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(54) **ROBOTIC SURGICAL DEVICES, SYSTEMS, AND RELATED METHODS**

(71) Applicant: **Virtual Incision Corporation**, Lincoln, NE (US)

(72) Inventors: **John Wilson**, Brooklyn, NY (US); **Jeff Shasho**, Brooklyn, NY (US); **Nishant Kumar**, Bergenfield, NJ (US); **Matt Mahin**, Longmont, CO (US); **Chris Santoro**, Brooklyn, NY (US); **Erik Mumm**, Longmont, CO (US); **Jason Herman**, East Northport, NY (US); **Shane Farritor**, Lincoln, NE (US)

(73) Assignee: **Virtual Incision Corporation**, Lincoln, NE (US)

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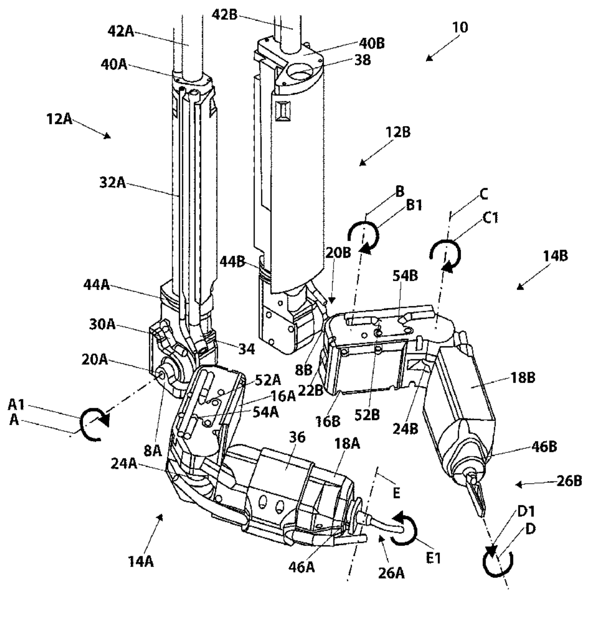
Primary Examiner — Gary Jackson
Assistant Examiner — Sebastian X Lukjan
(74) *Attorney, Agent, or Firm* — Davis, Brown, Koehn, Shors & Roberts, P.C.; Sean D. Solberg

(57) **ABSTRACT**

The embodiments disclosed herein relate to various medical device components, including components that can be incorporated into robotic and/or in vivo medical devices. Certain embodiments include various modular medical devices for in vivo medical procedures.

15 Claims, 36 Drawing Sheets



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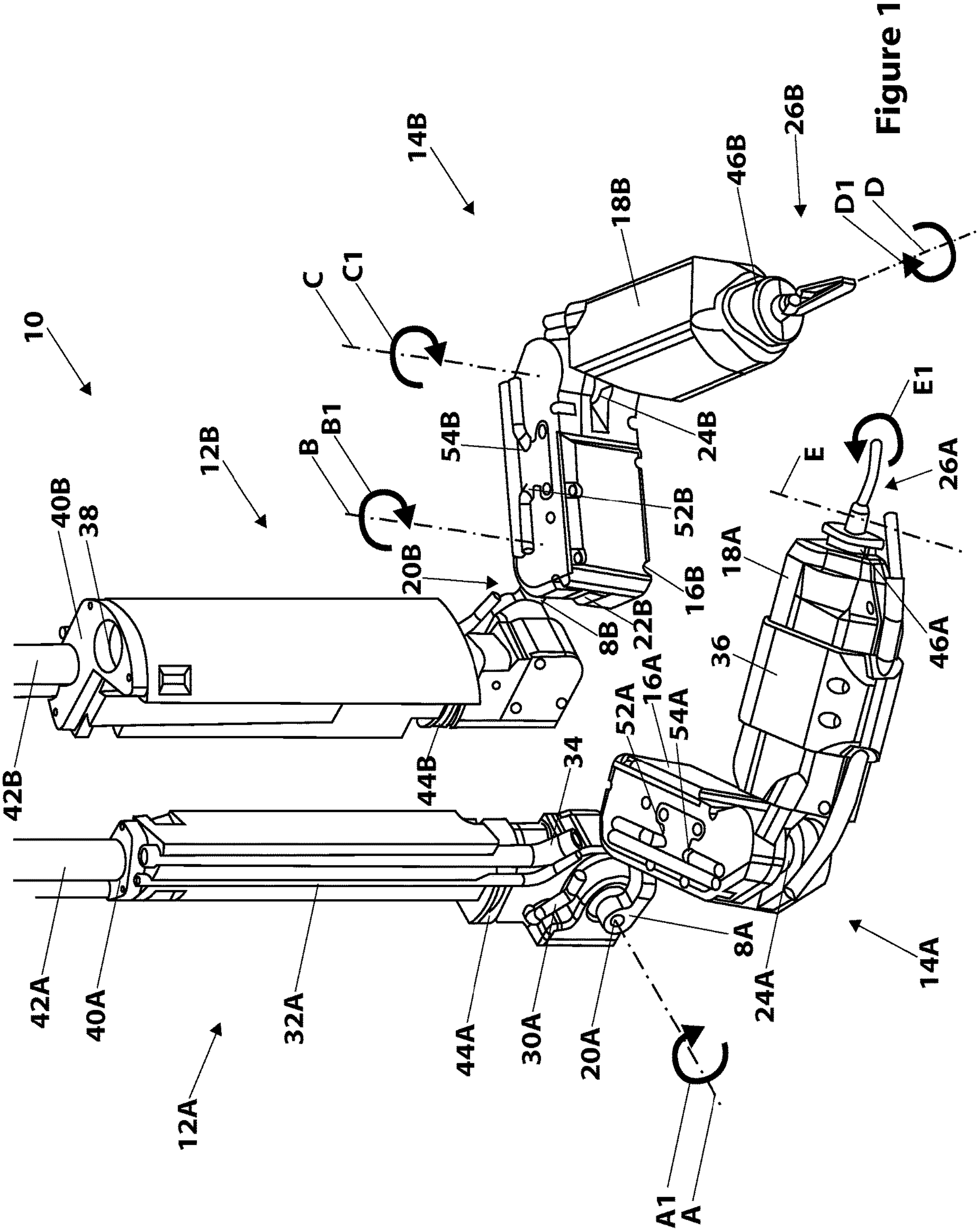
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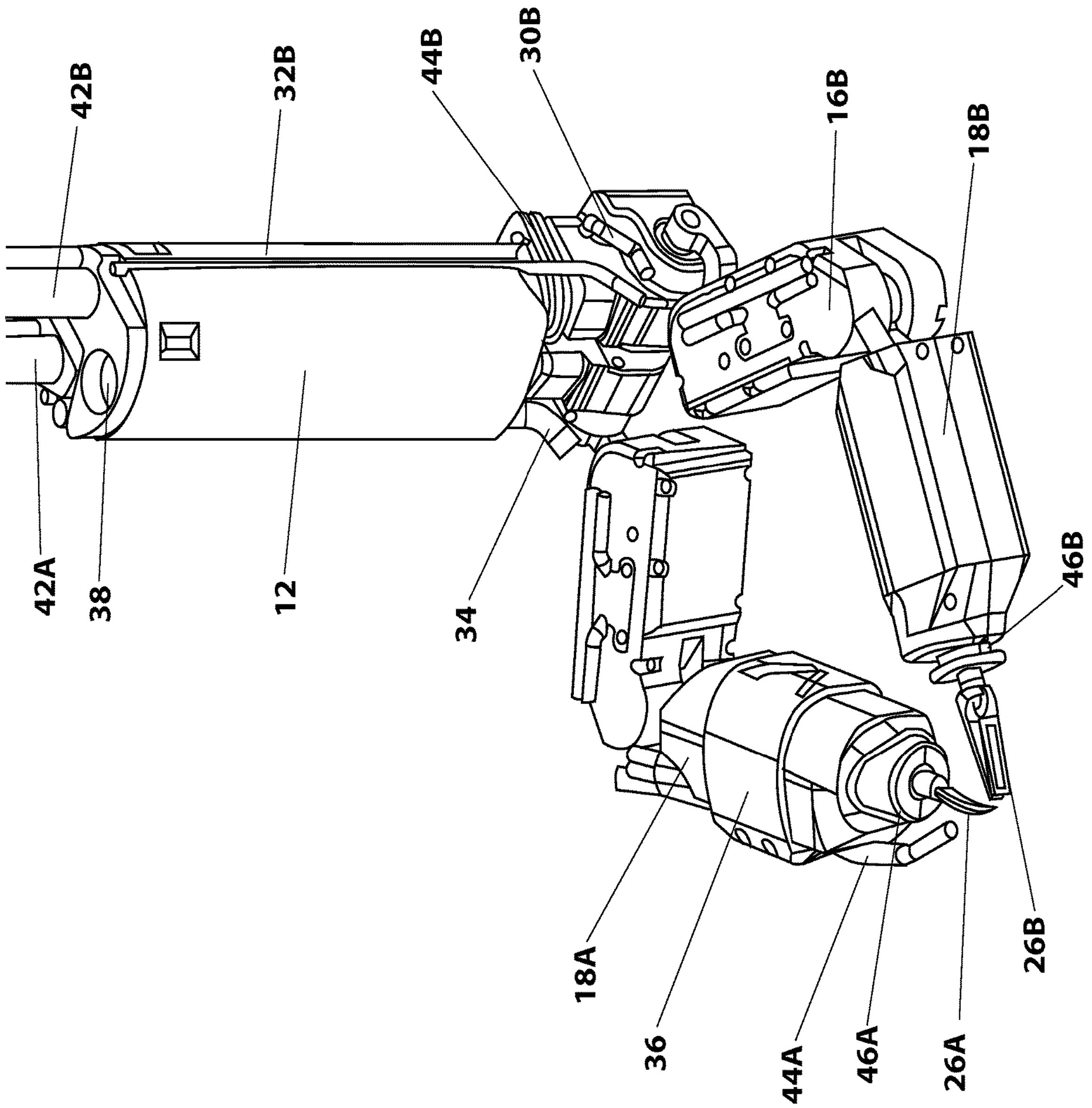
Figure 1



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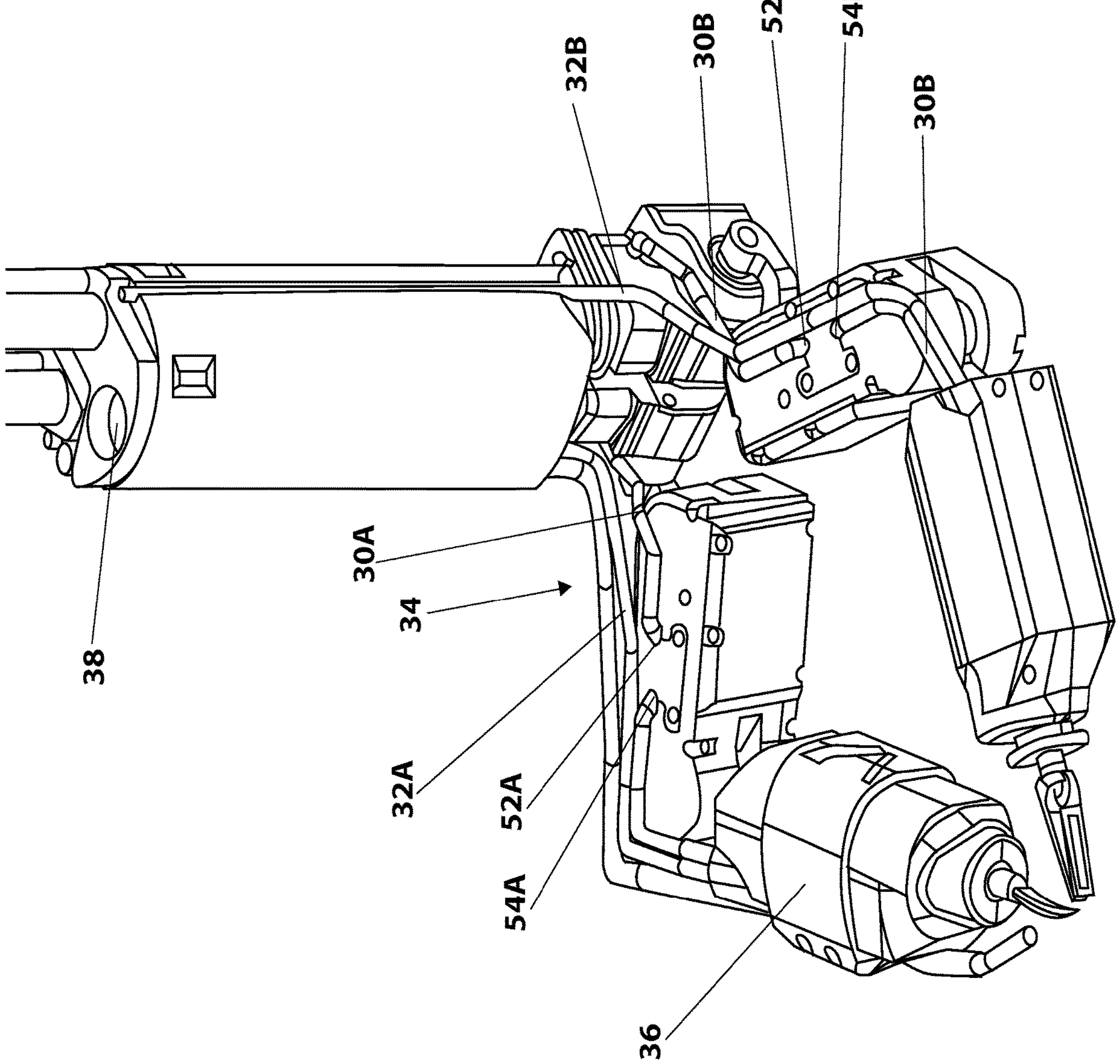
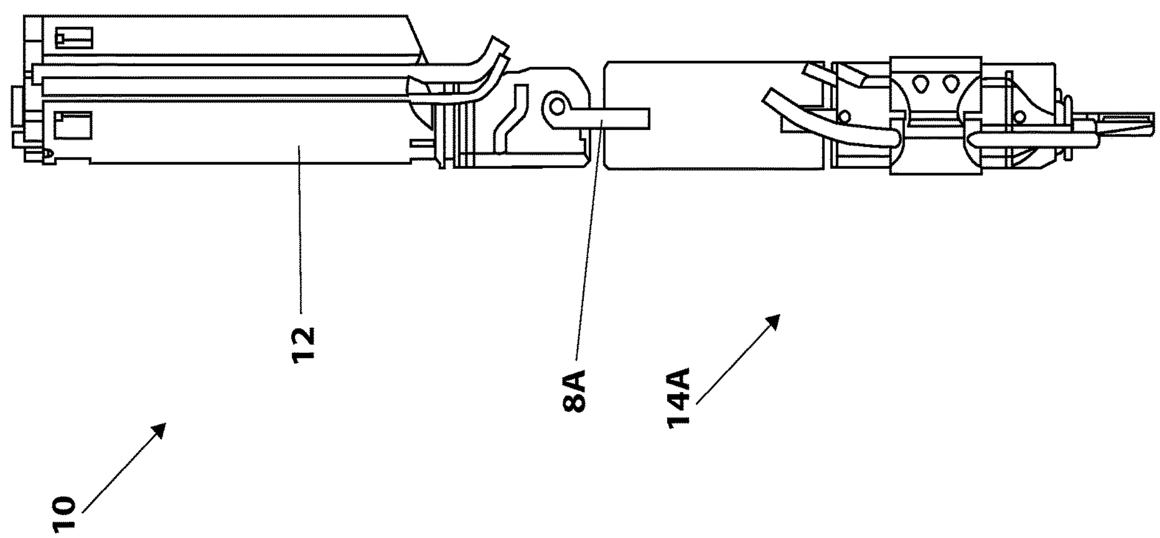


