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(54) **DRIVER-MOUNTED TORQUE SENSING MECHANISM**

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

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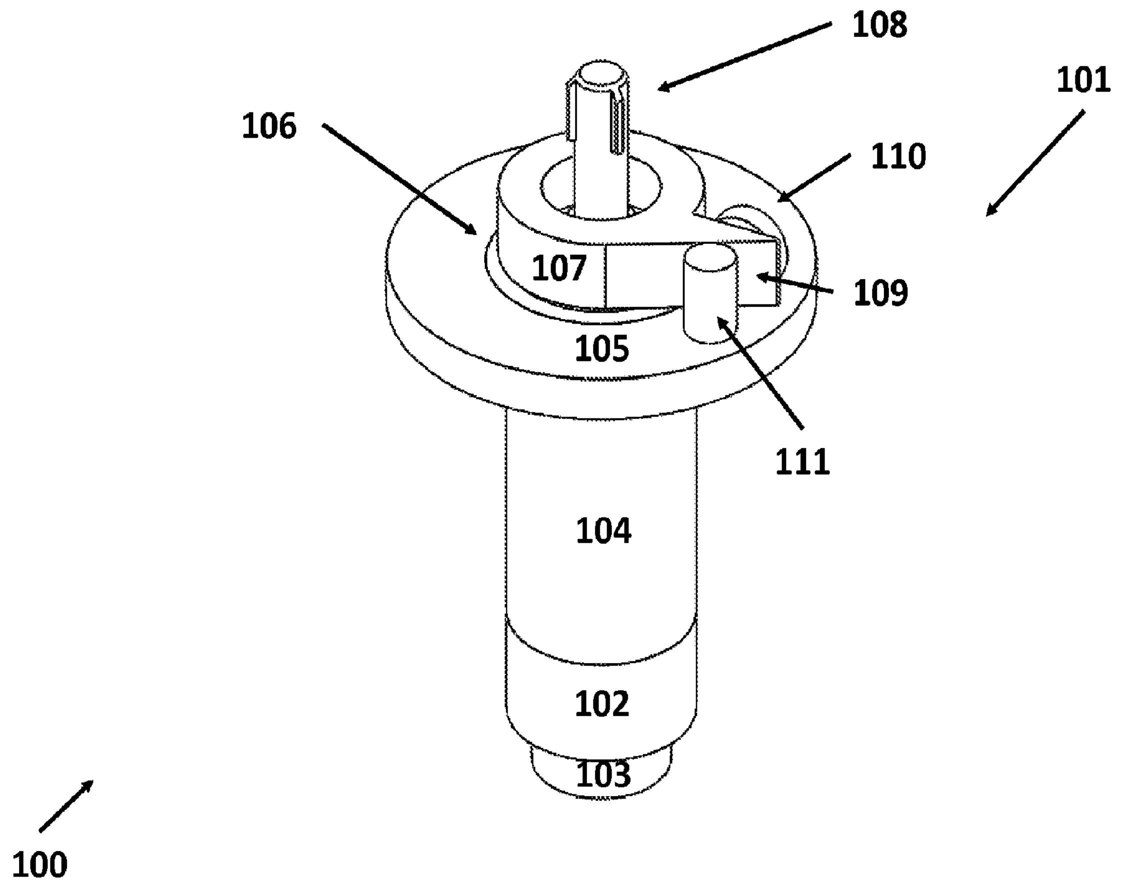
(57) **ABSTRACT**

A robotically-controlled drive unit includes a torque sensing mechanism to measure the torque applied to a rotatable body that is configured to tension an actuation tendon to operate robotic surgical tools and catheters. The drive unit includes a motor unit that generates an output torque in response to a robotic control signal. A beam element generates a reactive torque in response to the output torque generated by the rotor, and a force sensor detects the reactive torque and communicates the magnitude of the reactive torque to a robotic controller. The drive unit may further include a mechanism to perform bi-directional torque sensing, examples of which include additional force sensors and compression springs.



