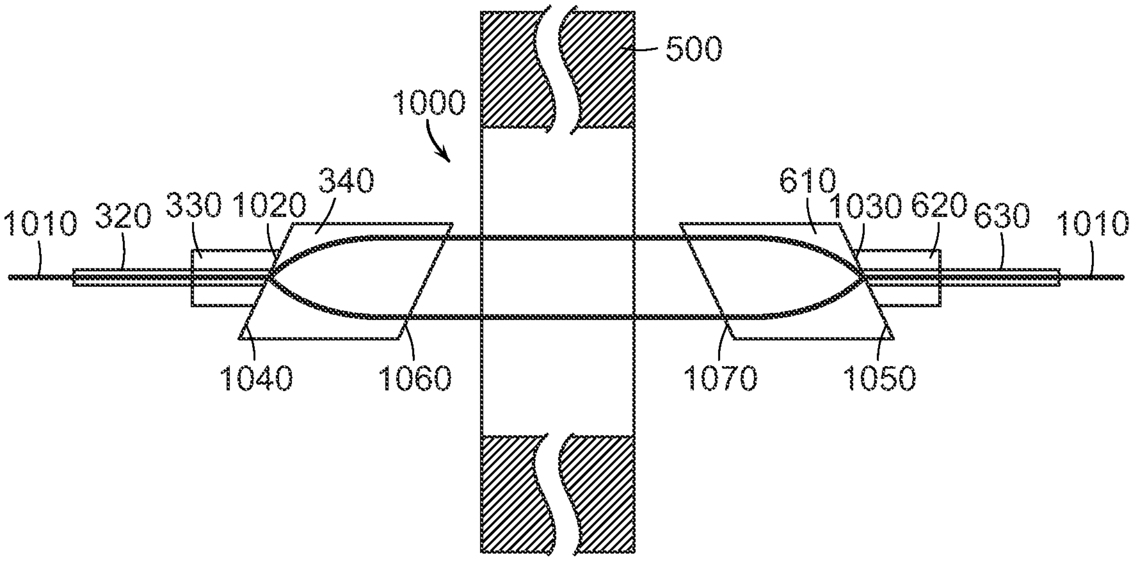

FIG. 11

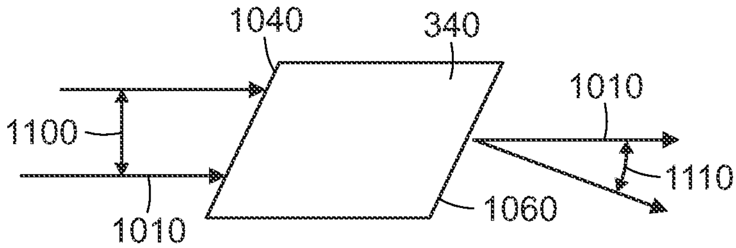

FIG. 12

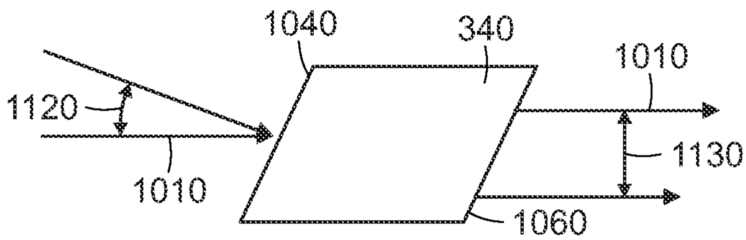

FIG. 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2012/053436

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G02B 6/42 (2012.01)
USPC - 385/70

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)
IPC(8) - G02B 6/26, 6/38, 6/42 (2012.01)
USPC - 385/70, 71, 77

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

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

PatBase, Google Patents, Google Scholar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2008/0177138 A1 (COURTNEY et al) 24 July 2008 (24.07.2008) entire document	1-6, 9-13, 15
Y		7-8, 14, 16-23
Y	US 2003/0077043 A1 (HAMM et al) 24 April 2003 (24.04.2003) entire document	7-8, 14, 16-23
A	US 5,039,193 A (SNOW et al) 13 August 1991 (13.08.1991) Abstract, col 4, lines 25-68, fig 1	1-36
A	US 2009/0299195 A1 (MULLER et al) 03 December 2009 (03.12.2009) para 0027-0036, 0040, fig 1	1-36

☐ Further documents are listed in the continuation of Box C. ☐

* 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	Date of mailing of the international search report
26 November 2012	10 DEC 2012

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774