Figure 2B

Figure 2C



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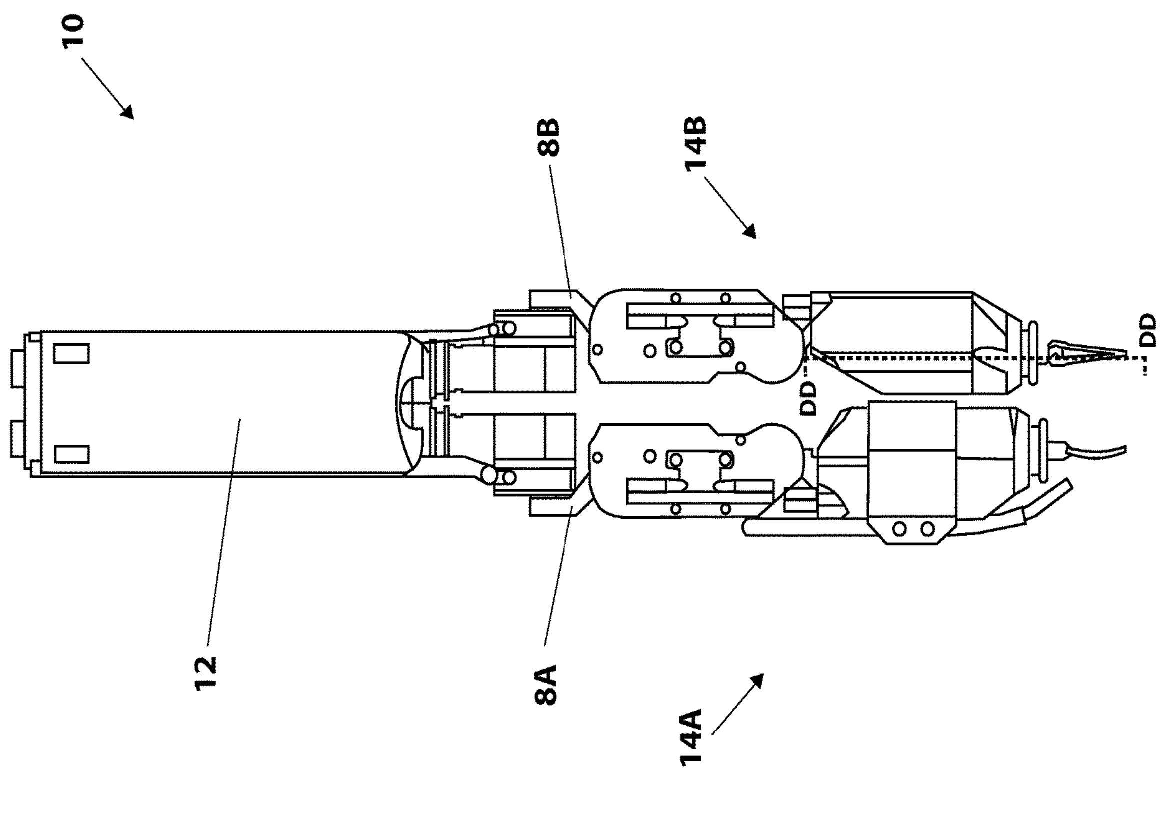

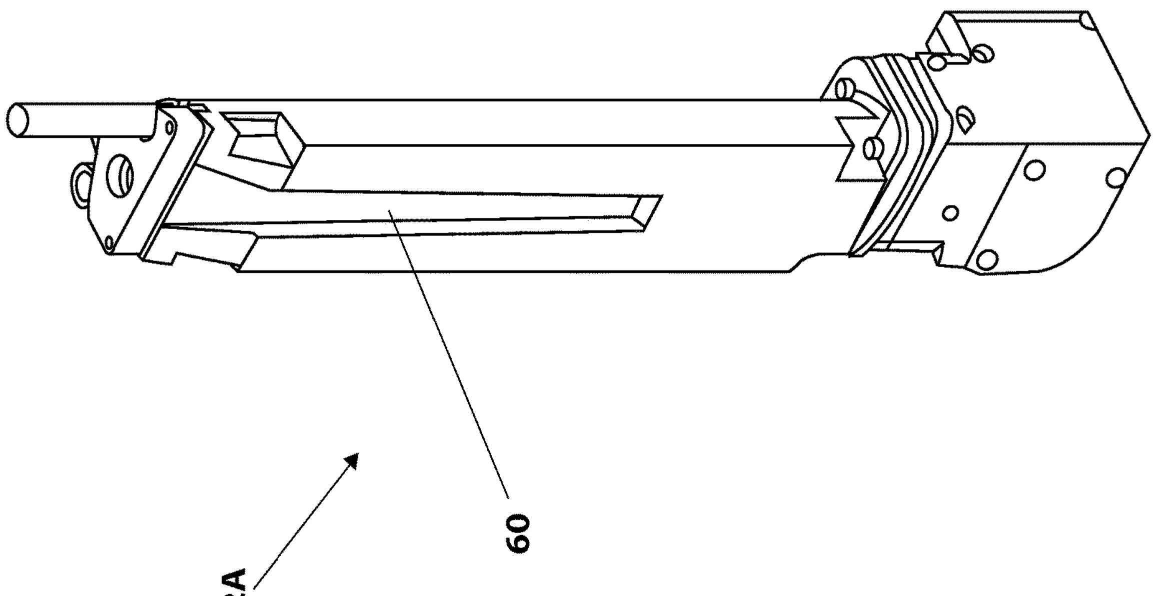

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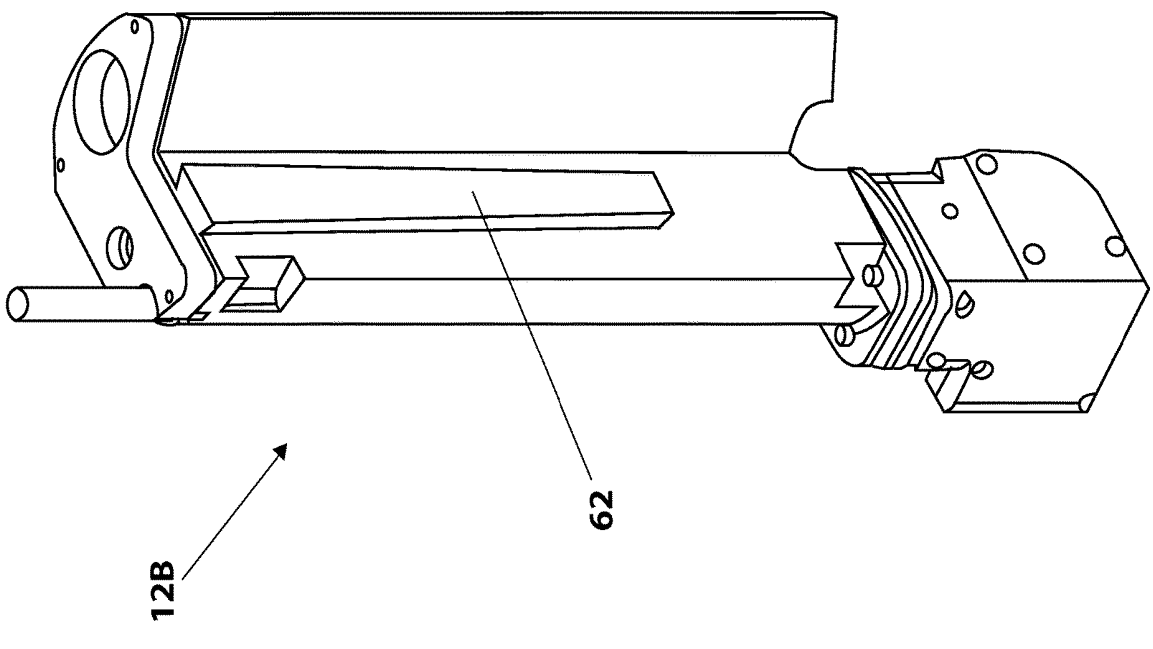

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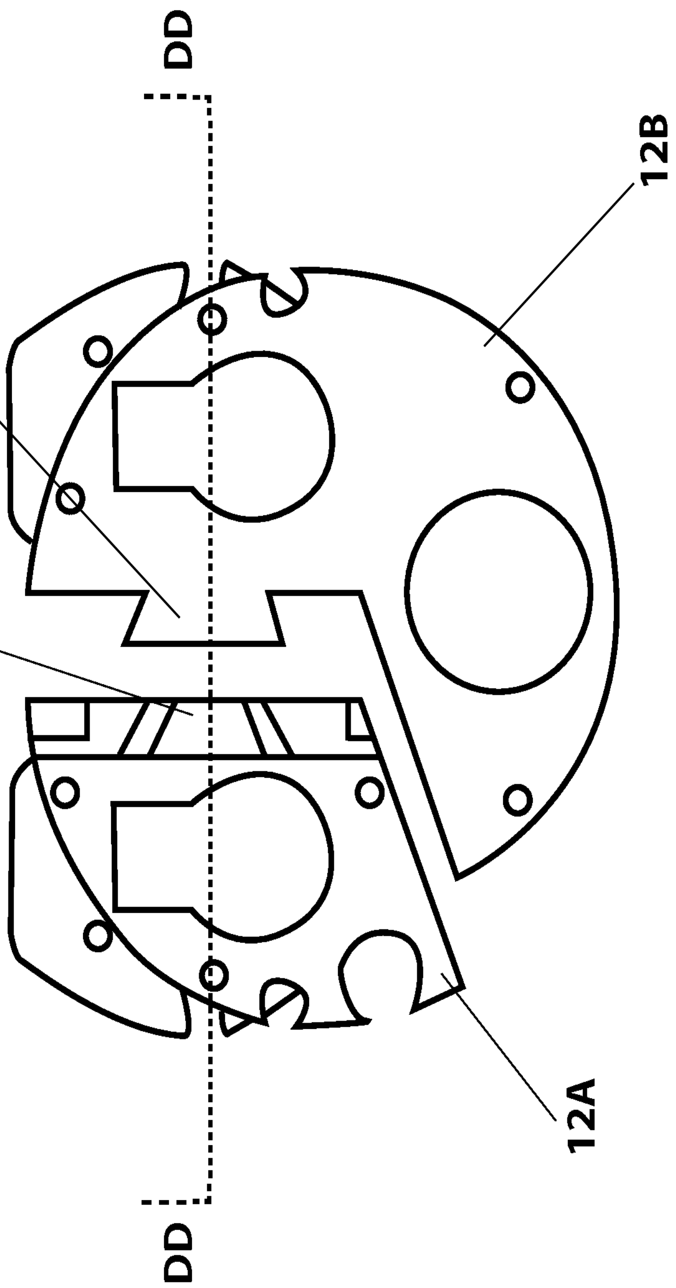

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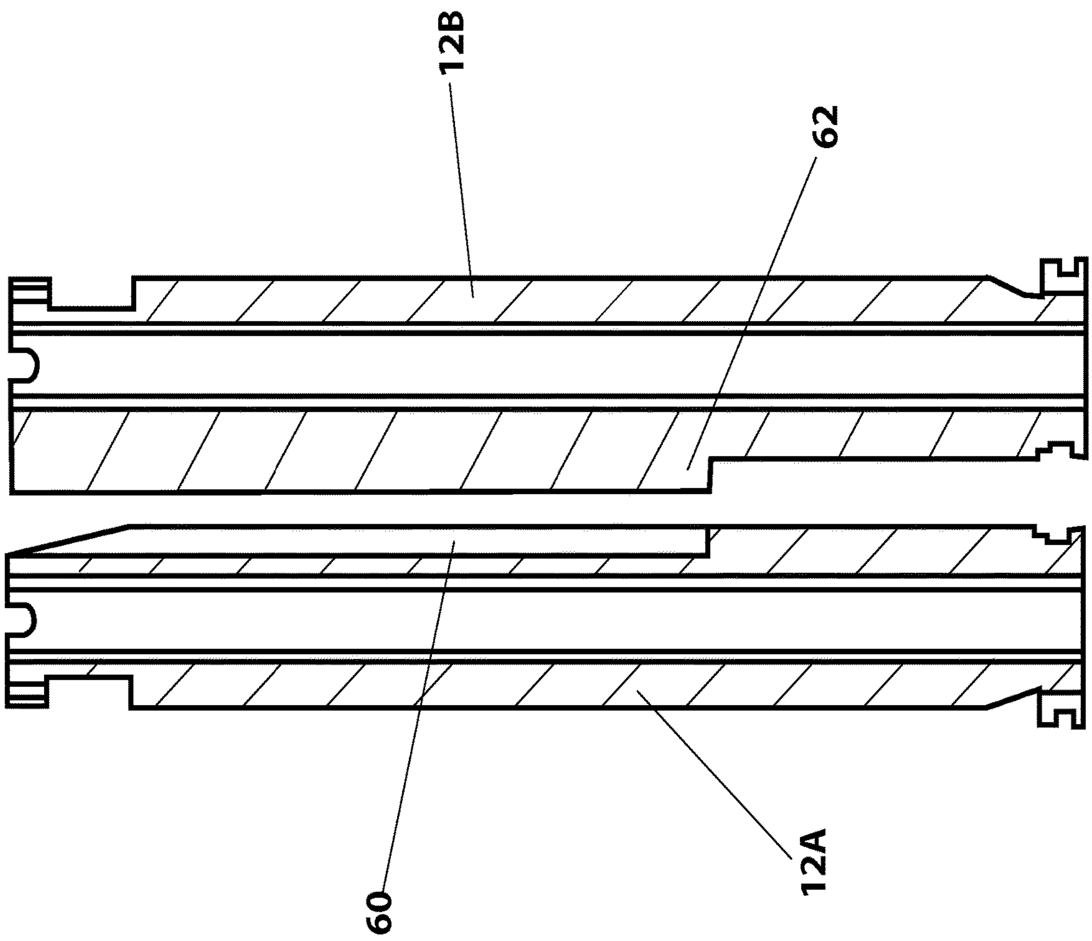

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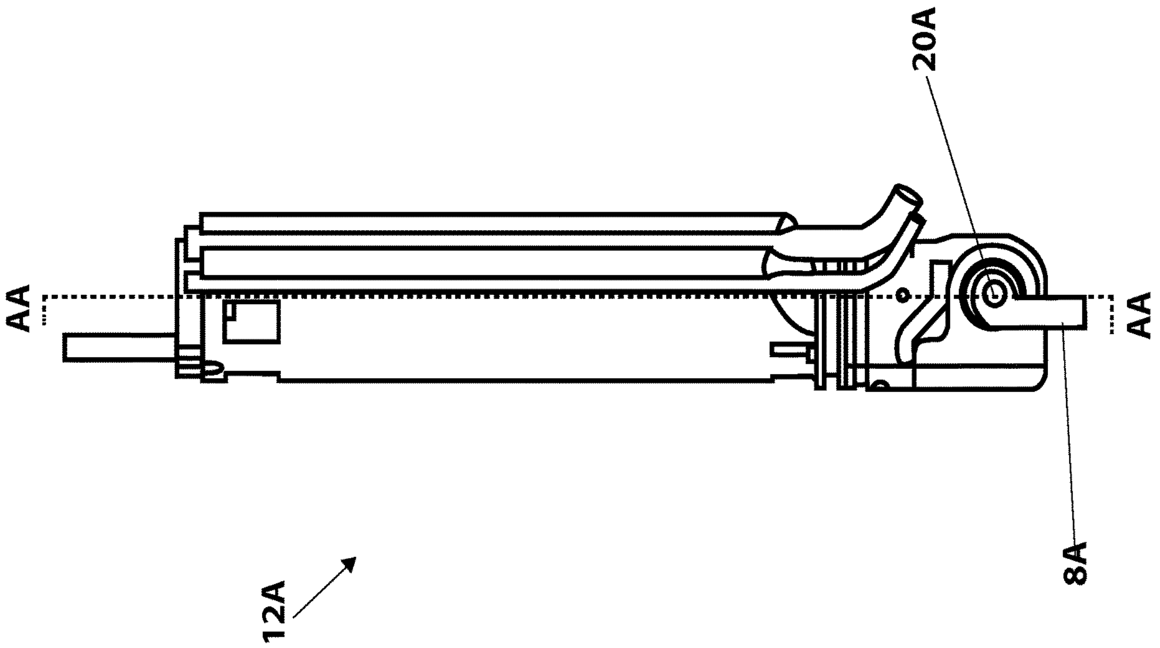

Figure 5A

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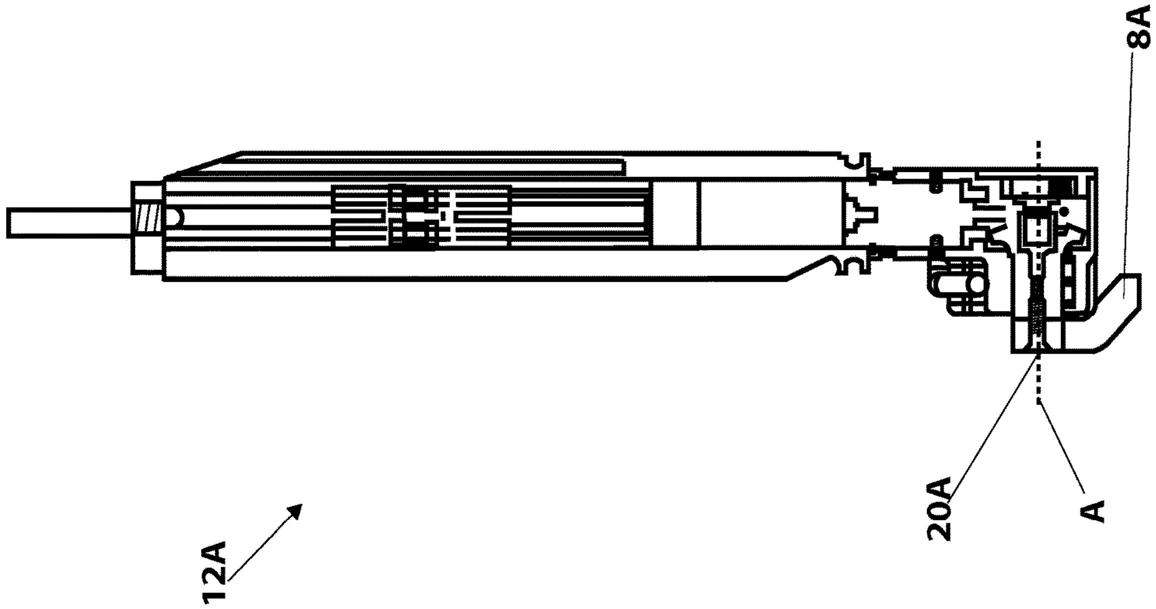