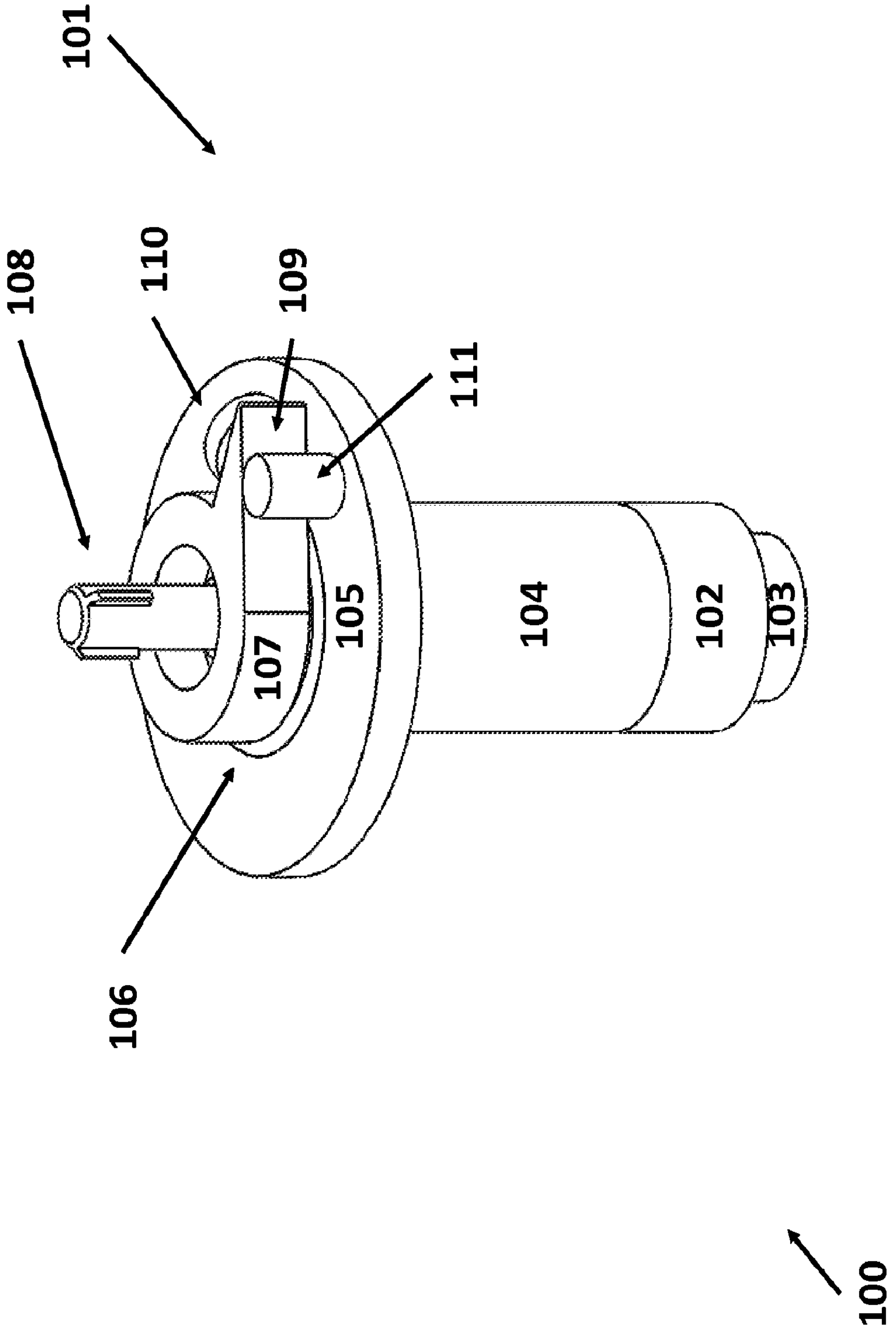



FIG. 1A

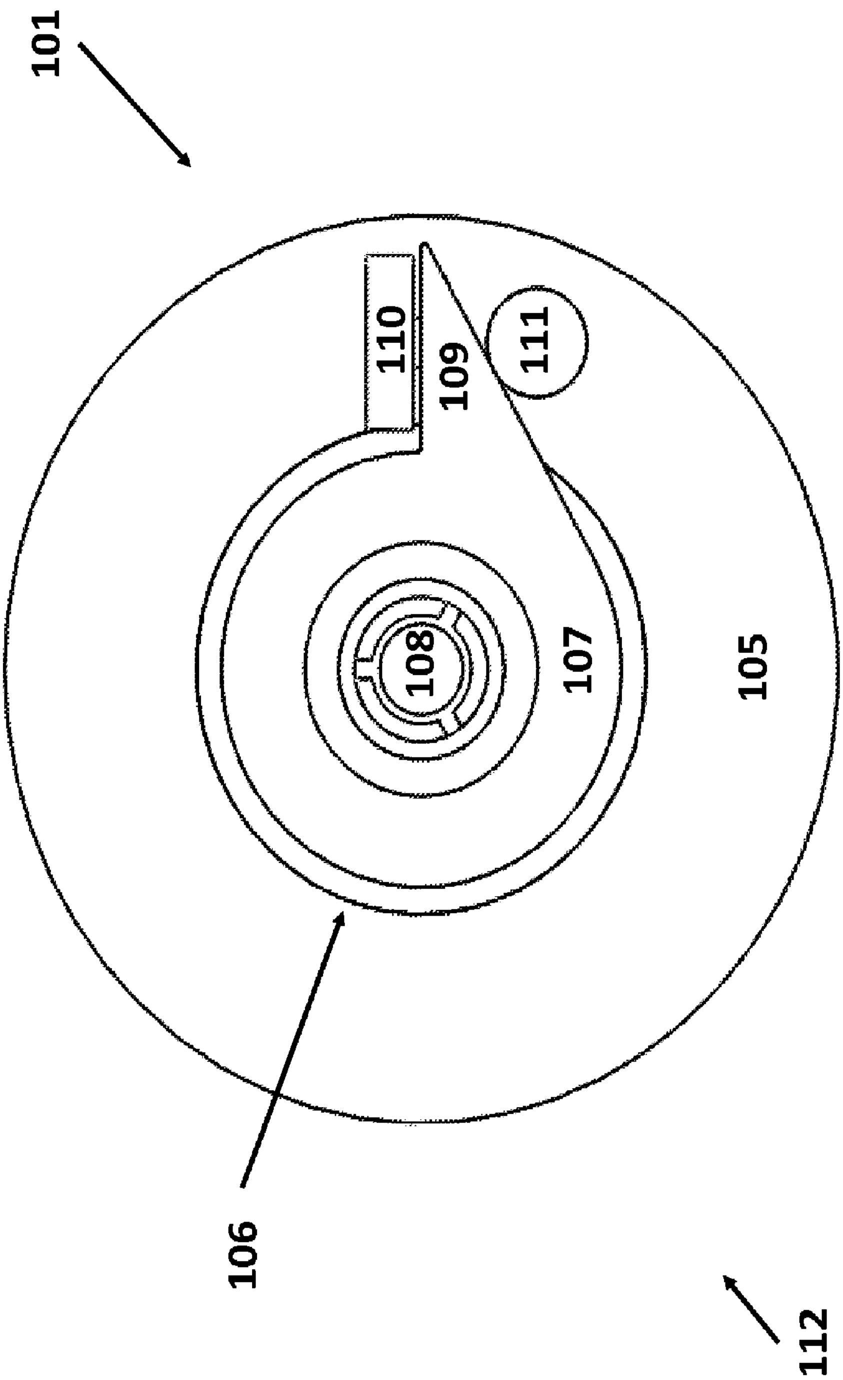



FIG. 1B

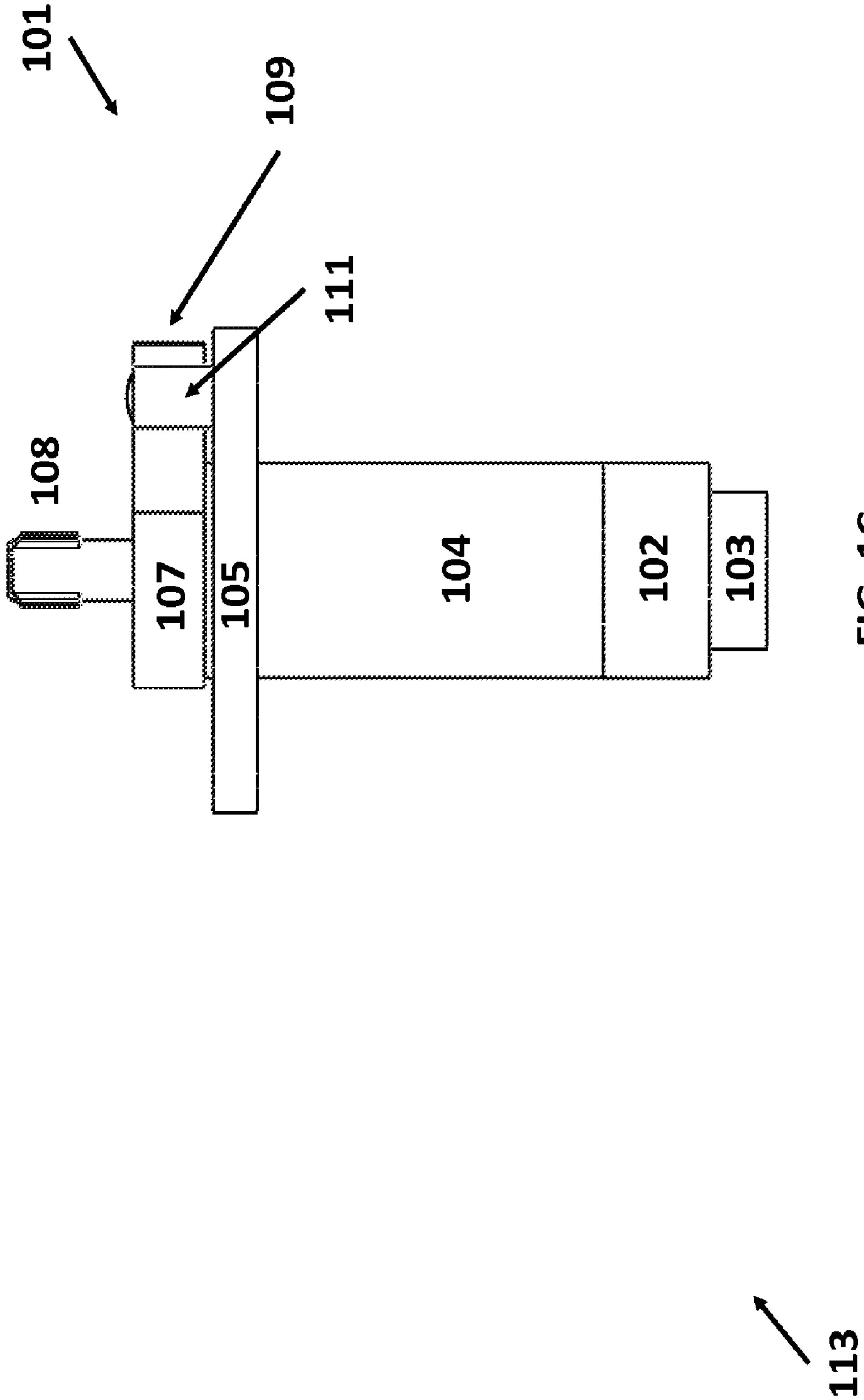



FIG. 1C

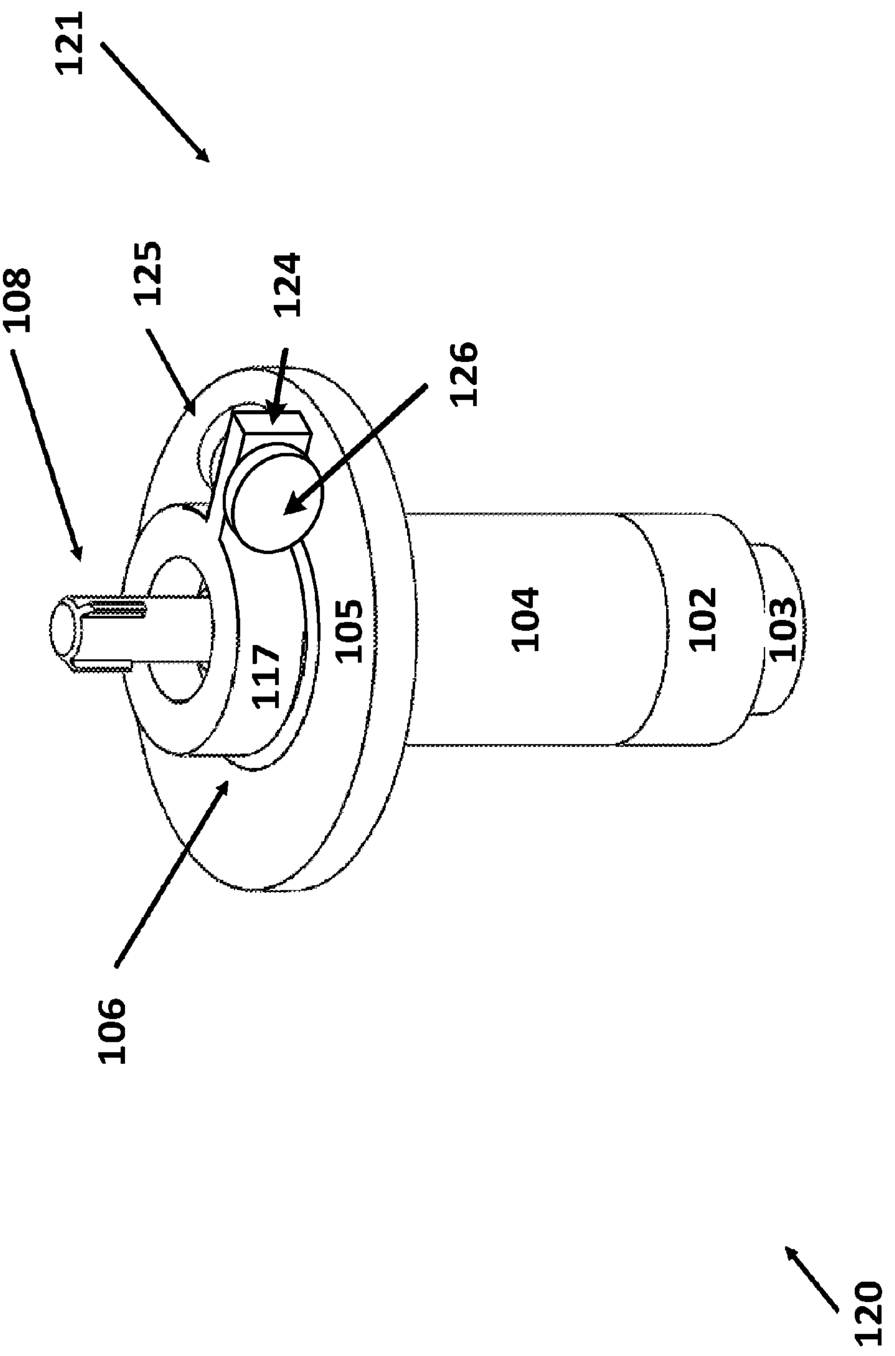



FIG. 1D

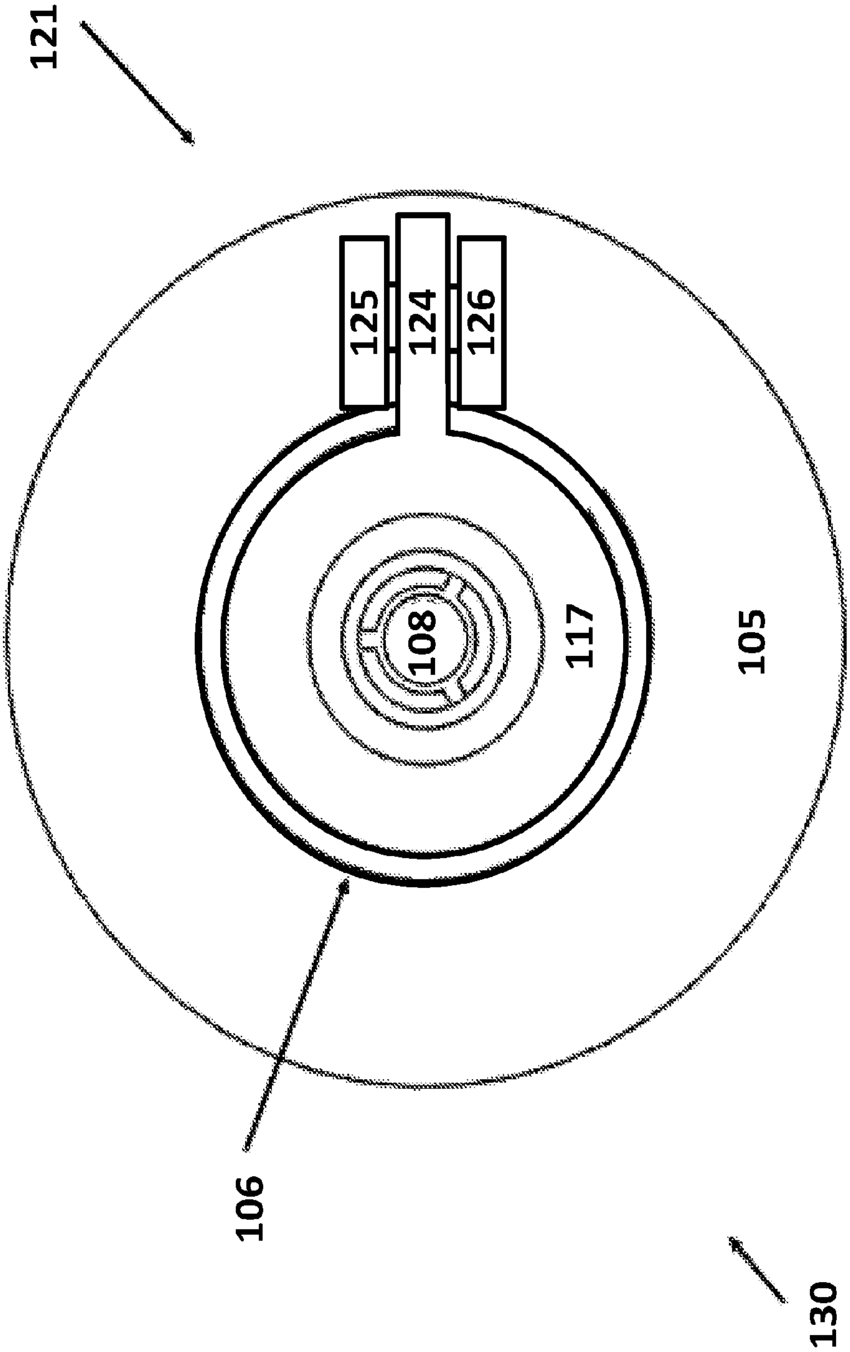



FIG. 1E

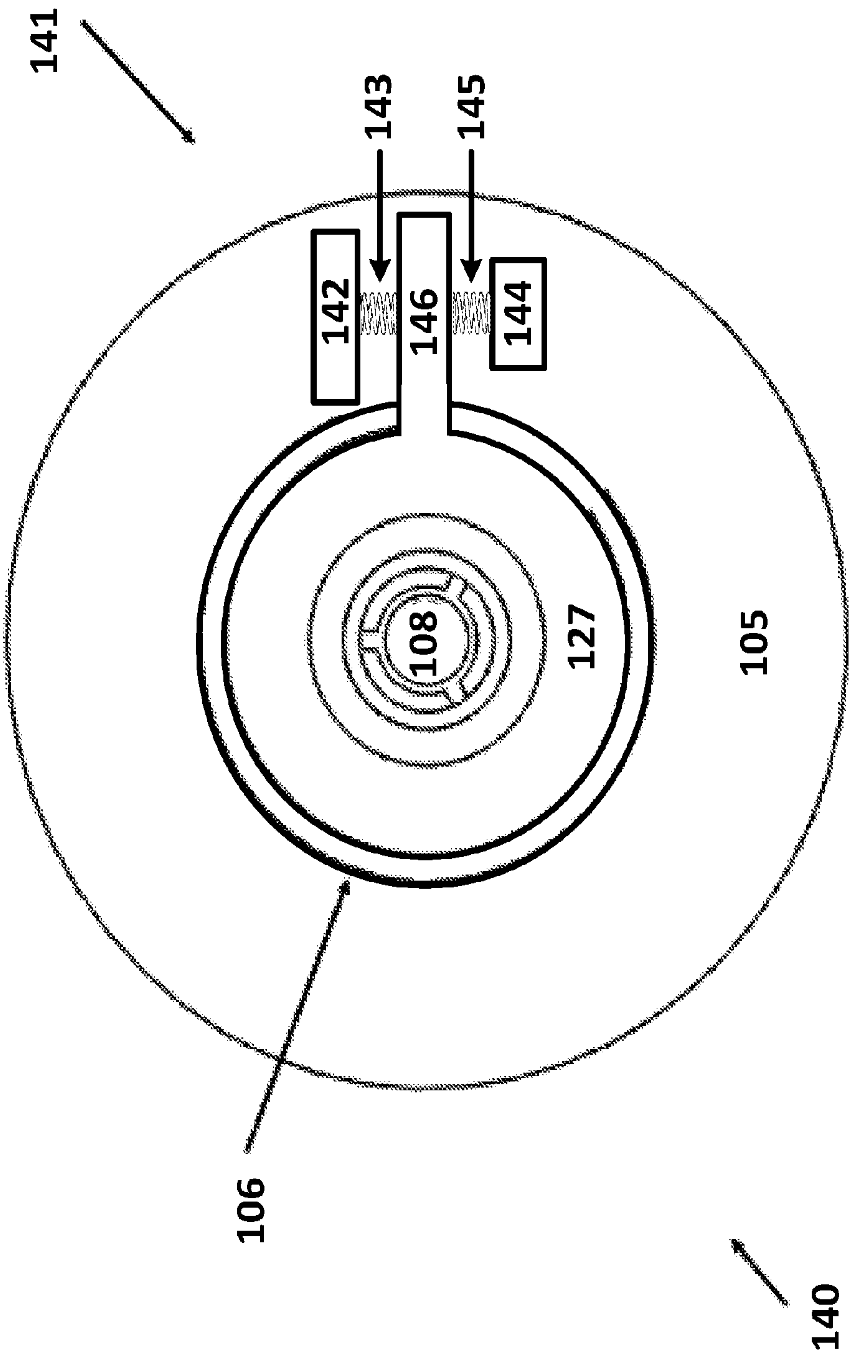



FIG. 1F

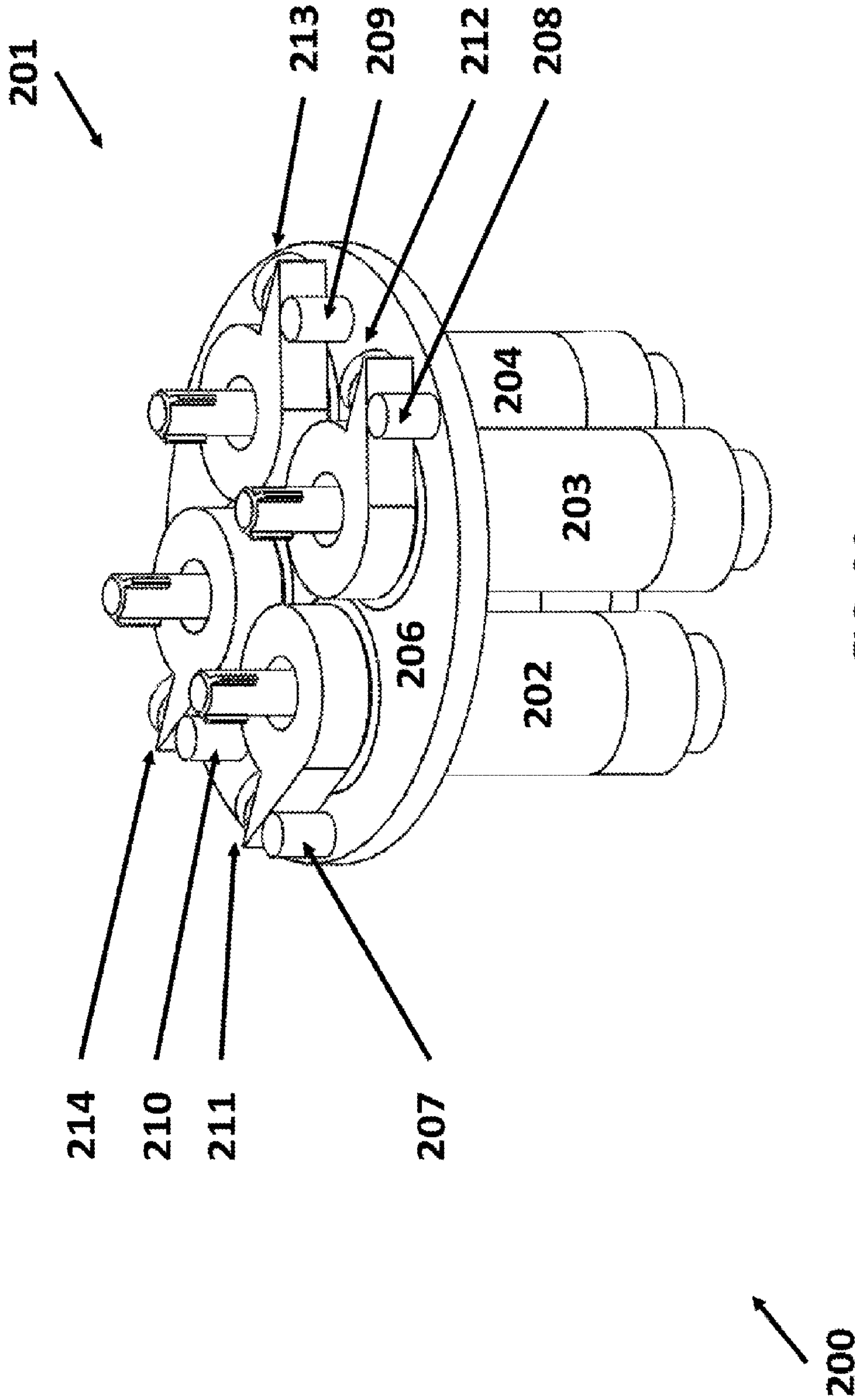



FIG. 2A

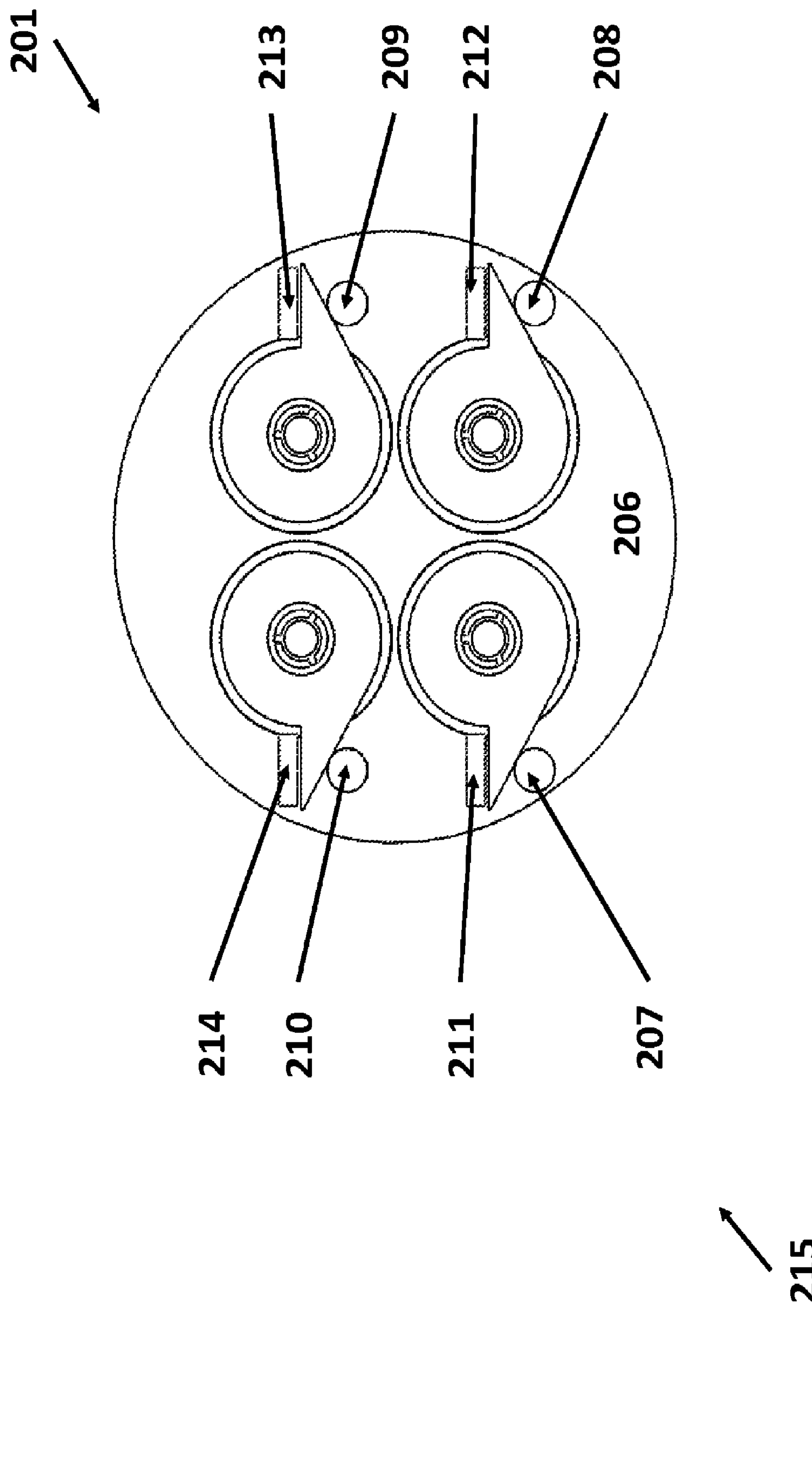



FIG. 2B