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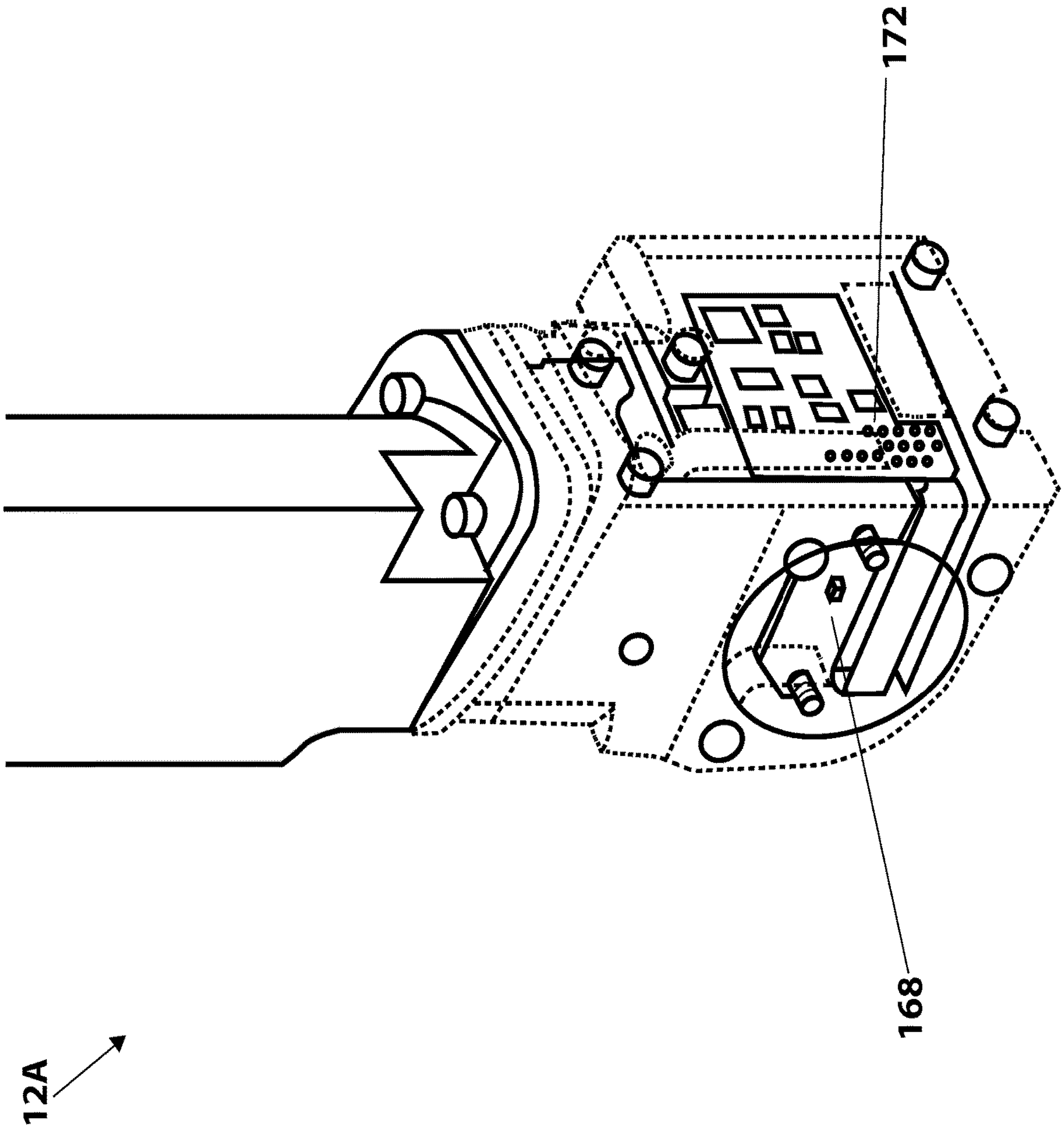

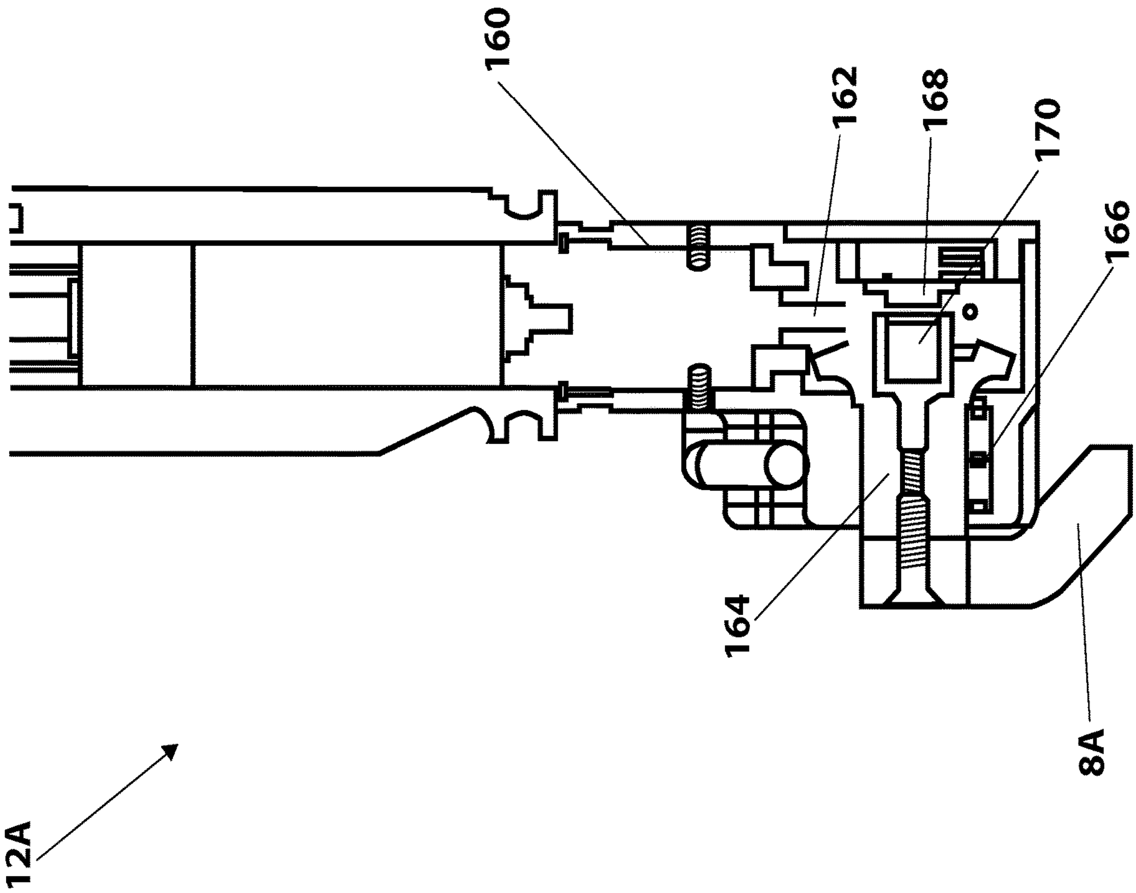

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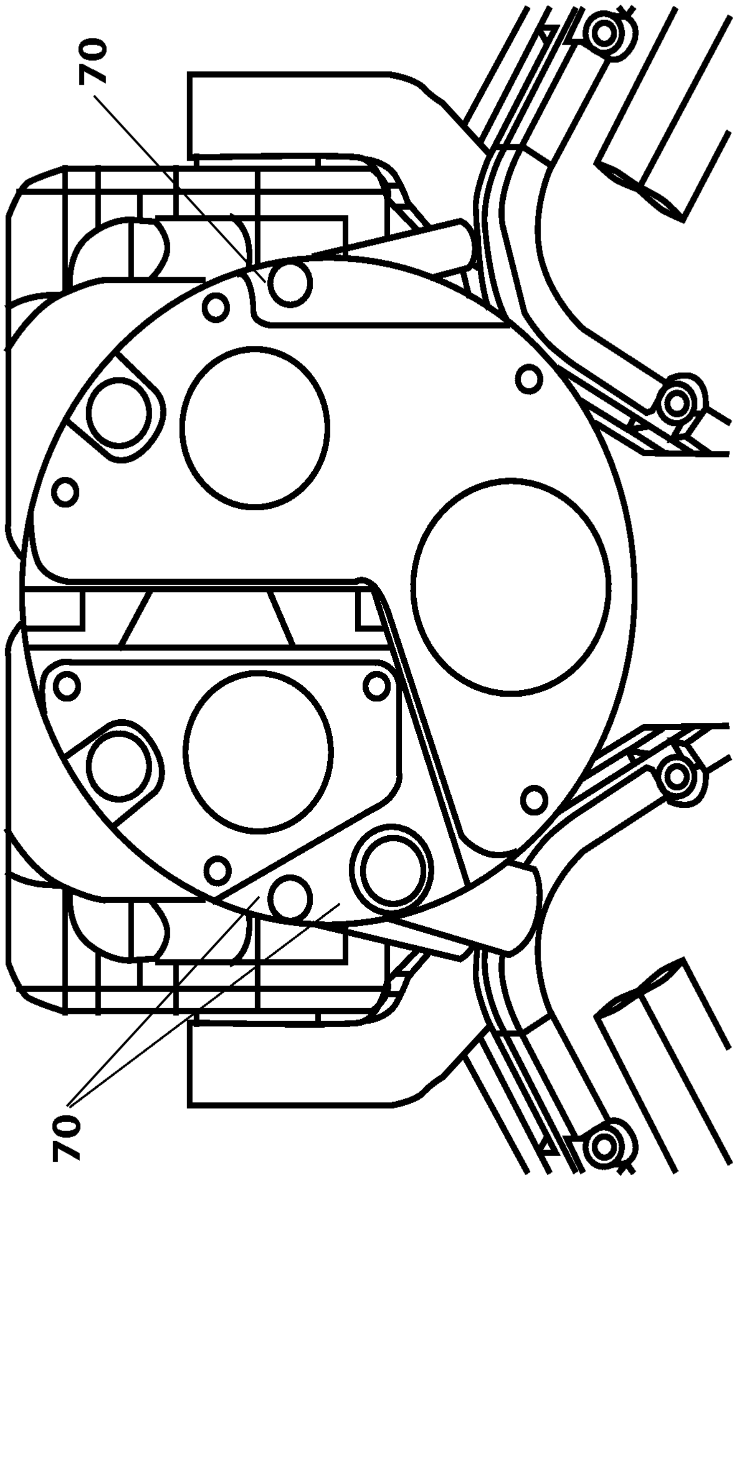

Figure 6

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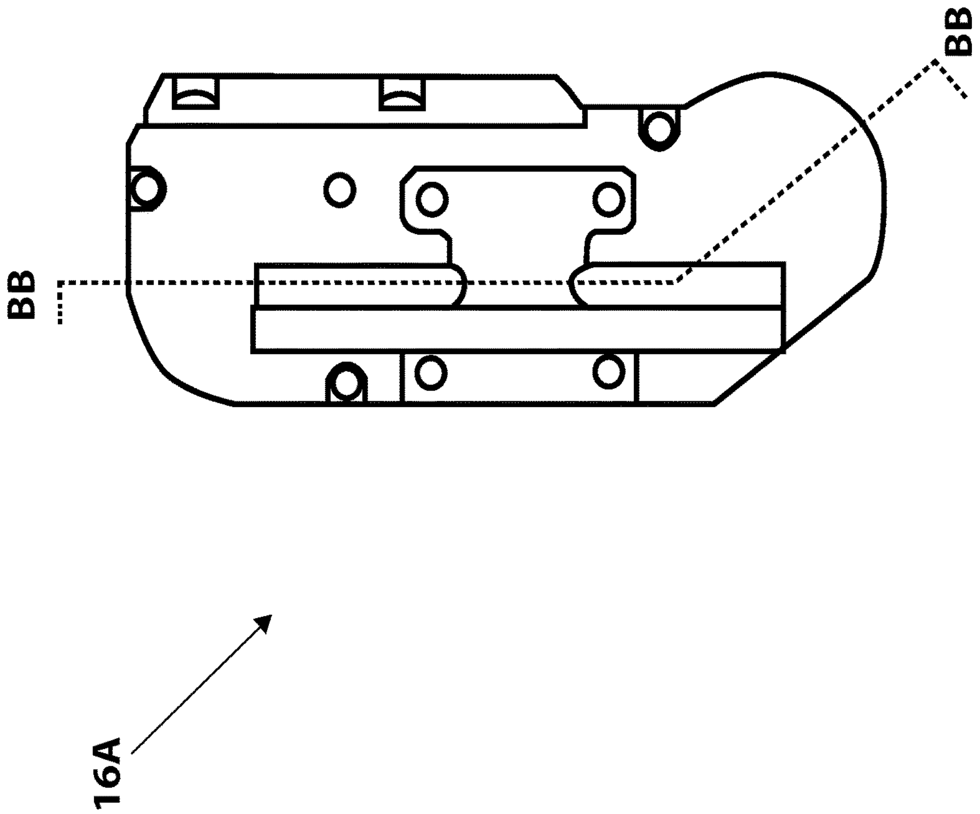

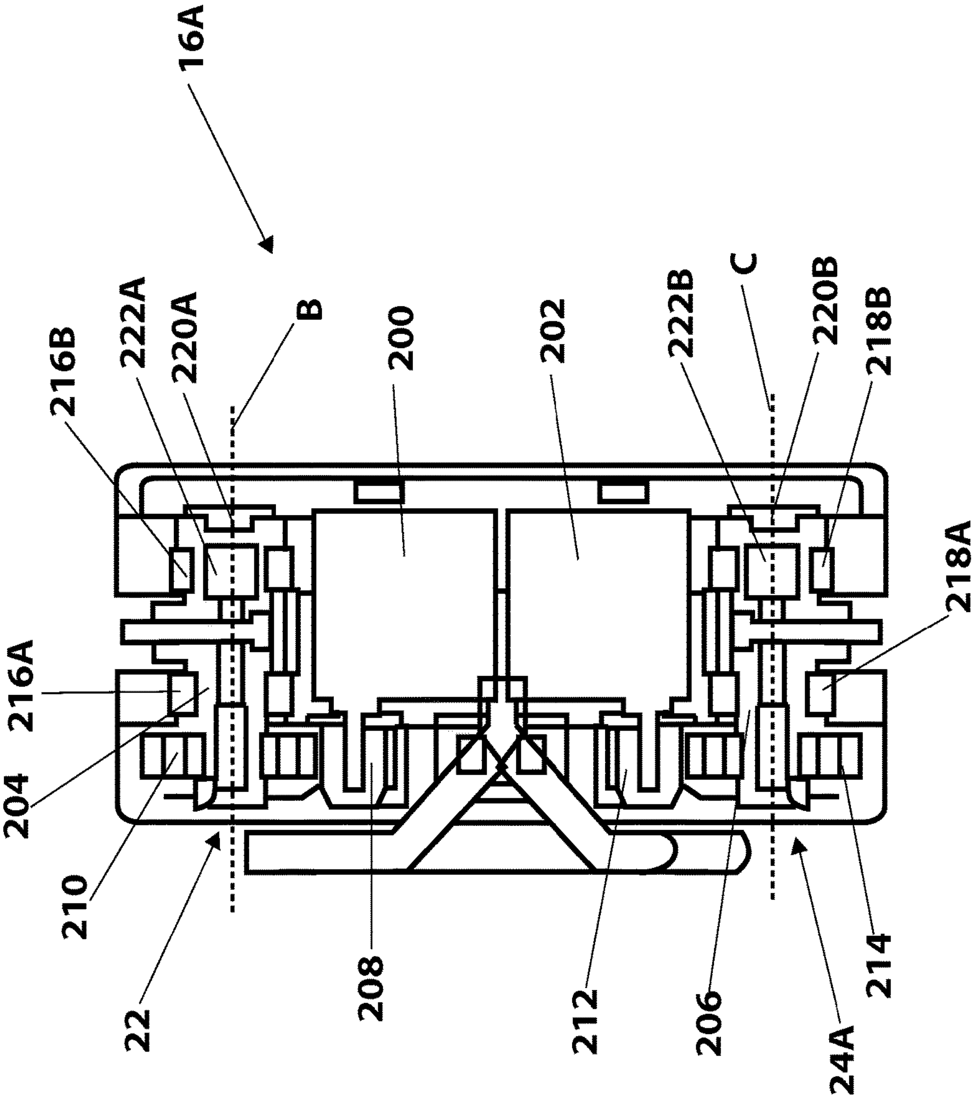
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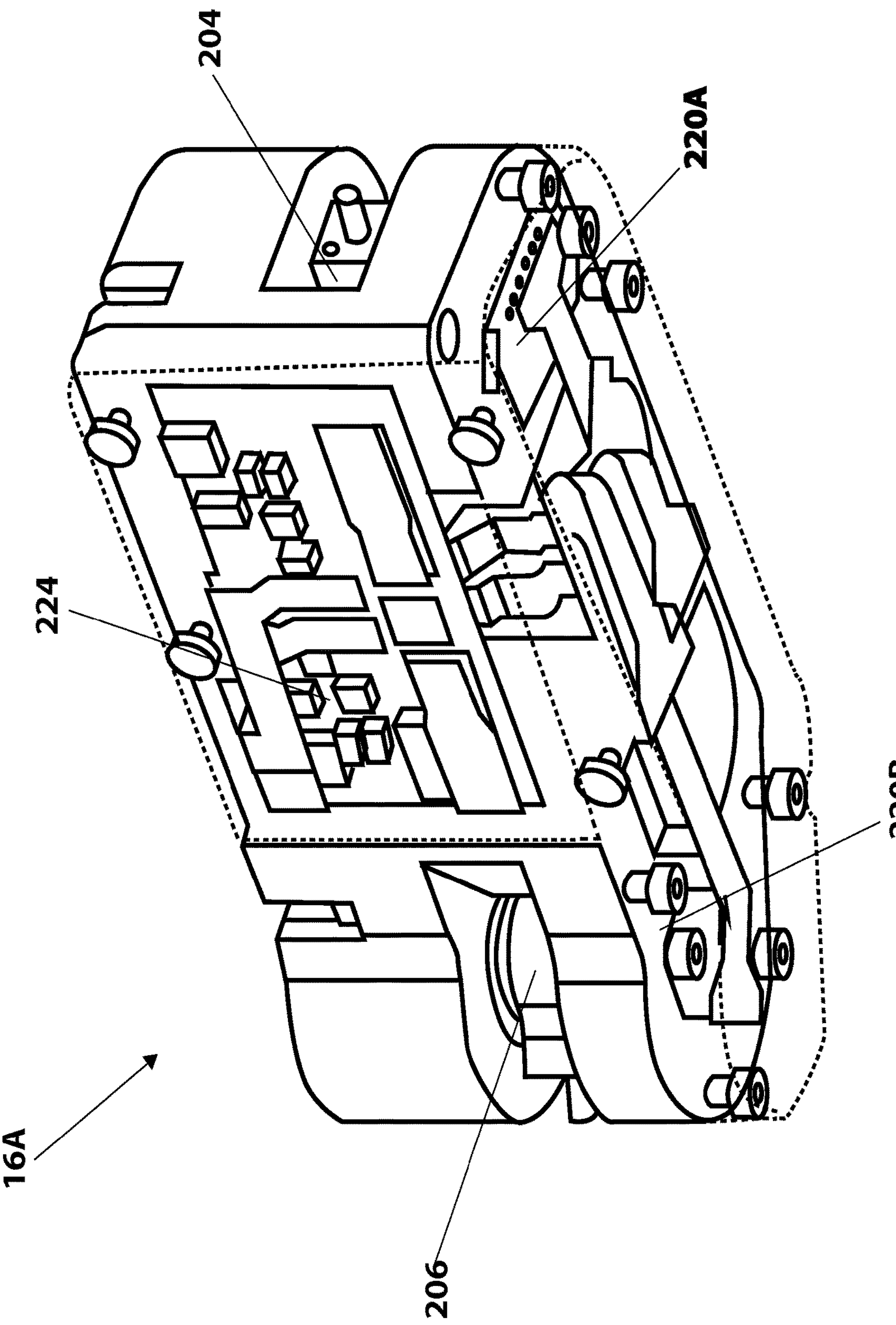
Figure 7B