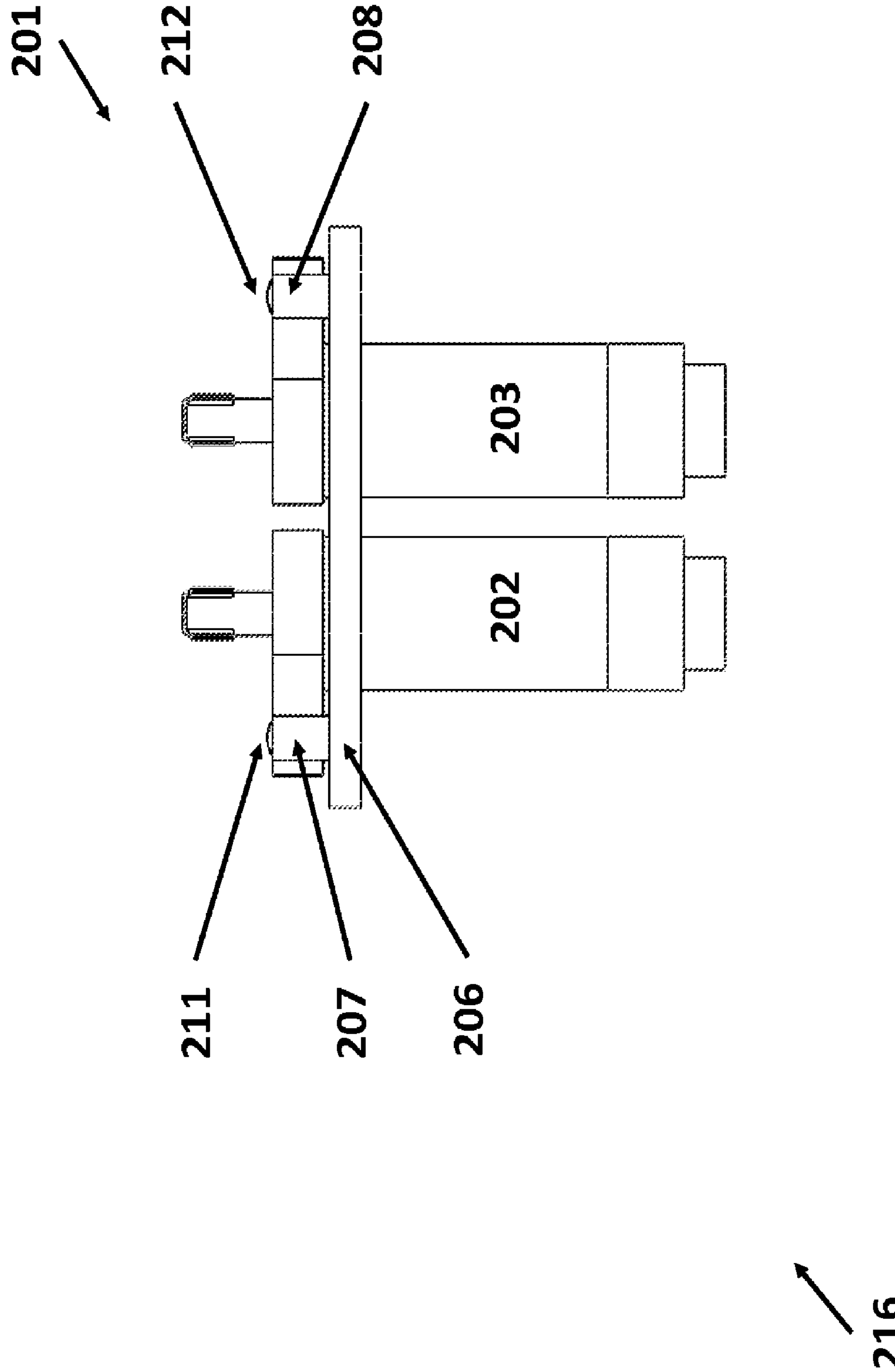



FIG. 2C

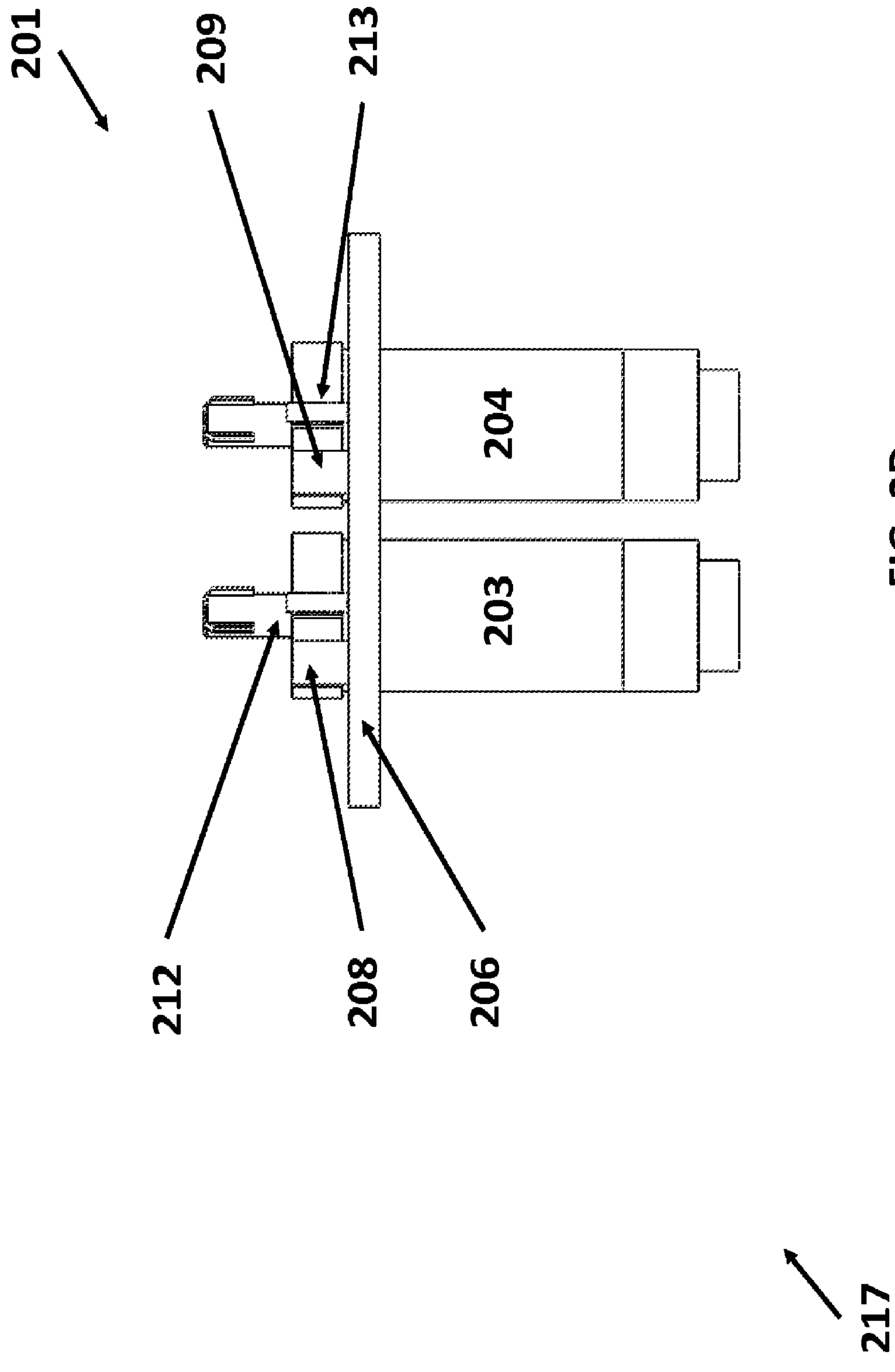



FIG. 2D

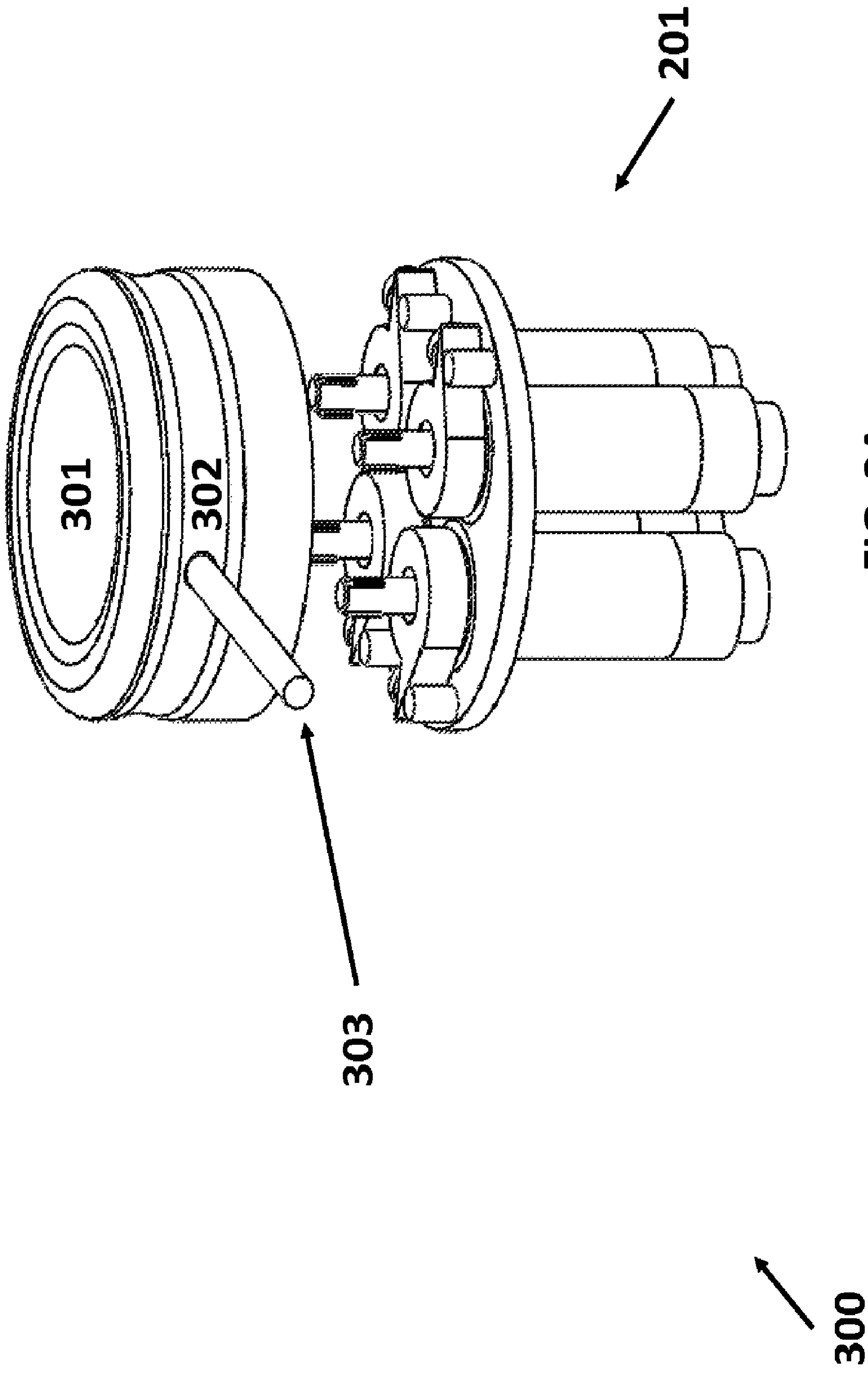



FIG. 3A

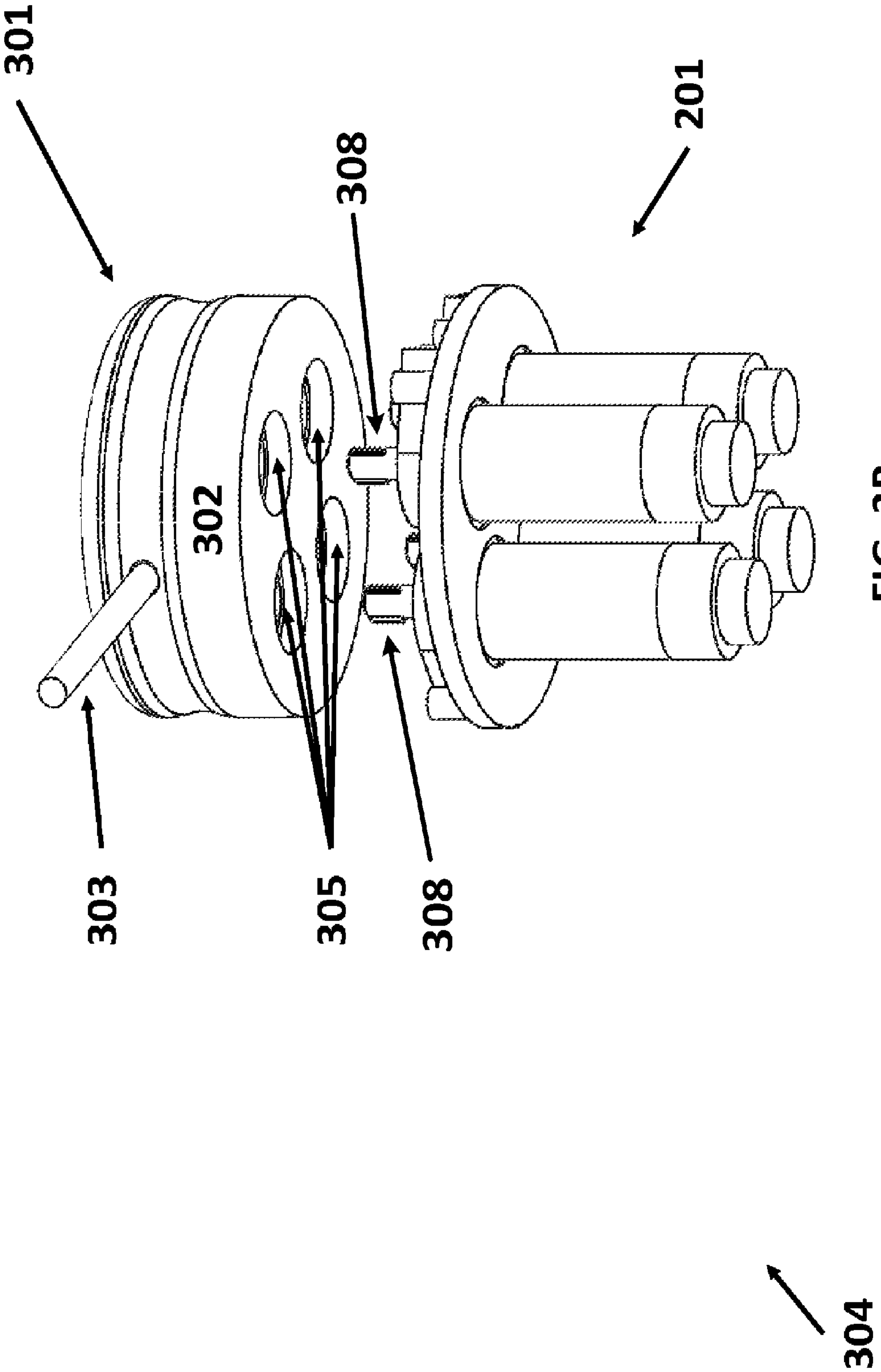



FIG. 3B

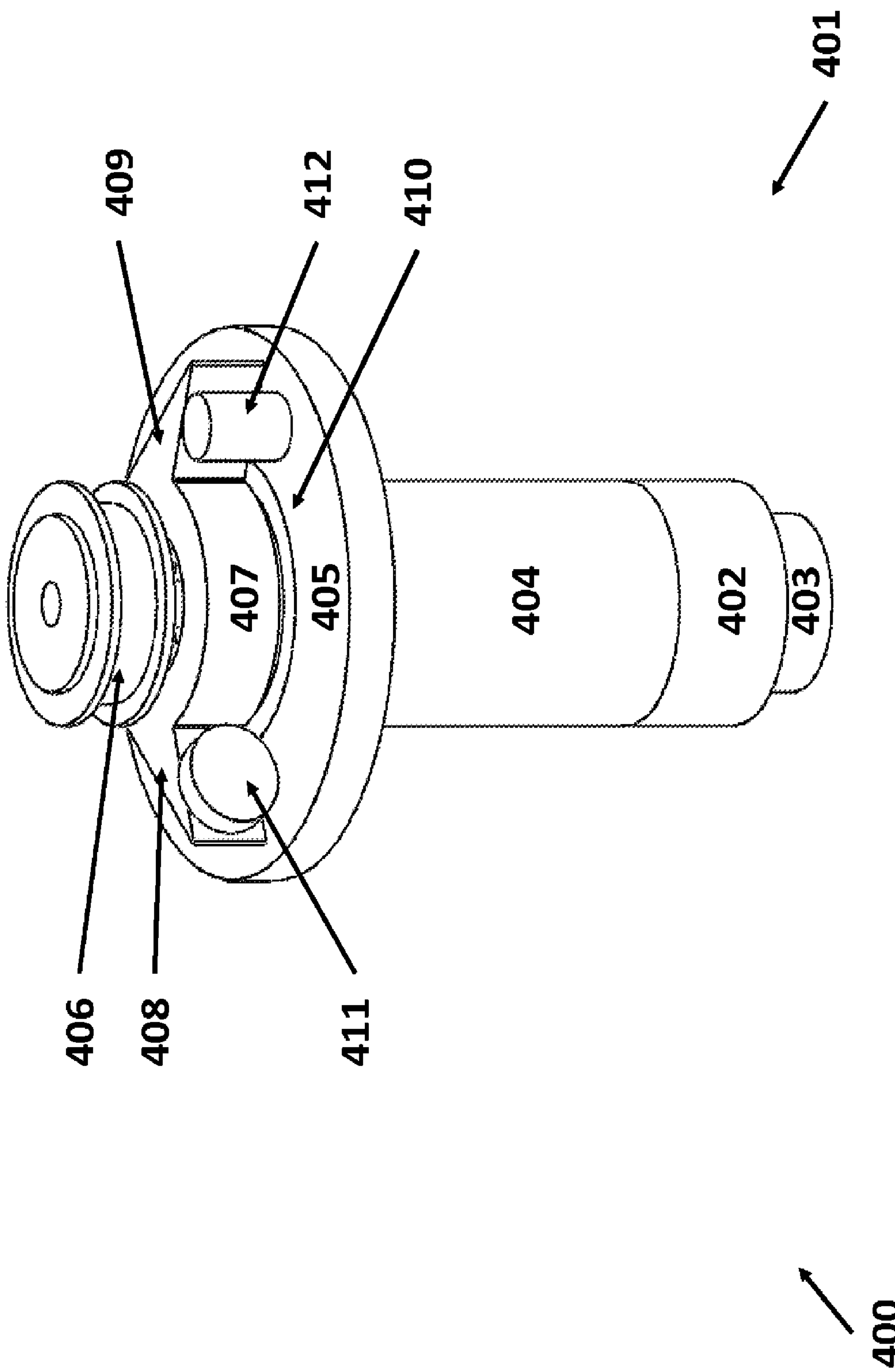



FIG. 4

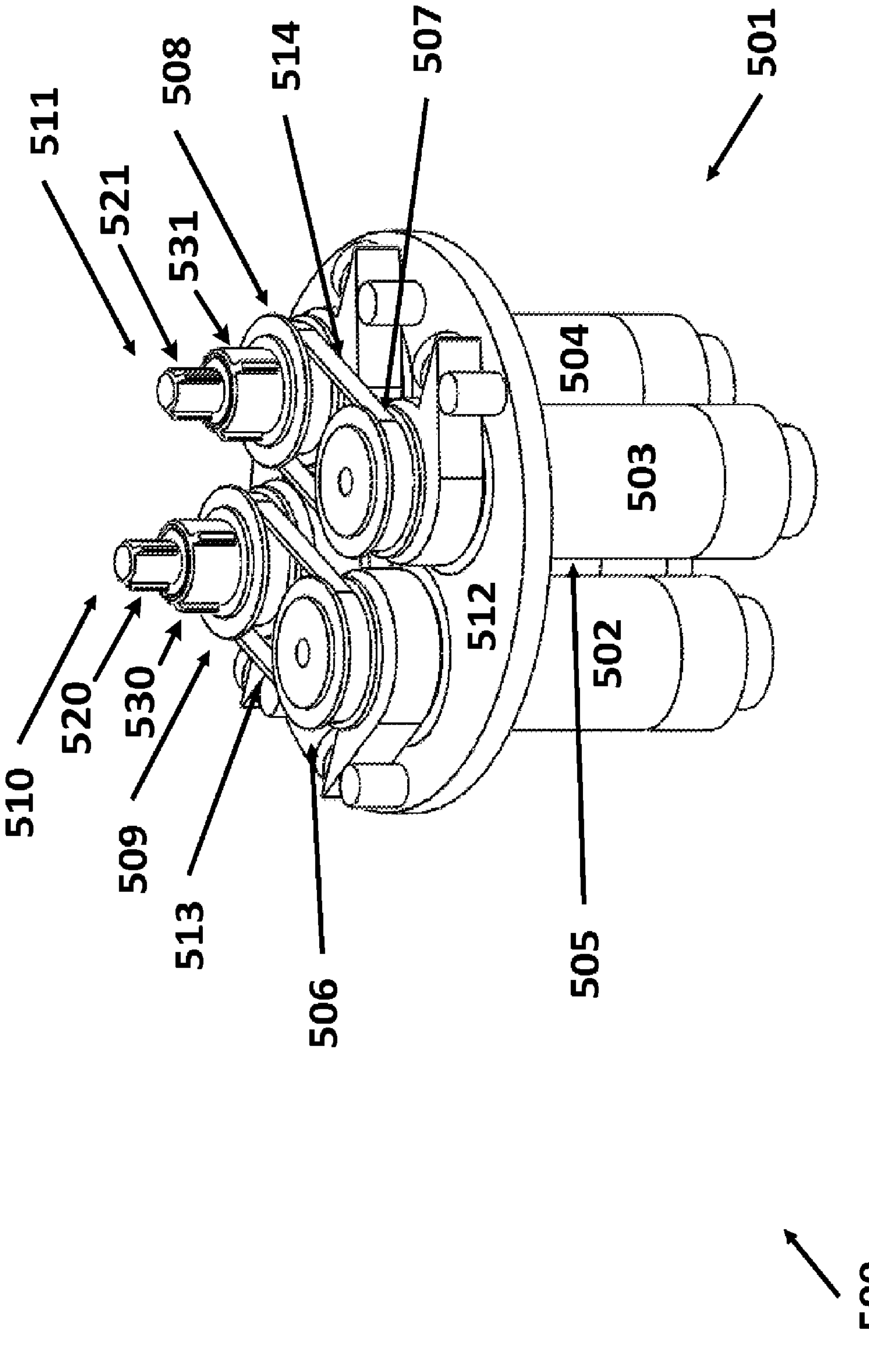

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FIG. 5A

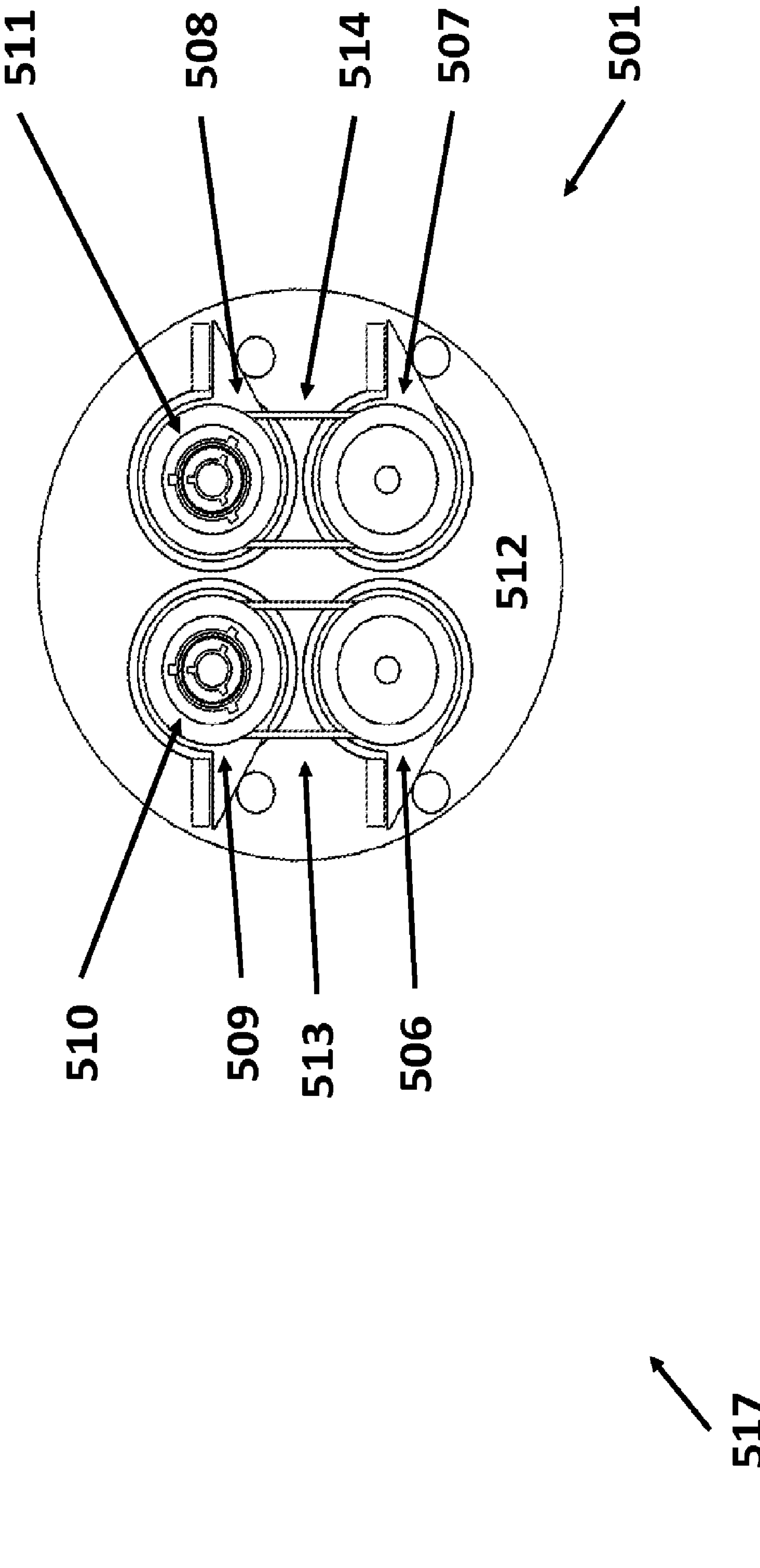


FIG. 5B