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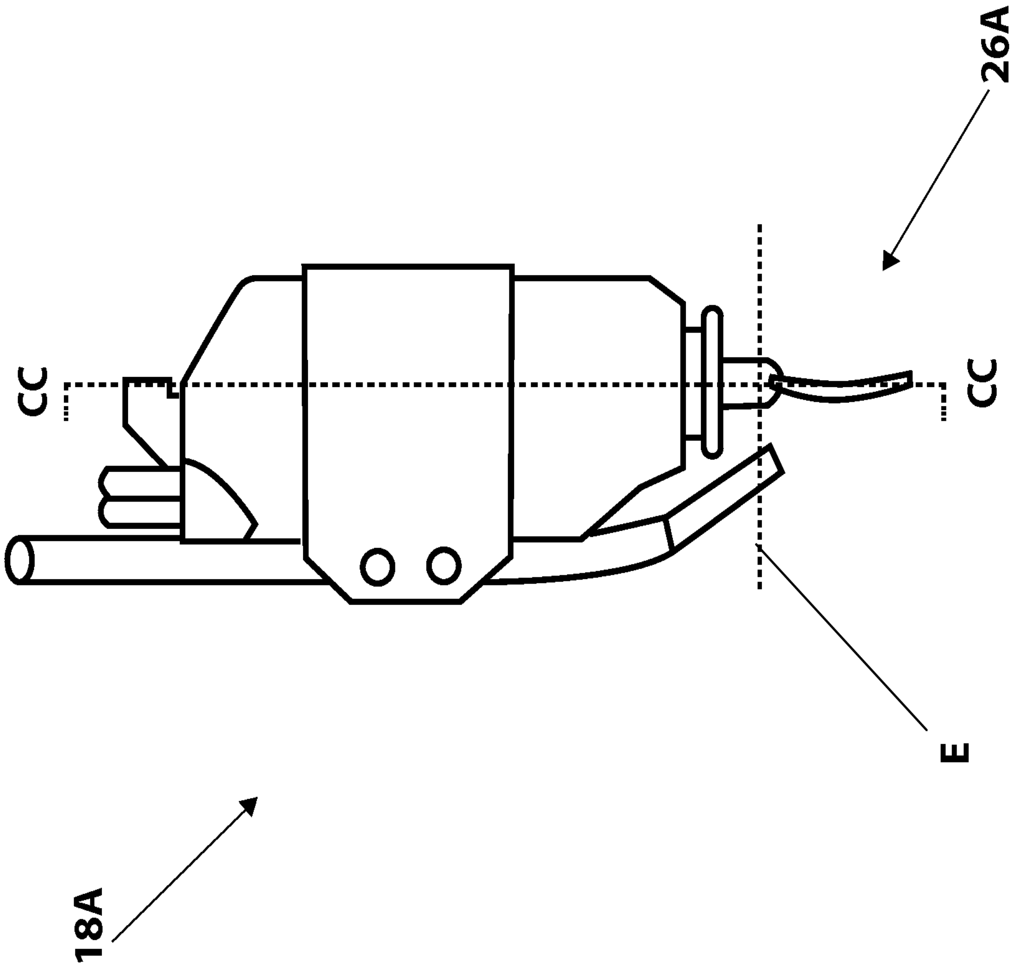

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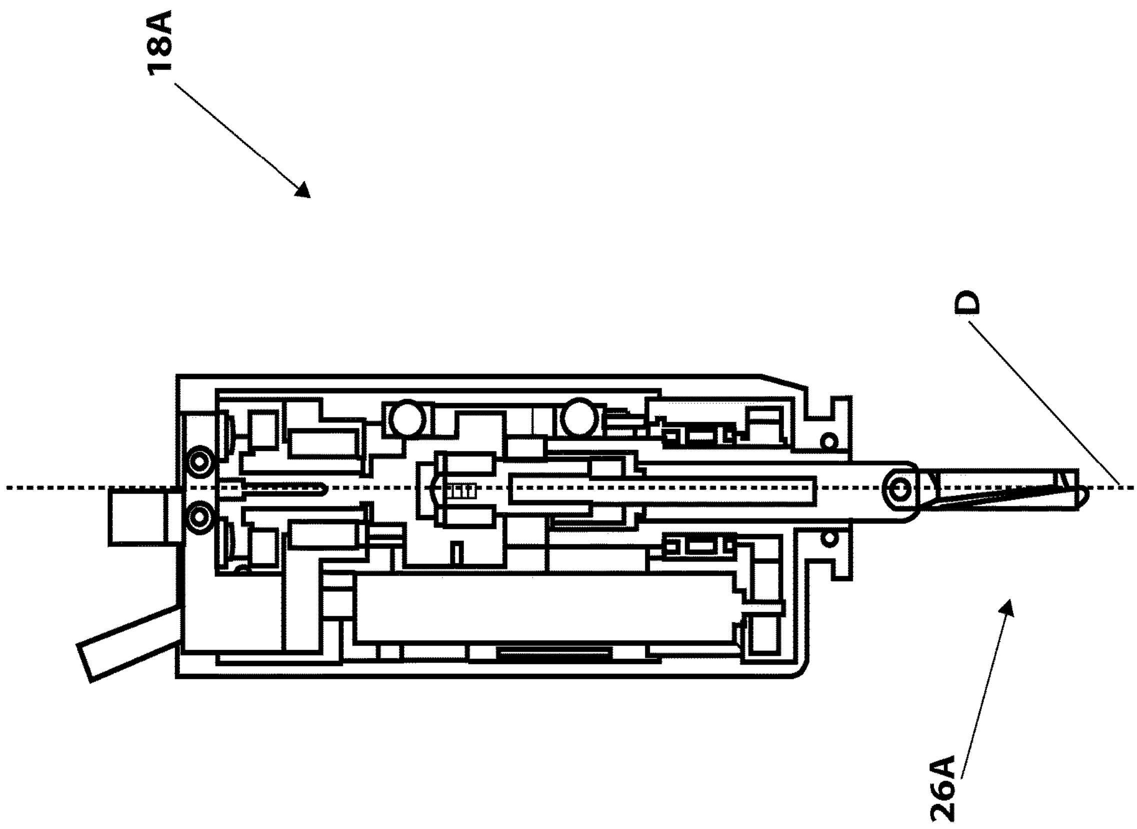

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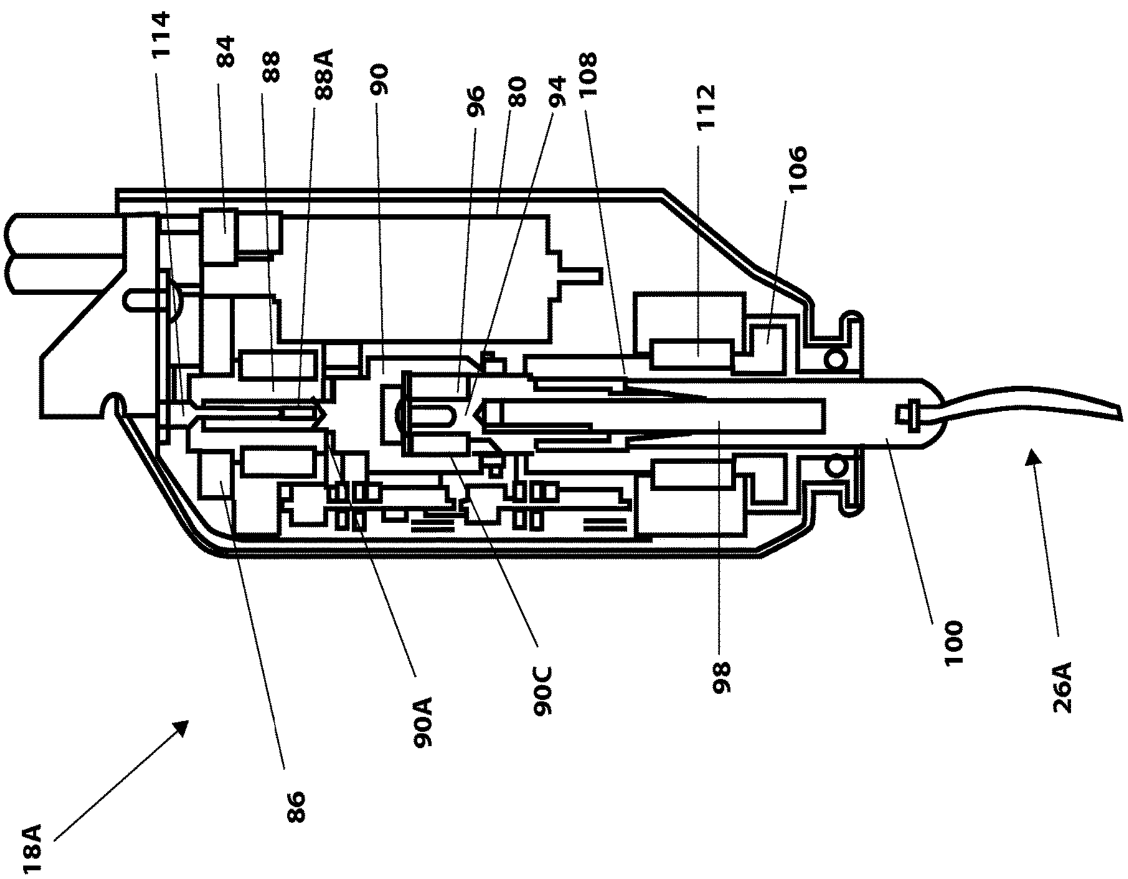