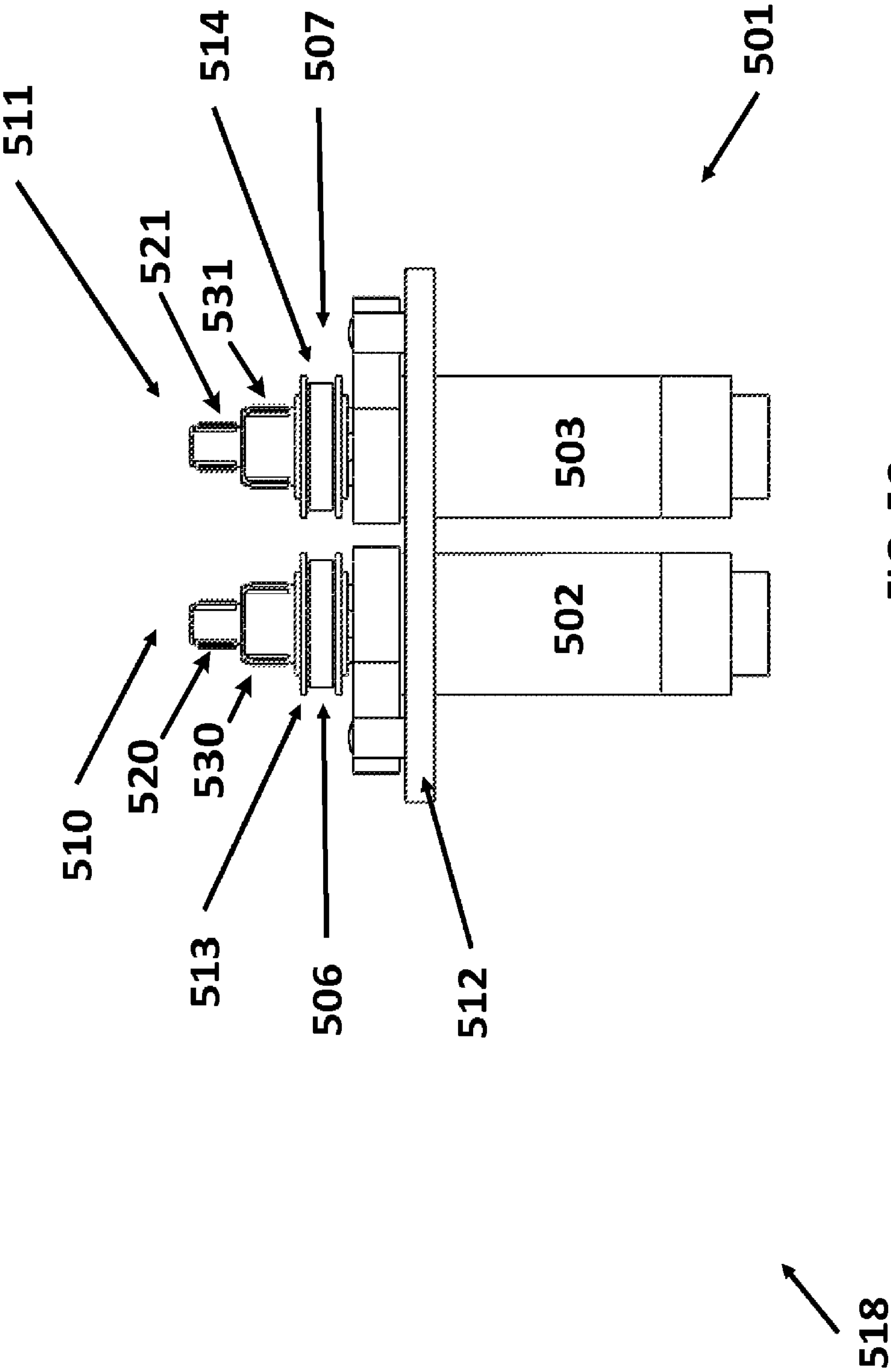


FIG. 5C

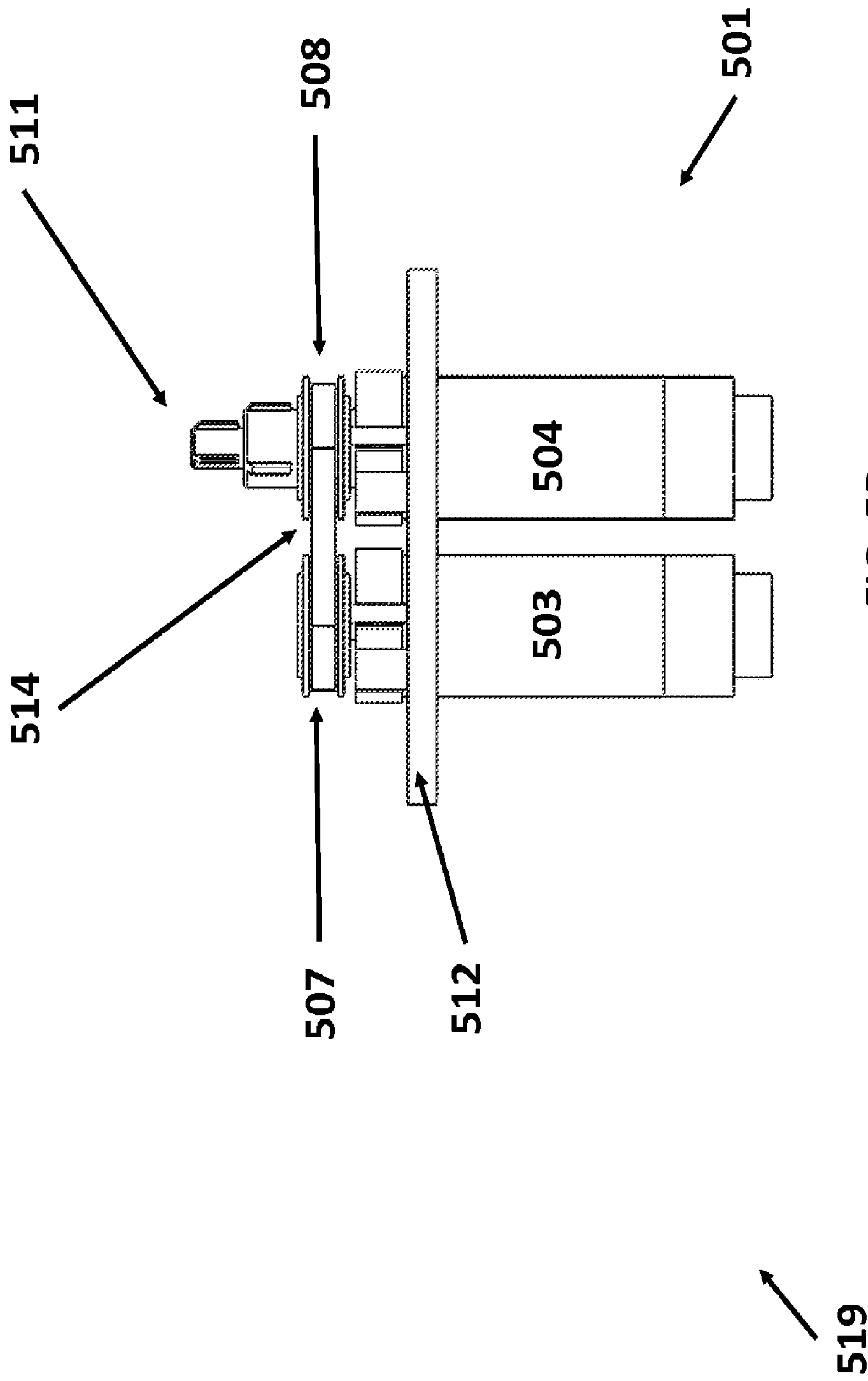


FIG. 5D

# DRIVER-MOUNTED TORQUE SENSING MECHANISM

## CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** This application claims the benefit of and priority to U.S. Provisional Application No. 62/190,179 filed Jul. 8, 2015, the entire contents of which are incorporated herein by reference. This application is related to U.S. patent application Ser. No. 14/523,760, filed Oct. 24, 2014, U.S. Provisional Patent Application No. 62/019,816, filed Jul. 1, 2014, U.S. Provisional Patent Application No. 62/037,520, filed Aug. 14, 2014, U.S. Provisional Patent Application No. 62/057,936, filed Sep. 30, 2014, U.S. Provisional Patent Application No. 62/134,366, filed Mar. 17, 2015, the entire contents of which are incorporated herein by reference.