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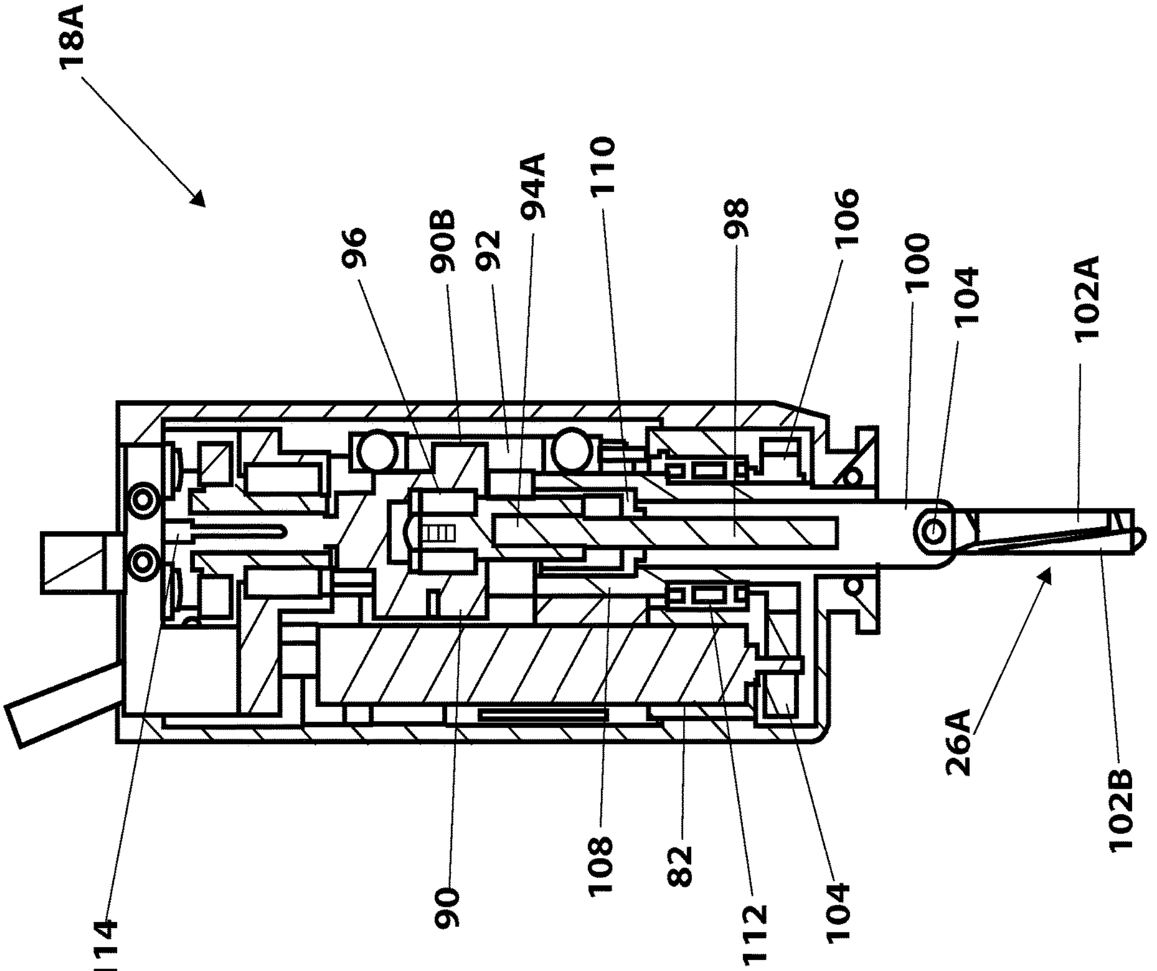
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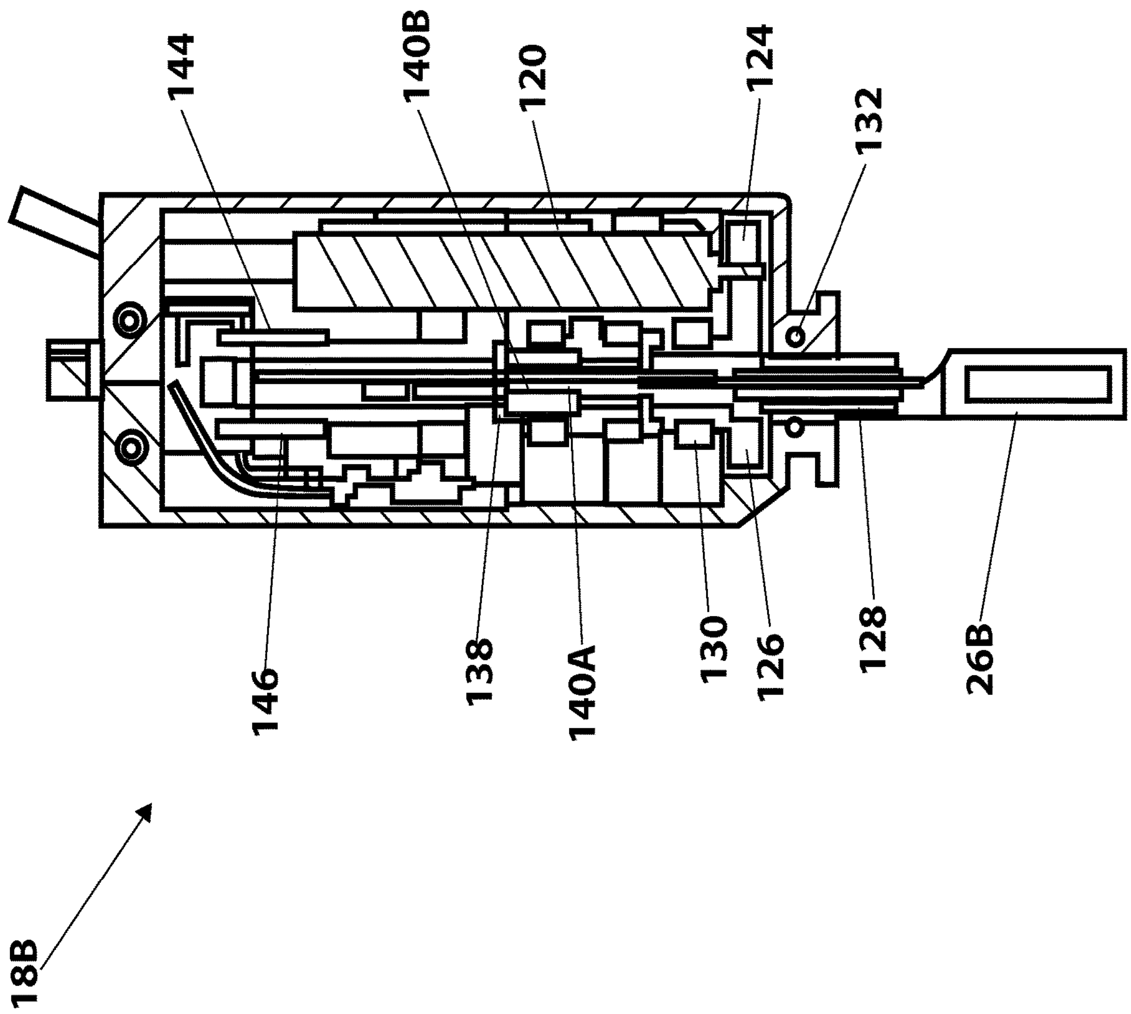
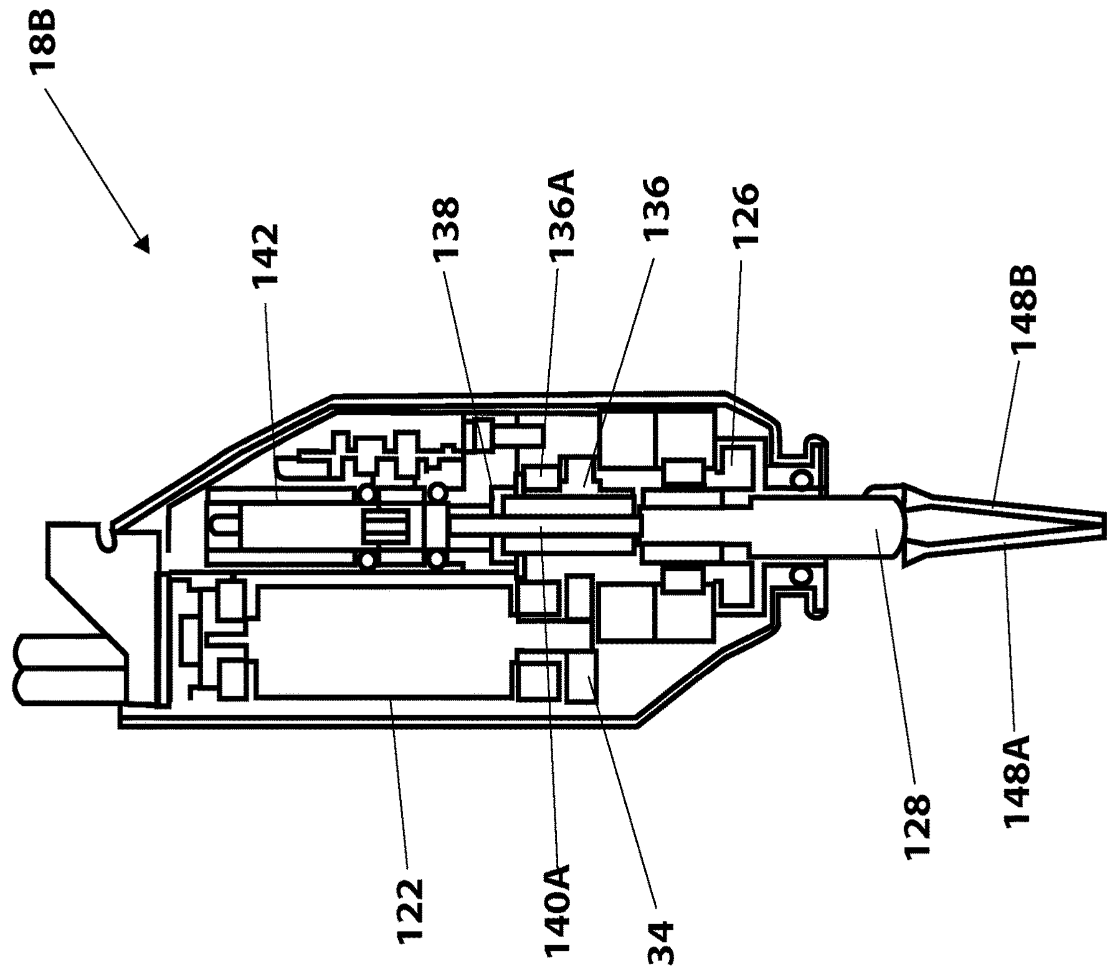
Figure 8D

Figure 9A





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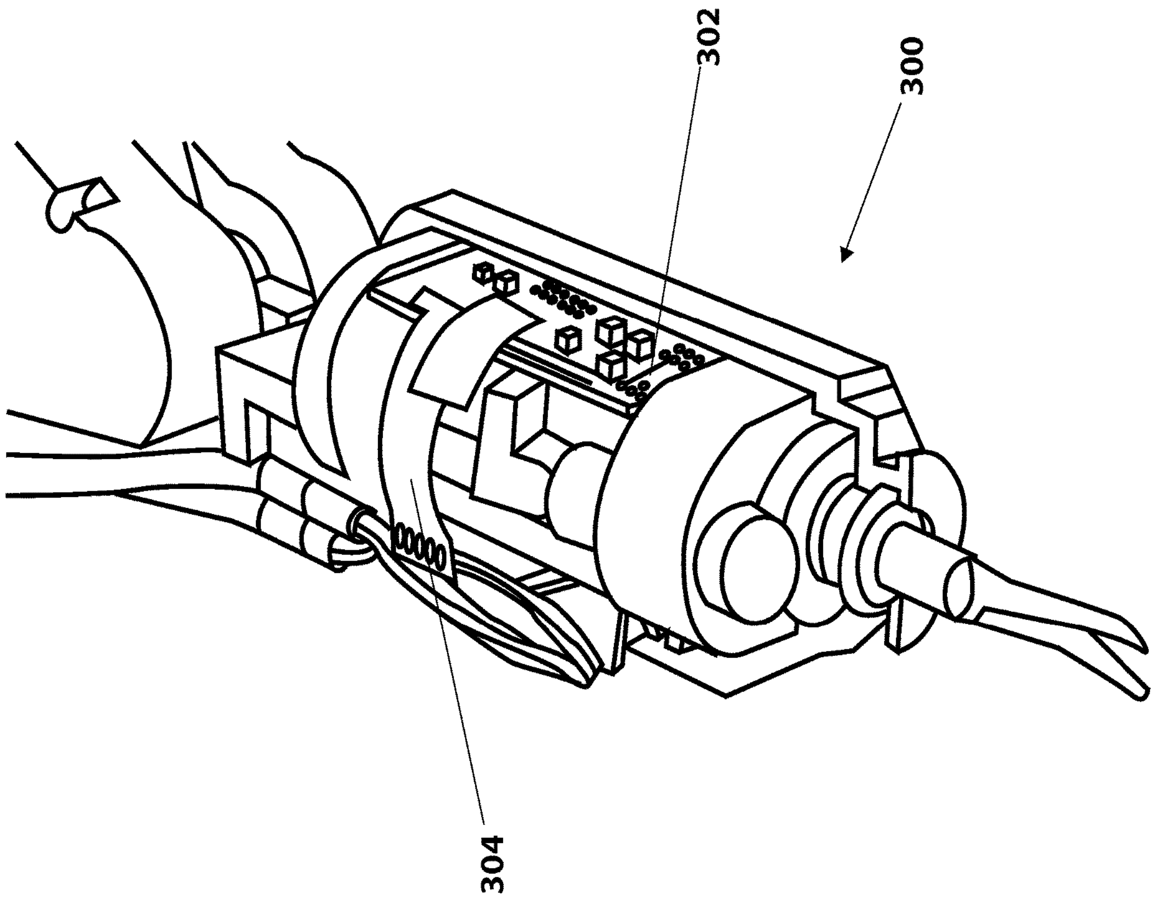


Figure 10

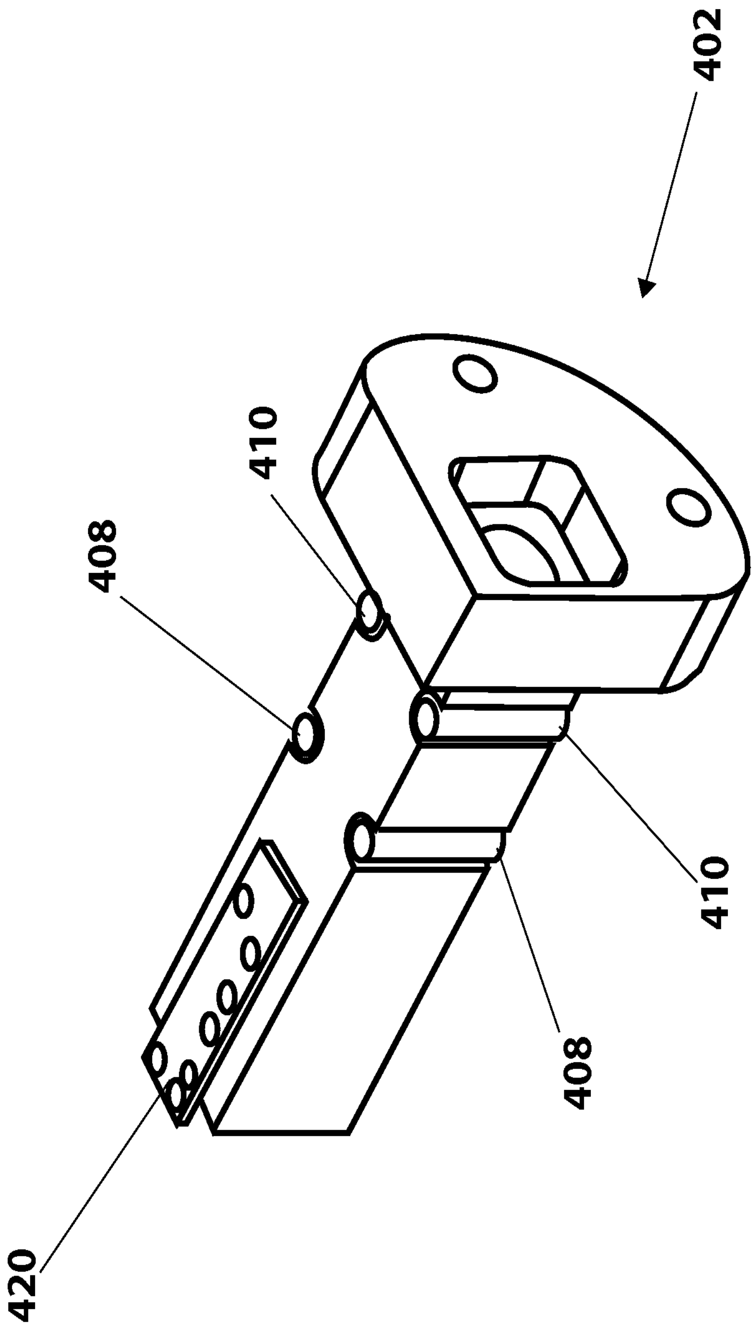
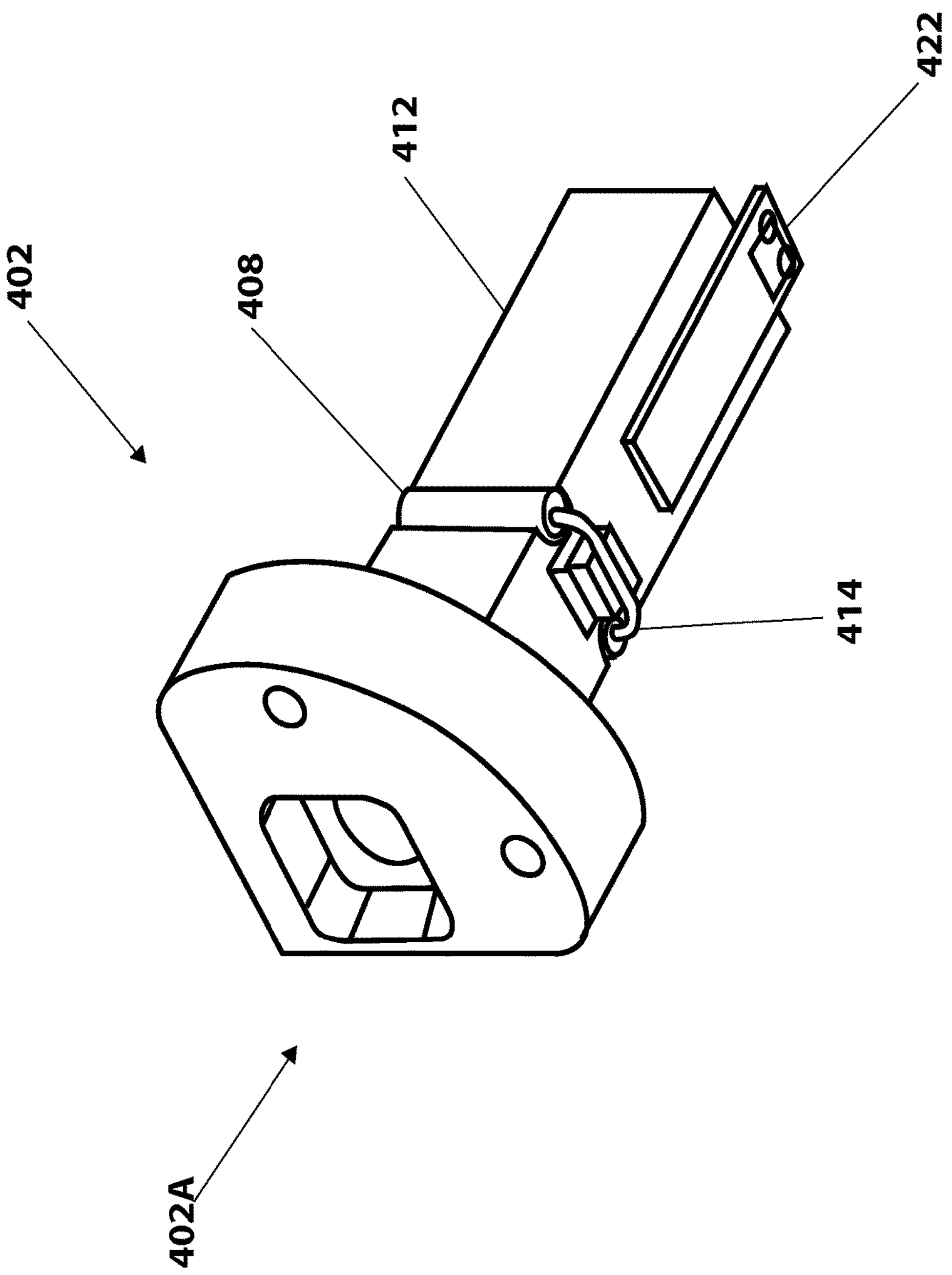