## BACKGROUND

**[0002]** 1. Field of Art

**[0003]** This description relates to a driver-mounted tension sensing design that may be used in conjunction with a medical robotics platform for a number of surgical procedures. More particularly, the driver-mounted tension sensing mechanism detects torques exerted by output shafts within an instrument device manipulator that actuates tendons to operate an elongated instrument.

**[0004]** 2. Description of Related Art

**[0005]** Use of robotic technologies presents a number of advantages over traditional, manual surgery procedures. In particular, robotic surgeries often allow for greater precision, control, and access. Robotically-controlled technologies, however, sometimes create engineering challenges that require creative engineering workarounds. In the case of robotically-controlled tools, the use of actuation tendons to operate robotic laparoscopic tools and catheters gives rise to control problems that often requires very precise monitoring of the torque applied to actuation tendons. Over the lifespan of an actuation tendon, the tendon may stretch and deform, and exhibit greater non-linearity with respect to force applied to the tendon and the expected actuation. Accordingly, within a robotically-controlled instrument, there is a need to accurately measure the torque applied to a rotatable body.

## SUMMARY

**[0006]** In general, the present description provides a medical device that includes a robotically-controlled drive unit configured to generate angular motion, the drive unit including an electric motor unit with a rotor that is configured to generate an output torque in response to a robotic control signal, a beam element configured to generate a reactive torque in response to the output torque generated by the rotor, and a force sensor configured to detect the reactive torque and communicate the magnitude of the reactive torque to a robotic controller, wherein the beam element is coupled to the electric motor unit and oriented perpendicularly to the longitudinal axis of the rotor.

**[0007]** In one aspect, the beam element is configured to rotate around the axis of the motor shaft using a ball bearing. In one aspect, the beam element is coupled to a rotatable component that is configured to rotate around the axis of the rotor using a ball bearing.

**[0008]** In one aspect, the drive unit further includes a gear head coupled to the electric motor unit, wherein the gear head is configured to amplify the output torque generated by the rotor. In another aspect, the drive unit further includes a drive base that includes a ball bearing configured to allow the beam element to move freely in response to the output torque. In another aspect, the drive unit further includes an output shaft operatively coupled to the gear head. In another aspect, the output shaft is configured to transmit angular motion to a rotatable body intended to actuate a tendon in an elongated body. In another aspect, the elongated body is an instrument configured for performing endolumenal procedures. In another aspect, the elongated body is a flexible instrument. In another aspect, the elongated body is a catheter. In another aspect, the elongated body is an instrument configured for performing laparoscopic procedures. In another aspect, the output shaft is configured to rotate an elongated body along its longitudinal axis.

**[0009]** In one aspect, the force sensor includes at least one of a load cell, piezoresistive device, a piezoelectric device, and a strain gauge. In one aspect, the drive unit further includes a stopper that is configured to keep the beam element from moving in the direction of the stopper. In another aspect, the stopper and the force sensor are positioned on opposite sides of the beam element. In another aspect, the stopper and the force sensor are coupled to a drive base.

**[0010]** In one aspect, the drive unit is incorporated into an instrument device manipulator as part of a surgical robotics platform. In one aspect, the instrument device manipulator includes a second drive unit. In one aspect, the robotic controller is remotely located. In one aspect, the robotic controller is configured to generate the robotic control signal. In one aspect, the robotic controller is configured to generate the robotic control signal based on the magnitude of the reactive torque detected by the force sensor. In one aspect, the drive unit includes a rotary encoder coupled to the electric motor unit and configured to detect angular motion of the motor shaft.

## BRIEF DESCRIPTION OF DRAWINGS

**[0011]** FIG. **1**A illustrates a perspective view of a drive unit configured to generate angular motion that incorporates a torque sensing mechanism, consistent with one embodiment.

**[0012]** FIG. **1**B illustrates a top view of the drive unit from FIG. **1**A, consistent with one embodiment.

**[0013]** FIG. **1**C illustrates a side view of the drive unit from FIGS. **1**A and **1**B, consistent with one embodiment.

**[0014]** FIG. **1**D illustrates a perspective view of a drive unit configured to generate angular motion, and that incorporates a bi-directional torque sensing mechanism with two force sensors, consistent with one embodiment.

**[0015]** FIG. **1**E illustrates a top view of the drive unit from FIG. **1**D, consistent with one embodiment.

**[0016]** FIG. **1**F illustrates a top view of a drive unit configured to generate angular motion, and that incorporates a bi-directional torque sensing mechanism with compression springs, consistent with one embodiment.

**[0017]** FIG. **2**A illustrates a perspective view of a plurality of drive units as configured to be used in an instrument device manipulator, consistent with one embodiment.

**[0018]** FIG. **2**B illustrates a top view of an instrument device manipulator from FIG. **2**A, consistent with one embodiment.

**[0019]** FIGS. **2**C and **2**D illustrate alternative side perspectives on the instrument device manipulator from FIGS. **2**A and **2**B.

**[0020]** FIG. **3**A illustrates one view of the alignment of an instrument device manipulator in combination with an associated instrument, consistent with one embodiment.

**[0021]** FIG. **3**B illustrates another view of the alignment of an instrument device manipulator in combination with an associated instrument, consistent with one embodiment.

**[0022]** FIG. **4** illustrates an instrument drive mechanism that incorporates a torque sensing mechanism, consistent with one embodiment.

**[0023]** FIG. **5**A illustrates the incorporation of a drive unit with a bi-directional torque sensing mechanism into an instrument device manipulator with co-axial output shafts, consistent with one embodiment.

**[0024]** FIG. **5**B illustrates the incorporation of a drive unit with a bi-directional torque sensing mechanism into an instrument device manipulator with co-axial output shafts from an another perspective, consistent with one embodiment.

**[0025]** FIG. **5**C illustrates the incorporation of a drive unit with a bi-directional torque sensing mechanism into an instrument device manipulator with co-axial output shafts from an yet another alternative perspective, consistent with one embodiment.

**[0026]** FIG. **5**D illustrates the incorporation of a drive unit with a bi-directional torque sensing mechanism into an instrument device manipulator with co-axial output shafts from yet another alternative perspective, consistent with one embodiment.

## DETAILED DESCRIPTION

**[0027]** Although certain preferred embodiments and examples are disclosed below, inventive subject matter extends beyond the specifically disclosed embodiments to other alternative embodiments and/or uses, and to modifications and equivalents thereof. Thus, the scope of the claims appended hereto is not limited by any of the particular embodiments described below. For example, in any method or process disclosed herein, the acts or operations of the method or process may be performed in any suitable sequence and are not necessarily limited to any particular disclosed sequence. Various operations may be described as multiple discrete operations in turn, in a manner that may be helpful in understanding certain embodiments; however, the order of description should not be construed to imply that these operations are order dependent. Additionally, the structures, systems, and/or devices described herein may be embodied as integrated components or as separate components.

**[0028]** To guarantee control fidelity, it may be important to monitor the tendon tension when robotically-controlling endoscopic and laparoscopic instruments that use tendon-like members. While there are a number of approaches to monitoring tendon tension, tension measurement in the instrument driver provides a number of practical advantages, including reduction of cost in the instrument. This is particularly important where the instruments are intended to be disposable, or "reposable," over time. Accordingly, the present description provides a sensing apparatus that may be mounted within the instrument driver.

**[0029]** FIG. **1**A illustrates a perspective view of a drive unit configured to generate angular motion that incorporates a torque sensing mechanism, consistent with one embodiment.

**[0030]** As shown in isometric view **100**, a drive unit **101** may generally include a motor unit **102**, a rotary encoder **103**, and a gear head **104**, and a drive base **105**. The motor unit **102** may include a motor, such as a brushed or brushless motor or other type of electric motor.

**[0031]** Rotary encoder **103** monitors and measures the angular speed of the driveshaft of motor unit **102**. In some embodiments, rotary encoder **103** may be a redundant rotary encoder. The structure, capabilities, and use of an appropriate redundant encoder is disclosed in U.S. Provisional Patent Application No. 62/037,520, filed Aug. 14, 2014, the entire contents of which are incorporated by reference.

**[0032]** Within a larger robotic system, a control signal from a controller component may trigger angular motion in the motor unit **102**. The resulting output torque generated by the motor **102** may be transmitted to gear head **104** through a shaft coupled to the rotor of motor **102**. Drive base **105** may include a bearing **106** that may be any type of low-friction bearing, such as a ball bearing and a roller bearing. In the alternative, the bearing **106** may be switched for a bushing or any other mechanical component that allows for angular motion. In some embodiments, the gear head **104** may be attached to the motor **102** to increase torque of the motor output, at the cost of the rotational speed. The increased torque generated by gear head **104** may be transmitted into gear head shaft **108**. The gear head shaft **108** may include a series of splines configured to interface with rotatable bodies, such as pulleys, that may be used to tension tendons and articulate an instrument having an elongated body. Other embodiments may use alternative engagement structures, such as pegs, indentations, etc. In some embodiments, a gear head **104** may be unnecessary and thus omitted.

**[0033]** A rotary component **107** may be coupled to the gear head **104** and motor unit **102**. Thus, any reactive angular motion in gear head **104** and motor unit **102** generated in response to torque in the rotor of motor unit **102** (and thus gear head shaft **108**) may be reflected in substantially identical angular motion in rotary component **107**. The rotary component **107** may be configured to freely rotate on a circular interface with bearing **106** in the drive base **105**. The use of a ball bearing is intended to provide a frictionless or near-frictionless path for the rotary component **107** to rotate. In some embodiments, the circular interface may be co-axial with the gear head shaft **108**, resulting a co-axial path for rotation of the rotary component **107** around the gear head shaft **108**.

**[0034]** Designed to wrap around gear head shaft **108**, the rotary component **107** may be configured to freely rotate in the in response to angular motion (and thus torque) of gear head shaft **108**. As discussed earlier, in some embodiments, the rotary component **107** may be operatively coupled to the gear head **104** and motor unit **102** such that the rotary component rotates consistent with angular motion in the motor unit **102** or gear head **104** that may be generated in response to torque from the rotor of the motor unit **102** or gear head shaft **108**.

**[0035]** The rotary component **107** may include a beam element **109** that may be configured to exert a (reactive) force on a sensor **110** in response to clockwise angular motion and torque of gear head shaft **108**. For example, as shown in view **100**, beam element **109** may protrude horizontally from the rotary component **107** and orthogonal to the axis of the gear head shaft **108**.

**[0036]** In practice, clockwise angular motion, and the resulting torque, by gear head shaft **108** generates rotational motion in the counter-clockwise direction for rotary component **107**. As beam element **109** may be fixedly coupled to the rotary component **107**, its counter-clockwise motion around the axis of the gear head shaft **108** results in the beam element **109** exerting force on the force sensor **110**. In some embodiments, the reactive force on the force sensor **110** is proportional to the torque of the gear head shaft **108**. Force sensor **110** may be any sensor that can detect applied force from the beam element **109**, such as a load cell, piezoresistive device, a piezoelectric device, or a strain gauge. Drive unit **101** may also include a stopper **111** to prevent angular motion in the opposite direction of force sensor **110**, i.e., in the same direction as the torque of the gear shaft head **108**. In some embodiments, the stopper **111** or force sensor **110** may be fixedly coupled to the base drive **105**.

**[0037]** The stopper, force sensor, and drive base may be fixed relative to each other. For example, in some embodiments, the base may be anchored or coupled to a single rigid frame, base, or mount. In addition, the force sensor may be "pre-loaded" by positioning the stopper against the beam element, such that the force sensor detects a force measurement, e.g., a "baseline", even when there is no angular motion in the gear head shaft **108**. When torque occurs and force is applied against the force sensor, the force measurement may increase. If torque is applied in the opposite direction, the force measurement may decrease. This allows for a single force sensor to detect angular motion in both clockwise and counter-clockwise directions. An example embodiment that detects angular motion in both clockwise and counter-clockwise directions is discussed below with respect to FIG. **1**F.

**[0038]** In some embodiments, the base **105** may be coupled to an exterior shell, electronic components, or other mechanisms within an instrument drive mechanism. A base may also stabilize drive unit **101** within an instrument device manipulator within a larger robotic system. In some embodiments, the drive base (or coupled motor mounts) may be constructed from aluminum to reduce weight.

**[0039]** Torque in the gear head shaft **108** may be used to tension tendons within an attached instrument. The instrument may incorporate an elongate body, such as an endoscope or a catheter, which incorporates tendons, such as pull wires or cables, to actuate or articulate a distally located end effector or a distal end.

**[0040]** FIG. **1**B illustrates a top view of the drive unit from FIG. **1**A, consistent with one embodiment. As shown in top view **112**, rotary component **107** may be concentric with the axis of the gear head shaft **108**. Additionally, beam element **109** may extend from rotary component **107** and may be shaped to exert force on force sensor **110** as the rotary component **107** (and the coupled gear head and motor unit) rotates in a counter-clockwise fashion in response to clockwise motion of the gear head shaft **108**.

**[0041]** Although drive unit **101** may be configured with stopper **111** to prevent clockwise motion by rotary component **107** and beam element **109**, in some embodiments, the drive unit may be configured to detect reactive force from the beam sensor in both directions. For example, in some embodiments, the stopper **111** may be replaced with a second force sensor that is configured to detect reactive force from beam element **109** when rotary component **107** (and the coupled gear head and motor unit) rotates in a clockwise fashion in response to counter-clockwise angular motion from the gear head shaft **108**. An example embodiment of the drive unit that has a second force sensor is discussed below with respect to FIGS. **1**D-**1**E.

**[0042]** FIG. **1**C illustrates a side view of the drive unit from FIGS. **1**A and **1**B, consistent with one embodiment. As shown in side view **113**, drive unit **101** is oriented such that the proximal (bottom) end of the motor unit **102** is coupled to a rotary encoder **103** while the distal (top) end of the motor unit **102** is coupled to a gear head **104** with a gear head shaft **108** that ultimately derives torque from the rotor of the motor unit **102**. Rotary component **107** may be coupled to a ball bearing interface (**106**) that allows the rotary component **107** to freely rotate relative to base **105** and around the gear head shaft **108**.

**[0043]** Beam element **108** may extend and protrude from rotary component **107** and may be shaped to exert force on force sensor **110** as the rotary component **107** rotates in a counter-clockwise fashion in response to clockwise motion of the gear head shaft **108**.

**[0044]** FIG. **1**D illustrates a perspective view of a drive unit configured to generate angular motion, and that incorporates a bi-directional torque sensing mechanism with two force sensors, consistent with one embodiment. As shown in isometric view **120**, a drive unit **121** may generally include a motor unit **102**, a rotary encoder **103**, and a gear head **104**, and a drive base **105**, as discussed above with respect to FIGS. **1**A-**1**C.

**[0045]** Similar to the rotary component **107** of FIGS. **1**A-**1**C, a rotary component **117** may be coupled to the gear head **104** and motor unit **102**. The rotary component **117** may include a beam element **124** that may be configured to exert a (reactive) force on sensors **125** and **126** in response to angular motion and torque of gear head shaft **108**. For example, as shown in view **120**, beam element **124** may protrude horizontally from the rotary component **117** and orthogonal to the axis of the gear head shaft **108**.

**[0046]** In practice, clockwise angular motion, and the resulting torque, by gear head shaft **108** generates rotational motion in the counter-clockwise direction for rotary component **117**. As beam element **124** may be fixedly coupled to the rotary component **117**, its counter-clockwise motion around the axis of the gear head shaft **108** results in the beam element **124** exerting force on the force sensor **125**. Conversely, counter-clockwise angular motion, and the resulting torque, by gear head shaft **108** generates rotational motion in the clockwise direction for rotary component **117**. Accordingly, the clockwise motion of the beam element **124** around the axis of the gear head shaft **108** results in the beam element **124** exerting force on the force sensor **126**.

**[0047]** In some embodiments, the reactive force on the force sensors **125**, **126** is proportional to the torque of the gear head shaft **108**. Force sensors **125**, **126** may be any sensor that can detect applied force from the beam element **124**, such as a load cell, piezoresistive device, a piezoelectric device, or a strain gauge.

**[0048]** The force sensors **125**, **126** and drive base **105** may be fixed relative to each other. For example, in some embodiments, the base may be anchored or coupled to a single rigid frame, base, or mount.

**[0049]** FIG. **1**E illustrates a top view of the drive unit from FIG. **1**D, consistent with one embodiment. As shown in top view **130**, rotary component **117** may be concentric with the axis of the gear head shaft **108**. Additionally, beam element **124** may extend from rotary component **117** and may be shaped to exert force on force sensors **125**, **126** as the rotary component **117** (and the coupled gear head and motor unit) rotates in response to motion of the gear head shaft **108**.

**[0050]** FIG. **1**F illustrates a top view of a drive unit configured to generate angular motion, and that incorporates a bi-directional torque sensing mechanism with compression springs, consistent with one embodiment. A drive unit **141** may generally include a motor unit, a rotary encoder, and a gear head, and a drive base **105**, as discussed above with respect to FIGS. **1**A-**1**C.

**[0051]** Similar to the rotary components **107**, **117** of FIGS. **1**A-**1**E, a rotary component **127** may be coupled to the gear head and motor unit. The rotary component **127** may include a beam element **146** that may be configured to exert a (reactive) force, via a compression spring **143**, on sensor **142** in response to angular motion and torque of gear head shaft **108**. For example, the beam element **146** may protrude horizontally from the rotary component **127** and orthogonal to the axis of the gear head shaft **108**. The beam element may be coupled to the force sensor **142** via a compression spring **143** such that rotation of the rotary component **127** causes the beam element **146** to compress or stretch the compression spring **143**, whereby exerting a force on the force sensor **142**. The beam element may further be coupled to a stopper **144** via a compression spring **145** such that the compression spring **145** exerts a similar force on the beam element **146** as the compression spring **143** when there is no angular motion in the gear head shaft **108**. The force sensor **142**, stopper **144**, and drive base **105** may be fixed relative to each other. For example, in some embodiments, the base may be anchored or coupled to a single rigid frame, base, or mount. As a result, the force sensor **142** may be "pre-loaded" such that the force sensor detects a force measurement, e.g., a "baseline", even when there is no angular motion in the gear head shaft **108**. When torque occurs and force is applied against the force sensor, the force measurement may increase. In case with torque in the opposite direction, the force measurement may decrease. This allows for a single force sensor to detect angular motion in both clockwise and counter-clockwise directions.

**[0052]** In practice, clockwise angular motion, and the resulting torque, by gear head shaft **108** generates rotational motion in the counter-clockwise direction for rotary component **127**. As beam element **146** may be fixedly coupled to the rotary component **127**, its counter-clockwise motion around the axis of the gear head shaft **108** causes the beam element **146** to compress the compression spring **143**, which results in an increase in the force exerted by the compression spring **143** on the force sensor **142**. Conversely, counter-clockwise angular motion, and the resulting torque, by gear head shaft **108** generates rotational motion in the clockwise direction for rotary component **127**. Accordingly, the clockwise motion of the beam element **146** around the axis of the gear head shaft **108** causes the beam element **146** to decompress the compression spring **143**, which results in a decrease in the force exerted by the compression spring **143** on the force sensor **126**.

**[0053]** In some embodiments, the reactive force on the force sensor **142** is proportional to the torque of the gear head shaft **108**. Force sensor **142** may be any sensor that can detect applied force from the beam element **146** or compression spring **143**, such as a load cell, piezoresistive device, a piezoelectric device, or a strain gauge.

**[0054]** As shown in top view **140**, the rotary component **127** may be concentric with the axis of the gear head shaft **108**. Additionally, beam element **146** may extend from rotary component **127** and may be shaped to exert force on force sensor **142** via compression springs **143** as the rotary component **127** (and the coupled gear head and motor unit) rotates in response to motion of the gear head shaft **108**.

**[0055]** FIG. **2**A illustrates a perspective view of a plurality of drive units as configured to be used in an instrument device manipulator, consistent with one embodiment. As shown in isometric view **200**, four drive units, such as drive unit **202**, drive unit **203**, drive unit **204**, and drive unit **205** (obscured by drive unit **202**), each including components substantially disclosed in FIGS. **1**A-**1**C, may be arranged in parallel fashion within an instrument device manipulator **201** such that their gear head shafts are parallel as well.

**[0056]** The drive units **202**, **203**, **204**, and **205**, may be held in place in parallel fashion by a drive base **206** that is coupled to the respective gear head and/or the motor units of the coupled drive units. Even though the drive base **206** is shown to be circular in FIG. **2**A, the base may be any variety of shapes to accommodate the structure and/or shape of the instrument device manipulator.

**[0057]** As shown in view **200**, the force sensors and stoppers are organized and arranged on base **206** to avoid touching, colliding, or conflicting each other and, thus, provide incorrect force measurements. For example, force sensors **212** and **213** are arranged to detect counter-clockwise reactive force resulting from clockwise motion in their respective gear head shafts. Accordingly, the stoppers **208** and **209** are arranged to prevent reactive motion in a clockwise direction and thus prevent the respective beam elements from hitting each other. In similar fashion, force sensors **207** and **210** are arranged to detect counter-clockwise reactive force while stoppers **211** and **214** are arranged to prevent clockwise motion and thus collision from the respective beam elements.

**[0058]** Within a robotic system, the instrument device manipulator may receive control signals from a controller that actuates the motor units to generate an output torque to control the attached instruments. The force sensors on each drive unit may also be configured to communicate the magnitude of the force detected, thus measuring the torque generated by the motor units, allowing feedback to the controller regarding the resulting torque generated by the motor units in the instrument device manipulator. Using the feedback, the controller may provide the proper control signal to the drive units to increase, decrease or maintain torque.

**[0059]** FIG. **2**B illustrates a top view of an instrument device manipulator from FIG. **2**A, consistent with one embodiment. As shown in top view **215**, viewed from above instrument device manipulator **201**, the respective beam elements, stoppers, and force sensors relative to the drive base **206** are arranged and fixed in position to avoid collisions resulting from reactive torque in the output shafts. FIGS. **2**C and **2**D illustrate alternative side perspectives on the instrument device manipulator from FIGS. **2**A and **2**B. In frontal view **216** from FIG. **2**C illustrates the parallel alignment of drive units **202** and **203** and the relative arrangement of stoppers **207** and **208** and sensors **211** and **212** (both partially obscured). In side view **217** from FIG. **2**D, the parallel alignment of drive units **203** and **204** and the relative arrangement of stoppers **207** and **208** and sensors **211** and **212** (both partially obscured).

**[0060]** FIG. **3**A illustrates one view of the alignment of an instrument device manipulator in combination with an associated instrument, consistent with one embodiment. As shown in isometric view **300**, instrument driver **201** (shown without an outer skin or shell) may be configured to interface with an instrument **301**. In some embodiments, the instrument interface may occur through a removable sterile adapter that may be cleansed. Instrument **301** may generally include an instrument base **302** and an elongated body **303**, such as a catheter or endoscope, which is designed to be robotically actuated or robotically articulated for either endoscopic and laparoscopic procedures within a patient. Instrument **301** may be architected, constructed, and used in operative methods as disclosed in the aforementioned patents.

**[0061]** FIG. **3**B illustrates another view of the alignment of an instrument device manipulator in combination with an associated instrument, consistent with one embodiment. As shown in view **304**, the arrangement of parallel gear head shafts **308** in instrument device manipulator **201** allows for easy interfacing with associated instrument **301** and/or a sterile boundary interface. The parallel gear head shafts may be configured to align with ports **305** that each include a rotatable body, such as a pulley or spool, that may be fixedly coupled to a tendon or some other elongated member, such as a pull wire or cable, to actuate the elongated body **303**. Given the four ports **305** in instrument base **302**, instrument **301** provides for four separate means of actuation that be used to articulate the elongated body **303** with multiple degrees of freedom. The operative details of tendon actuation to actuate the elongated body may be consistent with the devices and methods disclosed in the aforementioned patents.

**[0062]** FIG. **4** illustrates an instrument drive mechanism that incorporates a torque sensing mechanism, consistent with one embodiment. As shown in isometric view **400**, a drive unit **401** may generally include a motor unit **402**, a rotary encoder **403**, a gear head **404**, a drive base **405**, and an output pulley **406**. Similar to the motor units disclosed in the aforementioned patents, the motor unit **402** may include a motor, such as a brushed or brushless motor or other electric motor.

**[0063]** Like the embodiments disclosed before, rotary encoder **403** monitors and measures the angular speed of the driveshaft of motor unit **402**. As in the previous embodiments, rotary encoder **403** may be a redundant rotary encoder.

**[0064]** As in earlier embodiments, drive base **405** may include a bearing (**410**) that may be any type of low-friction bearing, such as a ball bearing and a roller bearing. In the alternative, the bearing in drive base **405** may be switched for a bushing or any other mechanical component that allows for angular motion. In some embodiments, the gear head **404** may be attached to the motor **402** to increase torque of the motor output, at the cost of the rotational speed. The increased torque generated by gear head **404** may be transmitted into a gear head shaft and output pulley **406**.

**[0065]** In response to a control signal from a robotic controller, the torque generated by the motor **402** may be transmitted to output pulley **406** through a shaft coupled to the rotor of motor **402**. Tension sensing apparatus **405** may generally include rotary component **407** and a first beam element **408** and a second beam element **409** coupled to different radial locations on rotary component **407**. Designed to wrap around the rotor of motor unit **402**, the rotary component **407** may be configured to freely rotate in the counter-clockwise direction in response to clockwise angular motion (and thus torque) of the rotor motor unit **402** and output pulley **406**. In some embodiments, the rotary component **407** may be coupled to reflect and mirror angular motion in gear head **404**, motor **402** and/or encoder **403** that results from rotating the rotor of motor **402** and gear head shaft (not shown). While rotary component **407** may be coupled to drive base **405**, which is fixedly coupled to gear head **404**, the rotary component **407** may be configured to freely rotate on a circular interface with a plurality of ball bearings (**410**) on drive base **405**. The use of ball bearings is intended to provide a frictionless or near-frictionless path, such as in a bushing, for the rotary component **407** to move. In some embodiments, the circular interface may be co-axial with the rotor of the motor unit **402** and the output pulley **406**, resulting a co-axial path for rotation of the rotary component **407** around the rotor of motor unit **402**. In the absence of a gear head **404**, the drive base **405** may be coupled to the motor **402** as a motor mount through a bearing interface.

**[0066]** The orientation of the coupling of the rotary component **407**, the first beam element **408**, and the second beam element **409**, provides that the counter-clockwise torque generated by the rotary component **407** in response to clockwise torque from the rotor of motor **402** and output pulley **406** is detected by force sensor **411**. Although the first beam element **408**, and the second beam element **409** are orthogonal and perpendicular to the axial length of the rotary component, beam elements in other embodiments may oriented in other directions based on the position and location of their respective force sensors and stoppers.