Figure 11A

Figure 11B



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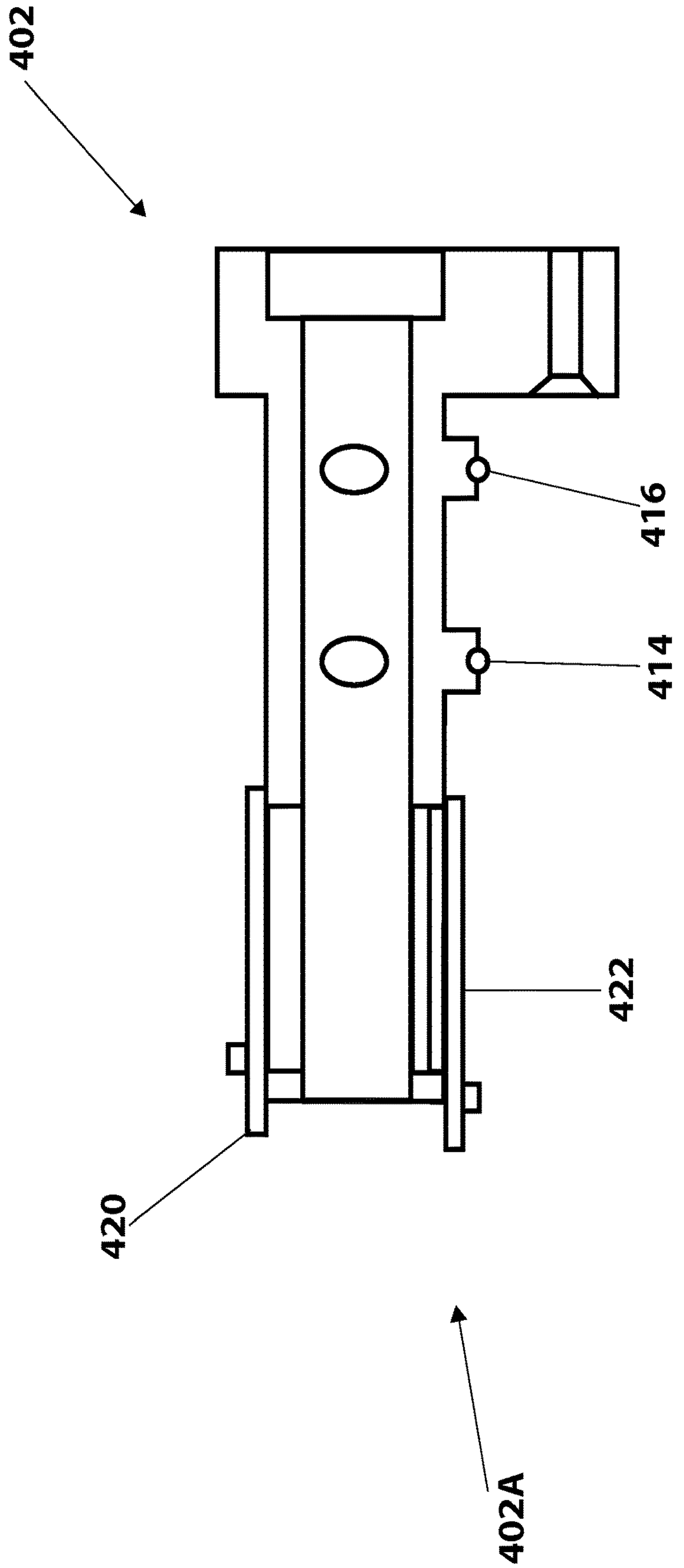

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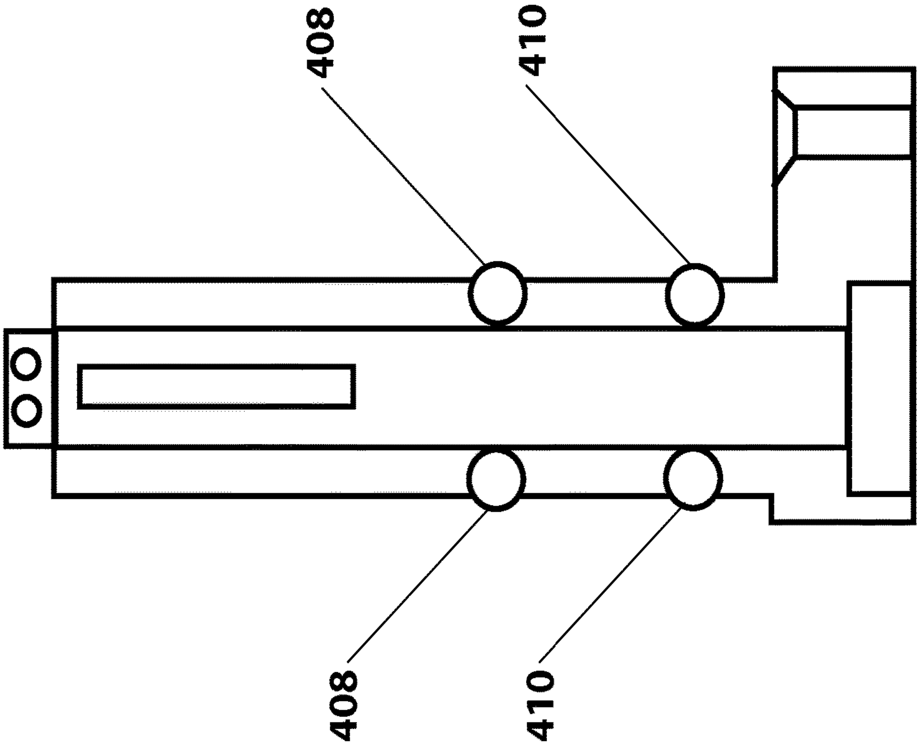

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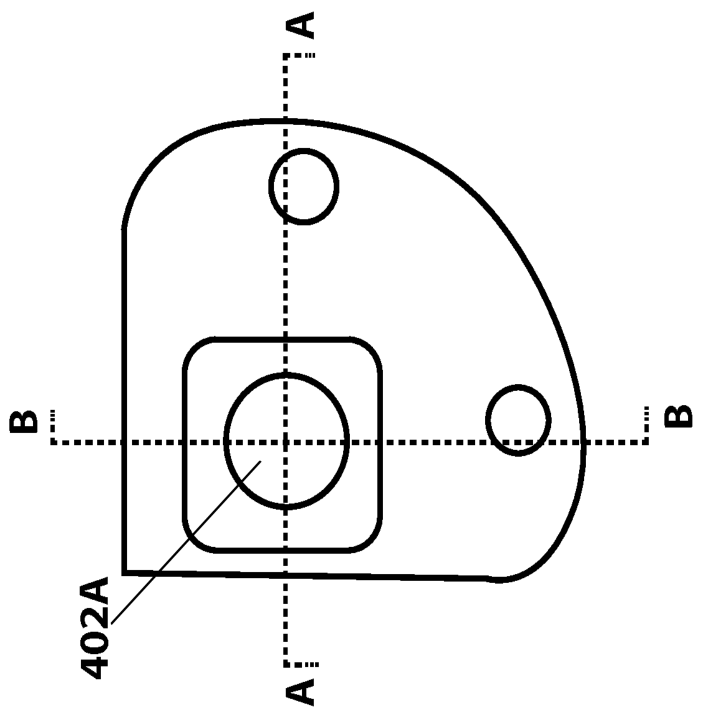

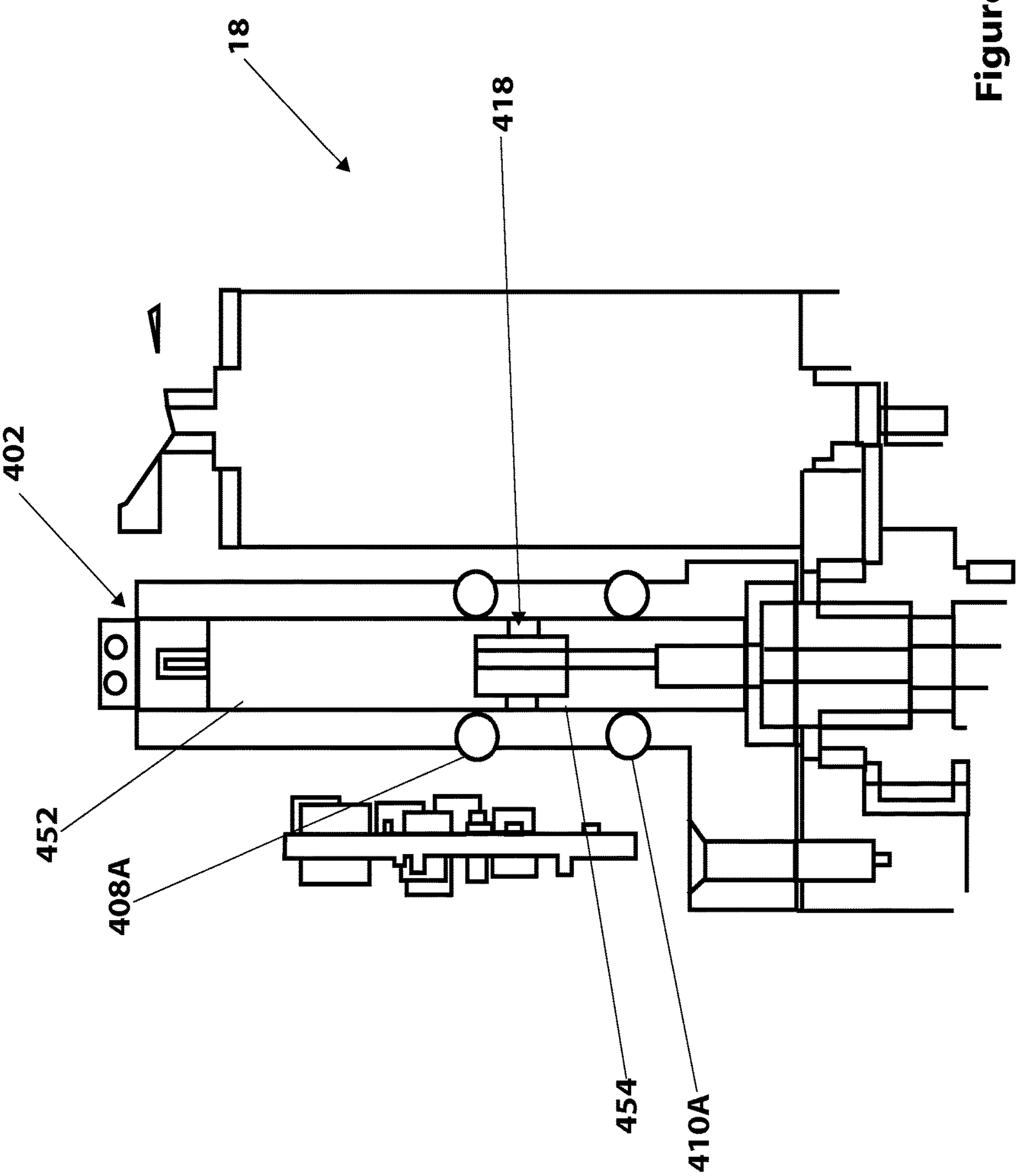

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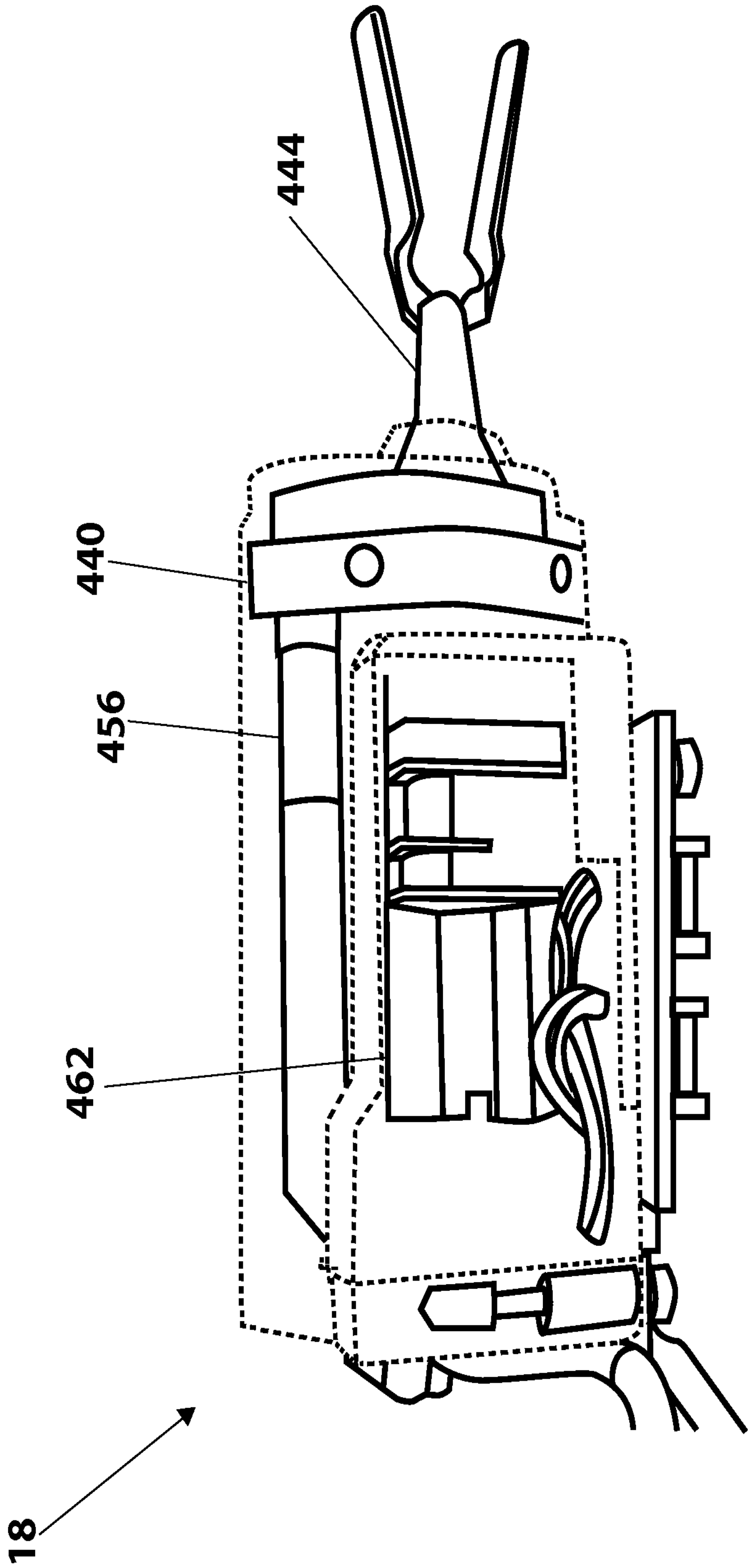

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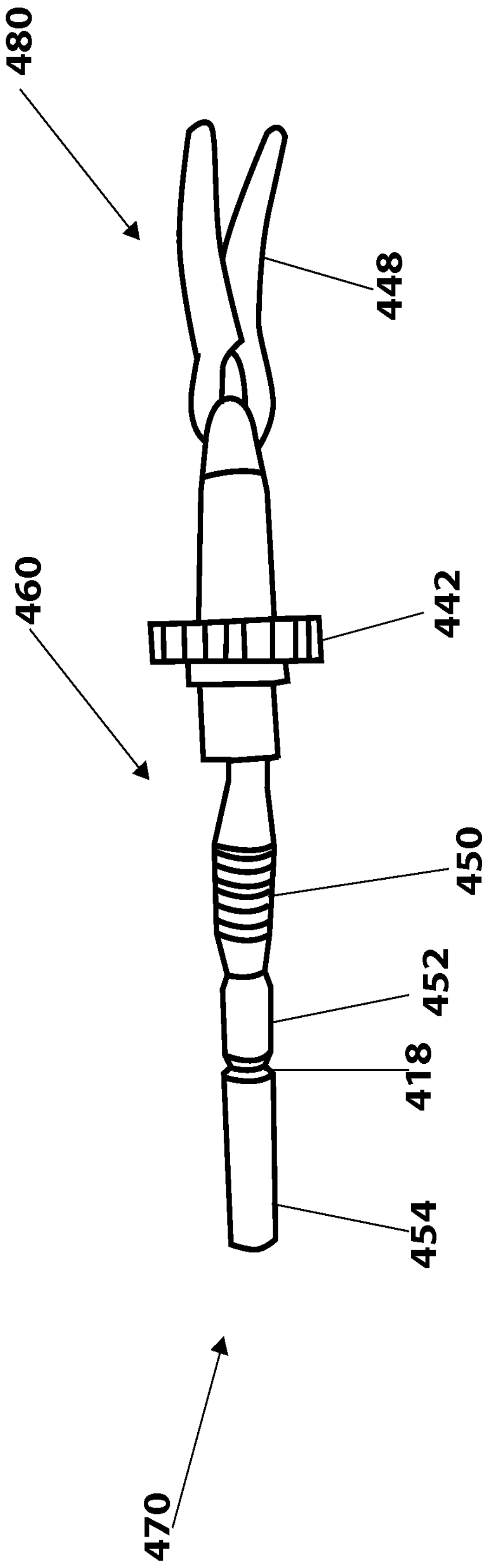

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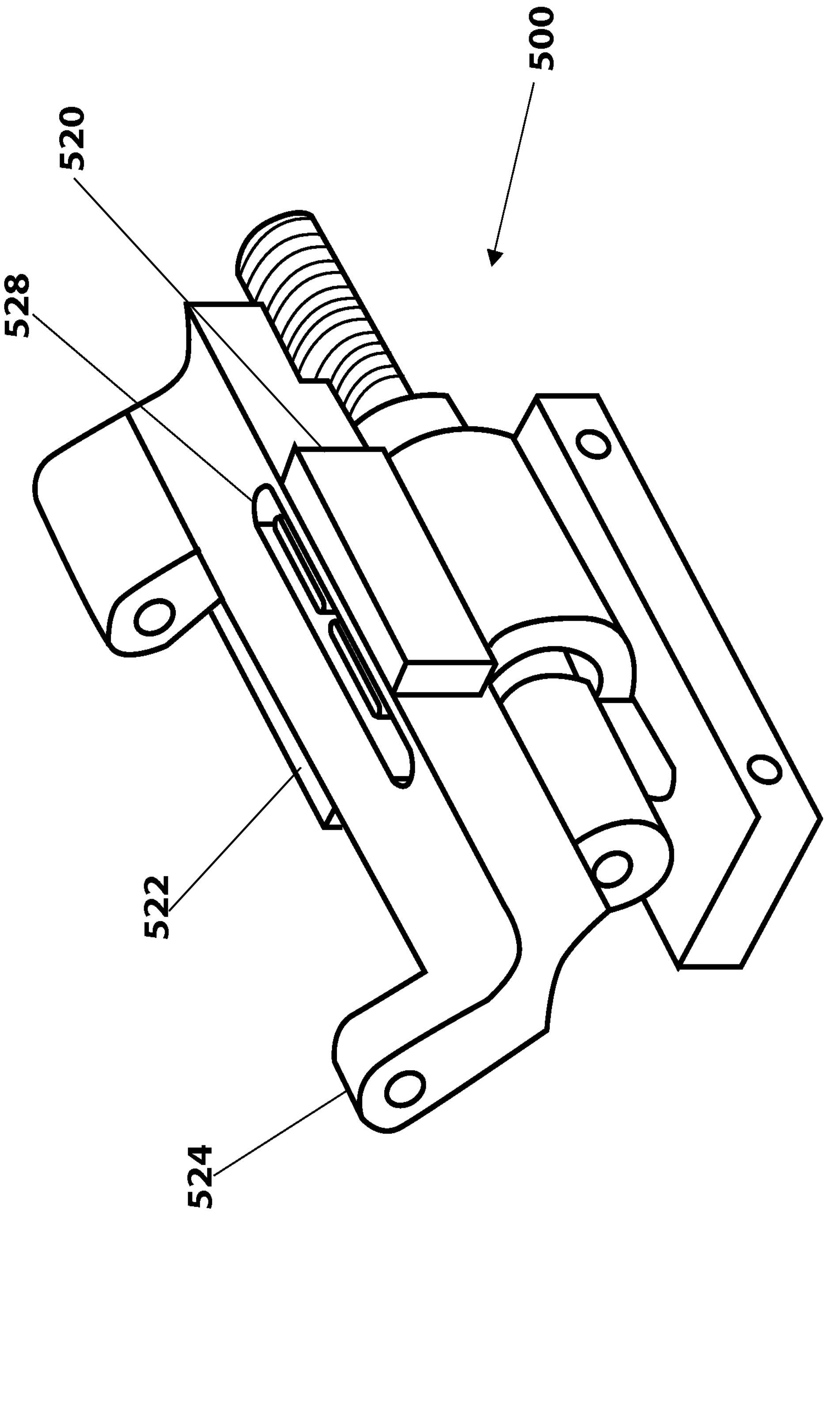
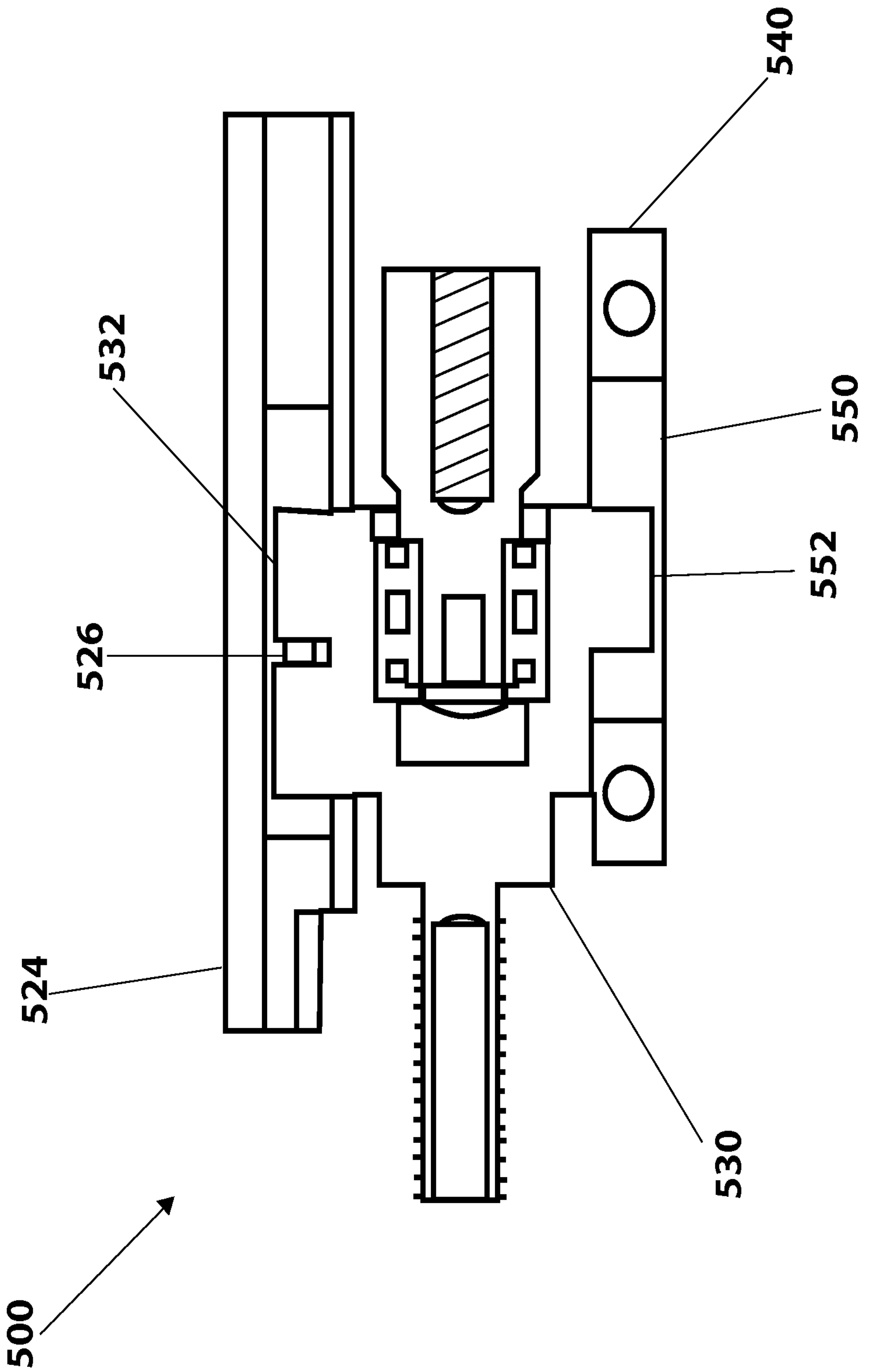


Figure 13A

Figure 13B



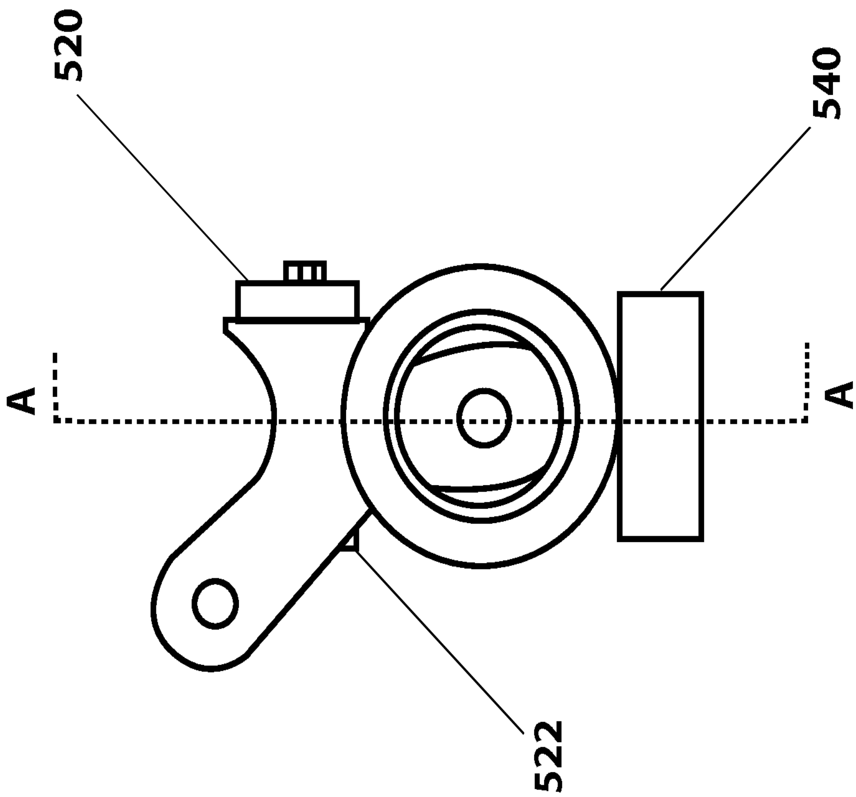


Figure 13C

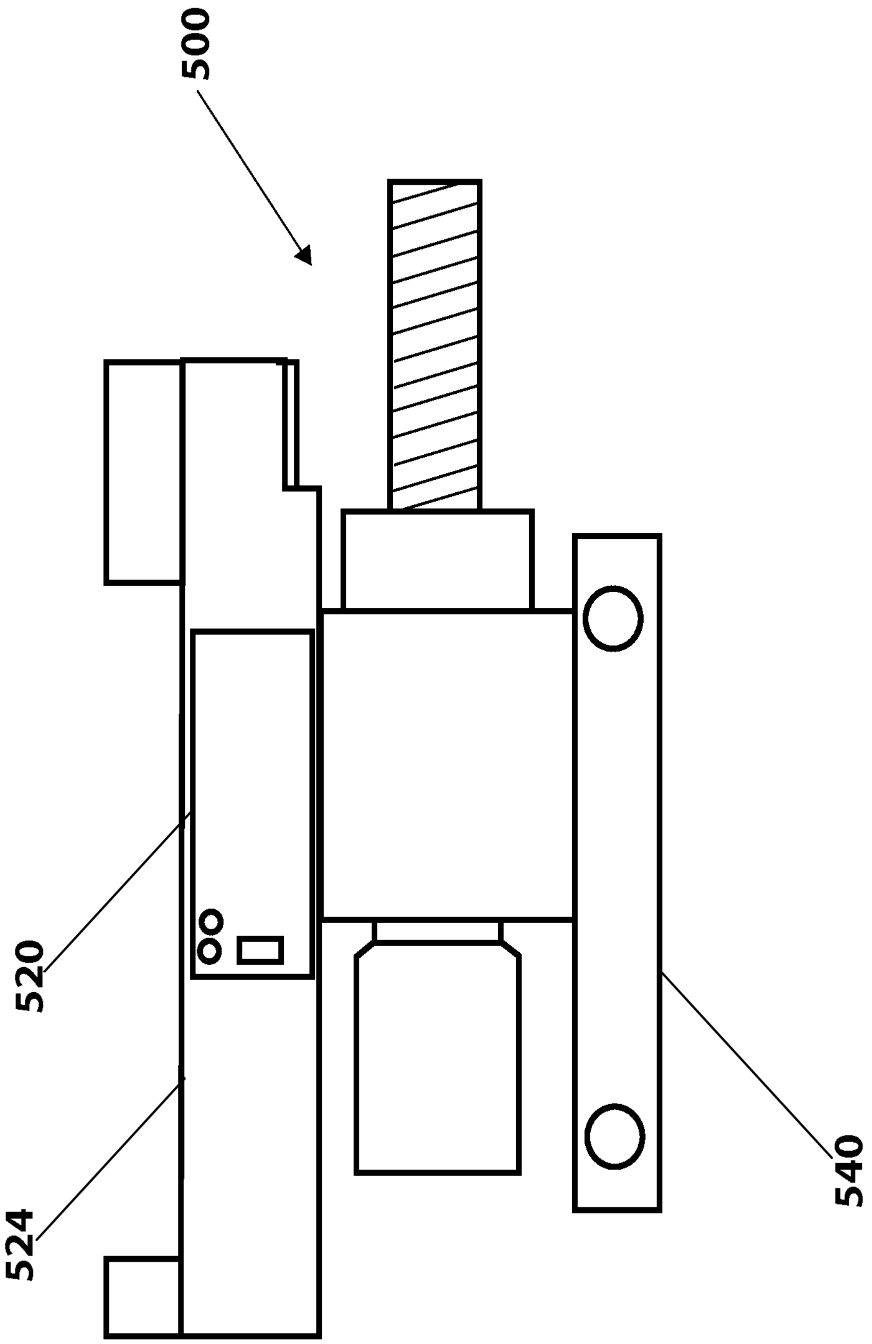


Figure 13D

ROBOTIC SURGICAL DEVICES, SYSTEMS, AND RELATED METHODS

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority from U.S. Provisional Application 61/680,809, filed Aug. 8, 2012, and entitled "Robotic Surgical Devices, Systems, and Methods," which is hereby incorporated herein by reference in its entirety.

TECHNICAL FIELD

The embodiments disclosed herein relate to various medical devices and related components, including robotic and/or in vivo medical devices and related components. Certain embodiments include various robotic medical devices, including robotic devices that are disposed within a body cavity and positioned using a support component disposed through an orifice or opening in the body cavity. Further embodiment relate to methods of operating the above devices.

BACKGROUND

Invasive surgical procedures are essential for addressing various medical conditions. When possible, minimally invasive procedures such as laparoscopy are preferred.

However, known minimally invasive technologies such as laparoscopy are limited in scope and complexity due in part to 1) mobility restrictions resulting from using rigid tools inserted through access ports, and 2) limited visual feedback. Known robotic systems such as the da Vinci® Surgical System (available from Intuitive Surgical, Inc., located in Sunnyvale, Calif.) are also restricted by the access ports, as well as having the additional disadvantages of being very large, very expensive, unavailable in most hospitals, and having limited sensory and mobility capabilities.

There is a need in the art for improved surgical methods, systems, and devices.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram showing a robotic surgical system, including a robotic device positioned inside a body and axis of rotation, according to one embodiment.

FIG. **2**A is a perspective view of a robotic medical device, according to one embodiment.

FIG. **2**B is a perspective view of a robotic medical device, according to one embodiment.

FIG. **2**C is a cut-away view of an arm of a robotic medical device, according to one embodiment.

FIG. **2**D is a sideview of a robotic medical device, according to one embodiment.

FIG. **3**A is a perspective view of a body portion of a robotic device and related equipment, according to one embodiment.

FIG. **3**B is a perspective view of another body portion of a robotic device and related equipment, according to one embodiment.

FIG. **4**A is an endlong view of the body portion of a robotic device and related equipment, according to one embodiment.

FIG. **4**B is a sideview of the body portion of a robotic device and related equipment, according to one embodiment.

FIG. **5**A is a sideview of a body portion of a robotic device and related equipment, according to one embodiment.

FIG. **5**B is a side cross-sectional view of a body portion of a robotic device and related equipment, according to one embodiment.

FIG. **5**C is a perspective cross-sectional view of a body portion of a robotic device and related equipment, according to one embodiment.

FIG. **5**D is a side cross-sectional view of a body portion of a robotic device and related equipment, according to one embodiment.

FIG. **6** is an endlong cross-sectional view of a body portion of a robotic device, according to one embodiment.

FIG. **7**A is a cross-sectional sideview of the upper arm of a robotic device, according to one embodiment.

FIG. **7**B is a cross-sectional sideview of the upper arm of a robotic device from an alternate view, according to one embodiment.

FIG. **7**C is a perspective internal view of the upper arm of a robotic device, according to one embodiment.

FIG. **8**A is a sideview of a forearm of a robotic device, according to one embodiment.

FIG. **8**B is a cross-sectional view of a forearm of a robotic device, according to one embodiment.

FIG. **8**C is another cross-sectional view of a forearm of a robotic device, according to one embodiment.

FIG. **8**D is yet another cross-sectional view of a forearm of a robotic device, according to one embodiment.

FIG. **9**A is cross-sectional sideview of the forearm of a robotic device, according to another embodiment.

FIG. **9**B is another cross-sectional sideview of the forearm of a robotic device, according to another embodiment.

FIG. **10** is a perspective internal view of a forearm of a robotic device, according to another exemplary embodiment.

FIG. **11**A contains a perspective view of an exemplary embodiment of the rotary slip ring assembly according to an exemplary embodiment.