**[0067]** In practice, clockwise angular motion of the rotor of motor **402** and output pulley **406** results in the generation of a proportional reactive counter-clockwise motion for the rotary component **407** as it rotates on ball bearings in the drive base **405**. As the first beam element **408** is coupled to the rotary component **407**, its direction of travel around the axis of the rotary component **407** would collide with the force sensor **411**. As the force sensor **411** is designed to measure the force from the impact of first beam component **408**, it may generate a signal that represents the magnitude of the force of that impact. This signal may be interpreted by a remotely-located robotic controller as a means of device feedback. Force sensor **411** may be any sensor that can detect applied force from the beam element **408**, such as a load cell, piezoresistive device, a piezoelectric device, or a strain gauge.

**[0068]** In contrast to the force sensor, the stopper **412** is intended to limit the range of motion of the rotary component **407** and the first beam element **408**. Where space is limited, the use of stopper **412** prevents beam element **408** from colliding with other components and generating inaccurate force readings at sensor **411** by "stopping" angular motion of beam element **409**. In contrast to the embodiment of FIG. **1**, in the embodiment of FIG. **4**, the stopper **412** is positioned at a greater distance from the force sensor **411**, and a second beam element (beam element **409**) contacts the stopper **412** rather than the same beam element that contacts the force sensor **411** (beam element **408**). In some embodiments, the stopper may be replaced by a second force sensor, allowing for the detection of angular force in both the clockwise and counter-clockwise directions.

**[0069]** Drive base **405** may also stabilize drive unit **401** within an instrument drive mechanism. In some embodiments, the drive base may be constructed from aluminum to reduce weight. In some embodiments, the motor unit **402** may be coupled to a gear head **404** to increase torque of the motor output, at the cost of the rotational speed. The increased torque generated by the gear head **404** may be transmitted to output pulley **406**. The output pulley **406** may be configured to transmit the torque and angular motion of the rotor of motor unit **402** to belt transmission or some other form of gear train transmission. The drive base **405** or other potential motor mount may be to an exterior shell, electronic components, or other mechanisms within an instrument drive mechanism.

**[0070]** As with the earlier embodiments, the stopper **412**, force sensor **411**, and drive base **405** may be a fixed relative to each other. For example, they may be anchored or coupled to a single rigid frame, base, or mount. In addition, force sensor **411** may be "pre-loaded" by positioning the stopper against the beam element **408**, such that the force sensor **411** detects a force measurement, e.g., a "baseline", even when there is no angular motion in the output pulley **406**. This allows for a single force sensor to detect angular motion in both clockwise and counter-clockwise directions.

**[0071]** FIG. **5**A illustrates the incorporation of a drive unit with a bi-directional torque sensing mechanism into an instrument device manipulator with co-axial output shafts, consistent with one embodiment. As shown in isometric view **500**, instrument device manipulator **501** may include four drive units (**502**, **503**, **504**, **505**) that incorporate output pulleys (**506**, **507**) and input pulleys (**508**, **509**) to generate angular force on a pair of axial output shafts (**510** and **511**). The four drive units may be held in place by a single drive base **512** that couples drive units **502**, **503**, **504**, **505** together through separate ball bearing interfaces that allow the drive units to independently rotate in response to rotor rotation in each corresponding motor unit.

**[0072]** Within instrument device manipulator, both drive units **502** and **503** are configured very similarly to drive unit **401** from FIG. **4**, wherein their motor units are configured to generate torque in output pulleys **506** and **507** in response to a control signal. Conversely, the rotary components for each drive unit are respectively configured to reactively rotate and interact with force sensors mounted on the drive base **512**. Similar to the force sensors and stoppers in instrument device manipulator **201** from FIG. **2**A, the force sensors and stoppers in instrument device manipulator **501** are fixedly positioned such that they do not conflict and prevent collisions from their respective beam elements.

**[0073]** Output pulleys **506** and **507**, belts **513** and **514**, and input pulleys **508** and **509** form a drivetrain. Output pulleys **506** and **507** are configured to transmit angular motion to belts **513** and **514** respectively. Belts **513** and **514** respectively transmit the angular motion from output pulleys **506** and **507** to input pulleys **509** and **508** respectively. In some embodiments, alternative drivetrains may be used, such as an alternative gear train or other transmission means.

**[0074]** Each coaxial output shaft **510** and **511**, located atop of drive units **505** and **504** respectively, includes an inner shaft **520**, **521** and an outer shaft **530**, **531**, both configured to rotate independent of the other through the use of a low friction interface, such as a ball bearing interface. The inner shafts **520**, **521**, the shafts with the smaller diameters, may be driven by the rotor of the motor unit, such as the rotors of motor units in drive units **505** and **504**. In contrast, the outer shafts **530**, **531**, the shafts with the larger diameters, may be driven by the corresponding input pulley that is coupled to the outer shaft. For example, the outer shaft of co-axial output shaft **511** is driven by input pulley **508**, which receives torque from output pulley **507** through belt **514**. Thus, the outer shafts' **530** and **531** rotations reflect the angular motion of the output pulleys **506** and **507**, respectively.

**[0075]** FIG. **5**B illustrates the incorporation of a drive unit with a bi-directional torque sensing mechanism into an instrument device manipulator with co-axial output shafts from an another perspective, consistent with one embodiment. As shown in overhead view **517**, drive base **512** of instrument device manipulator **501** couples four drive units through ball bearing interfaces that incorporate output pulleys (**506**, **507**) that drive input pulleys (**508**, **509**) to generate angular force on a pair of coaxial output shafts (**510** and **511**). As discussed earlier, belts **513** and **514** may transmit torque from output shafts **506** and **507** to input shafts **509** and **508** respectively. Moreover, coaxial output shafts **510** and **511** incorporate both an inner shaft with a smaller diameter, and an outer shaft with a larger diameter, as visible in view **517** by the two sets of splines in each coaxial shaft **510** and **511**. As discussed earlier, the inner shaft may be driven by the rotor of the motor unit within the drive unit, while the outer shaft may be driven by the drive train (belt) from the output pulley to the inner pulley.

**[0076]** FIG. **5**C illustrates the incorporation of a drive unit with a bi-directional torque sensing mechanism into an instrument device manipulator with co-axial output shafts from an yet another alternative perspective, consistent with one embodiment. As shown in frontal view **518**, the drive units within instrument device manipulator **501** are aligned in parallel and coupled by the drive base **512** through individually parallel ball bearings (not shown). The structure of the coaxial radial shafts **510** and **511**, with their inner shafts **520** and **521** and outer shafts **530** and **531** of varying diameters, are also visible in this view **518**. While output pulleys **506** and **507** are visible in this view, the input pulleys **508** and **509** are obscured.

**[0077]** FIG. **5**D illustrates the incorporation of a drive unit with a bi-directional torque sensing mechanism into an instrument device manipulator with co-axial output shafts from yet another alternative perspective, consistent with one embodiment. As shown in side view **519**, the drive units **503** and **504** within instrument device manipulator **501** are aligned in parallel and coupled by the drive base **512** through individually parallel ball bearings (not shown). The structure of the coaxial radial shaft **511**, with its inner shaft and outer shaft of varying diameter, is also visible in this view **519**. In addition, the transmission from output pulley **507** to input pulley **508** through belt **514** is also clearly visible in this view **519**.

[0078] The aforementioned embodiments may be integrated into a larger robotic system, where a robotic controller may generate control signals to the appropriate drive units to generate an output torque to control the attached instruments. The force sensor on the drive units may also be configured to communicate the magnitude of the reactive force detected, thus indicating the proportional torque generated, allowing feedback to the controller. Using the feedback, the controller may provide the proper control signal to the drive units to increase, decrease or maintain the level of torque.

[0079] The aforementioned embodiments may be designed to configure an instrument device manipulator and interface with an instrument as part of a larger robotics platform such as those disclosed in the aforementioned patent applications that are incorporated by reference. For example, the drive unit may be configured to be incorporated into an instrument drive mechanism or an instrument device manipulator that is attached to the distal end of a robotic arm through a sterile interface, such as a drape. The driving elements may be shafts (male) or shaft receptacles (female) with spline interfaces to transfer rotational motion from the instrument drive mechanism to the instrument. As part of a larger robotics system, robotic control signals may be communicated from a remotely-located user interface, down the robotic arm, and to the instrument device manipulator to control the embodiment (drive units). Conversely, force measurements may be communicated back to the controller and user interface to properly issue future control signals.

[0080] For purposes of comparing various embodiments, certain aspects and advantages of these embodiments are described. Not necessarily all such aspects or advantages are achieved by any particular embodiment. Thus, for example, various embodiments may be carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other aspects or advantages as may also be taught or suggested herein.

[0081] Elements or components shown with any embodiment herein are exemplary for the specific embodiment and may be used on or in combination with other embodiments disclosed herein. While the described embodiments are susceptible to various modifications and alternative forms, specific examples thereof have been shown in the drawings and are herein described in detail. The description is not limited, however, to the particular forms or methods disclosed, but to the contrary, covers all modifications, equivalents and alternatives thereof.

What is claimed is:

**1**. A robotically-controlled drive unit configured to generate angular motion comprising:
- an electric motor unit comprising a rotor that is configured to generate an output torque in response to a robotic control signal;
- a beam element configured to generate a reactive torque in response to the output torque generated by the rotor, the beam element coupled to the electric motor unit and oriented perpendicularly to the longitudinal axis of the rotor; and
- a force sensor configured to detect the reactive torque and communicate the magnitude of the reactive torque to a robotic controller.

**2**. The drive unit of claim **1**, wherein the beam element is configured to rotate around the axis of the rotor using a ball bearing.

**3**. The drive unit of claim **1**, further comprising a gear head coupled to the electric motor unit, wherein the gear head is configured to amplify the output torque generated by the rotor.

**4**. The drive unit of claim **3**, further comprising a drive base that comprises a ball bearing configured to allow the beam element to move freely in response to the output torque.

**5**. The drive unit of claim **3**, further comprising an output shaft operatively coupled to the gear head, the output shaft configured to transmit angular motion to a rotatable body intended to actuate a tendon.

**6**. The drive unit of claim **5**, wherein the tendon is a component of an instrument configured for performing at least one of an endolumenal procedure and a laparoscopic procedure.

**7**. The drive unit of claim **5**, wherein the output shaft is configured to rotate an elongated body along its longitudinal axis.

**8**. The drive unit of claim **1**, wherein the force sensor comprises at least one of a load cell, piezoresistive device, a piezoelectric device, and a strain gauge.

**9**. The drive unit of claim **1**, further comprising a stopper that is configured to keep the beam element from moving in the direction of the stopper, the stopper and the force sensor fixedly coupled to a drive base.

**10**. The drive unit of claim **9**, wherein the stopper and the force sensor are positioned on opposite sides of the beam element.

**11**. The drive unit of claim **1**, further comprising:
- a second beam element coupled to the electric motor unit and oriented perpendicularly to the longitudinal axis of the rotor; and
- a stopper configured to keep the second beam element from moving in the direction of the stopper, the stopper and the force sensor fixedly coupled to a drive base.

**12**. The drive unit of claim **1**, wherein the drive unit is incorporated into an instrument device manipulator as part of a surgical robotics platform, the instrument device manipulator further comprising a second drive unit.

**13**. The drive unit of claim **12**, wherein the second drive unit is operatively coupled to the drive unit, the second drive unit configured to transmit angular motion to the drive unit.

**14**. The drive unit of claim **13**, wherein the instrument device manipulator further comprises a third drive unit and a fourth drive unit, the third drive unit operatively coupled to the fourth drive unit, the third drive unit configured to transmit angular motion to the fourth drive unit.

**15**. The drive unit of claim **13**, the drive unit further comprising:
- an inner shaft operatively coupled to the electric motor unit, wherein the output torque of the electric motor unit causes the inner shaft to rotate; and
- an outer shaft operatively coupled to the second drive unit, wherein the angular motion from the second drive unit causes the outer shaft to rotate.

**16**. The drive unit of claim **9**, wherein the drive unit is incorporated into an instrument device manipulator as part of a surgical robotics platform, the instrument device manipulator further comprising a second drive unit, the second drive unit comprising:
- a second beam element;
- a second force sensor; and

a second stopper configured to keep the second beam element from moving in the direction of the second stopper, the second stopper and the second force sensor fixedly coupled to the drive base and positioned relative to the drive unit to avoid conflicts between the force sensors and the beam elements of the drive unit and the second drive unit.

**17**. The drive unit of claim **1**, wherein the robotic controller is remotely located and is configured to generate the robotic control signal.

**18**. The drive unit of claim **1**, wherein the robotic controller is configured to generate the robotic control signal based on the magnitude of the reactive torque detected by the force sensor.

**19**. The drive unit of claim **1**, further comprising a rotary encoder coupled to the electric motor unit and configured to detect angular motion of the rotor.

**20**. The drive unit of claim **1**, further comprising a second force sensor, the force sensor and the second force sensor positioned on opposite sides of the beam element from each other.

**21**. The drive unit of claim **20**, wherein the force sensor and the second force sensor are coupled to a drive base and fixed relative to each other.

**22**. The drive unit of claim **1**, further comprising a first compression spring disposed between the beam element and the force sensor.

**23**. The drive unit of claim **22**, further comprising a second compression spring disposed between the beam element and a stopper, the first compression spring and the second compression spring positioned on opposite sides of the beam element.

**24**. The drive unit of claim **9**, wherein the stopper is positioned relative to the beam element such that the force sensor detects a non-zero reactive torque when there is no output torque generated by the electric motor unit.

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摘要(译)

机器人控制的驱动单元包括扭矩感测机构，用于测量施加到可旋转体的扭矩，该扭矩感测机构构造成张紧致动腱以操作机器人手术工具和导管。驱动单元包括响应于机器人控制信号产生输出转矩的电机单元。梁元件响应于由转子产生的输出转矩产生反作用转矩，并且力传感器检测反作用转矩并将反作用转矩的大小传送给机器人控制器。驱动单元还可以包括执行双向扭矩感测的机构，其示例包括附加的力传感器和压缩弹簧。