FIG. **11**B contains another perspective view of an exemplary embodiment of the rotary slip ring assembly the embodiment of FIG. **11**A.

FIG. **11**C is a cross sectional sideview of the rotary slip ring assembly the embodiment of FIG. **11**A.

FIG. **11**D is another cross-sectional sideview of the embodiment of FIG. **11**A.

FIG. **11**E is an endview of the embodiment of FIG. **11**A.

FIG. **11**F is another cross-sectional sideview of the embodiment of FIG. **11**A, with associated components in the forearm.

FIG. **12**A is a cutaway sideview of an exemplary embodiment of the surgical device forearm and tool assembly.

FIG. **12**B is a side view of the tool assembly, according to an exemplary embodiment.

FIG. **13**A is a perspective cutaway view of an exemplary embodiment of the surgical device forearm showing an embodiment of a linear encoder.

FIG. **13**B is a cross-sectional sideview of the embodiment of a linear encoder according to FIG. **13**A.

FIG. **13**C is an end view of the embodiment of a linear encoder according to FIG. **13**A and showing the cross section of FIG. **13**B.

FIG. **13**D is a sideview of the embodiment of a linear encoder according to FIG. **13**A.

DETAILED DESCRIPTION

The various systems and devices disclosed herein relate to devices for use in medical procedures and systems. More specifically, various embodiments relate to various medical devices, including robotic devices and related methods and systems.

It is understood that the various embodiments of robotic devices and related methods and systems disclosed herein can be incorporated into or used with any other known medical devices, systems, and methods. For example, the various embodiments disclosed herein may be incorporated into or used with any of the medical devices and systems disclosed in copending U.S. application Ser. No. 11/766,683 (filed on Jun. 21, 2007 and entitled "Magnetically Coupleable Robotic Devices and Related Methods"), Ser. No. 11/766,720 (filed on Jun. 21, 2007 and entitled "Magnetically Coupleable Surgical Robotic Devices and Related Methods"), Ser. No. 11/966,741 (filed on Dec. 28, 2007 and entitled "Methods, Systems, and Devices for Surgical Visualization and Device Manipulation"), 61/030,588 (filed on Feb. 22, 2008), Ser. No. 12/171,413 (filed on Jul. 11, 2008 and entitled "Methods and Systems of Actuation in Robotic Devices"), Ser. No. 12/192,663 (filed Aug. 15, 2008 and entitled Medical Inflation, Attachment, and Delivery Devices and Related Methods"), Ser. No. 12/192,779 (filed on Aug. 15, 2008 and entitled "Modular and Cooperative Medical Devices and Related Systems and Methods"), Ser. No. 12/324,364 (filed Nov. 26, 2008 and entitled "Multi-functional Operational Component for Robotic Devices"), 61/640,879 (filed on May 1, 2012), Ser. No. 13/493,725 (filed Jun. 11, 2012 and entitled "Methods, Systems, and Devices Relating to Surgical End Effectors"), Ser. No. 13/546,831 (filed Jul. 11, 2012 and entitled "Robotic Surgical Devices, Systems, and Related Methods"), 61/680,809 (filed Aug. 8, 2012), Ser. No. 13/573,849 (filed Oct. 9, 2012 and entitled "Robotic Surgical Devices, Systems, and Related Methods"), and Ser. No. 13/738,706 (filed Jan. 10, 2013 and entitled "Methods, Systems, and Devices for Surgical Access and Insertion"), and U.S. Pat. No. 7,492,116 (filed on Oct. 31, 2007 and entitled "Robot for Surgical Applications"), U.S. Pat. No. 7,772,796 (filed on Apr. 3, 2007 and entitled "Robot for Surgical Applications"), and U.S. Pat. No. 8,179,073 (issued May 15, 2011, and entitled "Robotic Devices with Agent Delivery Components and Related Methods"), all of which are hereby incorporated herein by reference in their entireties.

Certain device and system implementations disclosed in the applications listed above can be positioned within a body cavity of a patient in combination with a support component similar to those disclosed herein. An "in vivo device" as used herein means any device that can be positioned, operated, or controlled at least in part by a user while being positioned within a body cavity of a patient, including any device that is coupled to a support component such as a rod or other such component that is disposed through an opening or orifice of the body cavity, also including any device positioned substantially against or adjacent to a wall of a body cavity of a patient, further including any such device that is internally actuated (having no external source of motive force), and additionally including any device that may be used laparoscopically or endoscopically during a surgical procedure. As used herein, the terms "robot," and "robotic device" shall refer to any device that can perform a task either automatically or in response to a command.

Certain embodiments provide for insertion of the present invention into the cavity while maintaining sufficient insufflation of the cavity. Further embodiments minimize the physical contact of the surgeon or surgical users with the present invention during the insertion process. Other implementations enhance the safety of the insertion process for the patient and the present invention. For example, some embodiments provide visualization of the present invention as it is being inserted into the patient's cavity to ensure that no damaging contact occurs between the system/device and the patient. In addition, certain embodiments allow for minimization of the incision size/length. Further implementations reduce the complexity of the access/insertion procedure and/or the steps required for the procedure. Other embodiments relate to devices that have minimal profiles, minimal size, or are generally minimal in function and appearance to enhance ease of handling and use.

Certain implementations disclosed herein relate to "combination" or "modular" medical devices that can be assembled in a variety of configurations. For purposes of this application, both "combination device" and "modular device" shall mean any medical device having modular or interchangeable components that can be arranged in a variety of different configurations. The modular components and combination devices disclosed herein also include segmented triangular or quadrangular-shaped combination devices. These devices, which are made up of modular components (also referred to herein as "segments") that are connected to create the triangular or quadrangular configuration, can provide leverage and/or stability during use while also providing for substantial payload space within the device that can be used for larger components or more operational components. As with the various combination devices disclosed and discussed above, according to one embodiment these triangular or quadrangular devices can be positioned inside the body cavity of a patient in the same fashion as those devices discussed and disclosed above.

As best shown in FIG. **1**, in certain exemplary embodiments, the device **10** has two coupleable bodies **12**A, **12**B, each of which is rotatably coupled to one of two arms **14**A, **14**B as shown. The coupleable bodies **12**A, **12**B are also referred to as "shoulders," "shoulder assemblies," "connectors," and "connector assemblies." More specifically, each arm **14**A, **14**B has a coupling link **8**A, **8**B that couples the arm **14**A, **14**B to one of the coupleable bodies **12**A, **12**B. Each arm has an inner link (also referred to herein as an "inner arm," "inner arm assembly," "upper arm," "upper arm assembly," "first link," or "first link assembly") **16**A, **16**B and an outer link (also referred to herein as an "outer arm," "outer arm assembly," "forearm," "forearm assembly," "second link," or "second link assembly") **18**A, **18**B. The upper arms **16**A, **16**B are rotatably coupled to the coupling links **8**A, **8**B, which are rotatably coupled to the coupleable bodies **12**A, **12**B. In the right arm **14**A, the upper arm **16**A is rotatably coupled to the forearm **18**A, while in the left arm **14**B, the upper arm **16**B is rotatably coupled to the forearm **18**B.

Each of the arms **14**A, **14**B has five degrees of freedom. That is, each arm **14**A, **14**B has four rotatable joints or components and a single bipolar tool. For example, as best shown in FIGS. **1**, **5**A, and **5**B, the coupling link **8**A, **8**B of each arm **14**A, **14**B has a rotatable joint **20**A, **20**B that is rotatable around an axis A that is perpendicular to the length of each of the coupleable bodies **12**A, **12**B, as shown by arrow A**1**. The rotatable joints **20**A, **20**B couple each of the coupleable bodies **12**A, **12**B to one of the coupling links **8**A, **8**B. This rotation around axis A is also called "shoulder pitch." FIGS. **5**A and **5**B depict the right coupleable body **12**A. More specifically, FIG. **5**A is a sideview of the right body **12**A, while FIG. **5**B is a cross-sectional cutaway view depicting the internal portion of the body **12**A marked by line AA-AA in FIG. **5**A. Further, FIG. **5**B depicts axis A around which rotatable joint **20**A rotates.

As best shown in FIGS. **1**, **7**A, and **7**B, the coupling link **8**A, **8**B of each arm **14**A, **14**B also has a rotatable joint **22**A, **22**B that is rotatable around an axis B that is perpendicular to the axis A, as shown by arrow B**1**. FIGS. **7**A and **7**B depict the right upper arm **16**A. More specifically, FIG. **7**A is a top view of the right upper arm **16**A, while FIG. **7**B is a cross-section cutaway sideview depicted the internal portion of the upper arm **16**A marked by line BB-BB in FIG. **7**A. FIG. **7**B also depicts axis B around which rotatable joint **22**A rotates. The rotatable joints **22**A, **22**B couple the coupling links **8**A, **8**B to the upper arms **16**A, **16**B. This rotation around axis B is also called "shoulder yaw."

Also best depicted in FIGS. **1**, **7**A, and **7**B, the arms **14**A, **14**B each have a rotatable joint **24**A, **24**B that is rotatable around an axis C that is parallel to axis B, as shown by arrow C**1**. FIG. **7**B depicts axis C around which rotatable joint **24**A rotates. The rotatable joints **24**A, **24**B couple the upper arms **16**A, **16**B to the forearms **18**A, **18**B. This rotation around axis C is also called "forearm yaw."

Additionally, as best shown in FIGS. **1** and **8**B, each of the forearms **18**A, **18**B (or a portion thereof) are configured to rotate around an axis D that is perpendicular to axis C, as shown by arrow D**1**. This rotation allows for the rotation or "roll" of the end effectors **26**A, **26**B coupled to the distal end of each of the forearms **18**A, **18**B. This rotation around axis D is also called "end effector roll."

Further, as best shown in FIGS. **1** and **8**A, each of the end effectors **26**A, **26**B, or, more specifically, certain components thereof, are configured to rotate or move around an axis E that is perpendicular to axis D, as shown by arrow E**1**. This rotation or movement allows for the opening and closing of the end effector **26**A, **26**B (also referred to as moving the end effector **26**A, **26**B between an open and closed position), such as a grasper or gripper or scissors. This rotation around axis E is also called "end effector opening/closing." FIG. **8**A is a top view of the right forearm **18**A, while FIG. **8**B is a cross-section cutaway sideview depicted the internal portion of the forearm **18**A marked by line CC-CC in FIG. **8**A. FIG. **8**A depicts axis E around which the end effector opening/closing occurs, while FIG. **8**B depicts axis D around which the end effector roll occurs.

As best shown in FIGS. **1**, **2**A, **3**A, **3**B, **4**A, and **4**B, the two coupleable bodies **12**A, **12**B are configured to be coupled together. That is, each of the two bodies **12**A, **12**B have configurations that are mateable to each other such that the right body **12**A can mate with and couple to the left body **12**B such that the two bodies **12**A, **12**B form a single body **12**. In one example, each of the bodies **12**A, **12**B have a matching coupling feature that allows the two bodies **12**A, **12**B to couple together such that they are retained in that coupled configuration. As shown in FIGS. **3**A, **3**B, **4**A, and **4**B, the right body **12**A has a tapered notch **60** defined in one wall of the body **12**A. The notch **60** is wider at the top of the notch **60** than it is at the bottom. Similarly, the left body **12**B has a tapered projection **62** that is sized and configured to fit in the notch **60**. The projection **62** is wider at the top of the projection **62** than it is at the bottom. In one embodiment, the two bodies **12**A, **12**B are coupled by positioning the left body **12**B such that the bottom portion of the projection **62** can be slid into the top portion of the notch **60** and urged downward such that the projection **62** is positioned in the notch **60**. When the projection **62** is correctly positioned in the notch **60**, the two bodies **12**A, **12**B are mated correctly and the coupling is maintained by the mating of the notch **60** and projection **62**. Alternatively, any other known mating or coupling feature or mechanism can be used. This coupleability of the two bodies **12**A, **12**B allows for the two bodies **12**A, **12**B to be coupled to each other prior to positioning the device **10** into the body or after the two arms **14**A, **14**B have been inserted into the target body cavity.

The upper arms **16**A, **16**B and the forearms **18**A, **18**B are operably coupled to an external controller (not shown) via electrical cables that transport both power and data. In certain embodiments, all six of the segments are operably coupled to such connection components (also referred to herein generally as "connection lines" or "connection components"), including both shoulders. In accordance with one implementation, two such connection components are provided, one for each arm. As best shown in FIG. **2**B, in this embodiment the cables are bus power and communication lines **30**A, **30**B that are disposed in or coupled to the connector **12**. The lines **30**A, **30**B transport power from an external power source (not shown) to the motors (not shown) disposed in the arm segments **16**A, **16**B, **18**A, **18**B and further transport data to and from the segments **16**A, **16**B, **18**A, **18**B to the controller. According to one embodiment, the proximal end of the lines **30**A, **30**B are operably coupled to an external source (not shown). According to one embodiment, the external source is an external controller that is a power supply and a communication port. Alternatively, the power supply and the controller can be separate external components. At their distal ends, the power and communication lines **30**A, **30**B are operably coupled to the microcontrollers and the motors in the arms **14**A, **14**B as well as the microcontrollers and motors in the shoulders. More specifically, as shown in FIGS. **1** and **2**B, the right line **30**A extends from the right connector **12**A to the right upper arm **16**A and is positioned through a hole **52**A formed in a top portion of the upper arm **16**A. In the upper arm **16**A, the line **30**A is operably coupled to the at least one microcontroller and the at least one motor (not shown) in the arm **16**A. From the upper arm **16**A, the line **30**A extends out of a hole **54**A and to the forearm **18**A, where the line **30**A is coupled to the at least one microcontroller and the at least one motor (not shown) in the forearm **18**A.

Similarly, as also shown in FIGS. **1** and **2**B, the left line **30**B extends from the left connector **12**B to the left upper arm **16**B and is positioned through a hole **52**B formed in a top portion of the upper arm **16**B. In the upper arm **16**B, the line **30**B is operably coupled to the at least one microcontroller and the at least one motor (not shown) in the arm **16**B. From the upper arm **16**B, the line **30**B extends out of a hole **54**B and to the forearm **18**B, where the line **30**B is coupled to the at least one microcontroller and the at least one motor (not shown) in the forearm **18**B. In certain embodiments, the lines **30**A, **30**B are reinforced or mechanically strain-relieved at the access points to the arm segments (such as holes **52**A, **52**B, **54**A, **54**B) to minimize or eliminate damage to the lines **30**A, **30**B caused by strain as a result of the movement of the arms **14**A, **14**B. Additionally the lines **30** A, **30**B are sealed at the access points to prevent fluid ingress into the robot.

As best shown in FIGS. **1**, **2**A, and **2**B, two cautery lines **32**A, **32**B are also disposed in or coupled to the connector **12**A, **12**B. In this depicted embodiment, the right cautery line **32**A is attached to an exterior portion of the right connector **12**A (as best shown in FIG. **1**), while the left cautery line **32**B is attached to an exterior portion of the left connector **12**B (as best shown in FIGS. **2**A and **2**B). The proximal ends of the lines **32**A, **32**B are coupled to an external power source (not shown). As best shown in FIG. **2**B, the right cautery line **32**A extends from the right connector **12**A to the right forearm **18**A, in which the line **32**A is operably coupled to the end effector **26**A. In one implementation, the portion of the line **32**A that extends from the connector **12**A to the forearm **18**A is coupled to an exterior portion of the upper arm **16**A as shown. Alternatively, the line **32**A could extend through an interior portion of the upper arm **16**A. Similarly, the left cautery line **32**B extends from the left connector **12**B to the left forearm **18**B, in which the line **32**B is operably coupled to the end effector **26**B. In one implementation, the portion of the line **32**B that extends from the connector **12**B to the forearm **18**B is coupled to an exterior portion of the upper arm **16**B as shown. Alternatively, the line **32**B could extend through an interior portion of the upper arm **16**B.

As best shown in FIGS. **1** and **2**B, a dual suction/irrigation line **34**A, **34**B is also coupled to the connector **12**. The dual line **34**A, **34**B is a known line that is comprised of at least one line that can be alternatively used for suction or irrigation. In certain other embodiments, more than one line can be provided, thus providing for suction and irrigation. In the embodiment depicted in FIGS. **1** and **2**B, at its proximal end, the dual suction/irrigation line **34** is coupled to an external irrigation/suction component (not shown) that provides suction or irrigation to the lumen. In one embodiment, the line **34**A, **34**B is coupled at its proximal end to a valve having two separate lines: one line extending to a known suction device and the other line extending to a known irrigation device. This commercially-available valve is known generally as a "trumpet valve." Alternatively, the dual line **34**A, **34**B is coupled to any known external component that provides suction and irrigation, or is coupled to two separate devices, one providing suction and the other providing irrigation. Alternatively, it is understood that two separate lines can be provided—a suction line and an irrigation line. In this embodiment, the dual suction/irrigationline **34**A is coupled to an exterior portion of the right connector **12**A. The suction/irrigation line **34**A extends from the right connector **12**A to the right arm **14**A, where the line **34**A is coupled to an exterior portion of the upper arm **16**A and to an exterior portion of the forearm **18**A as shown.

In one embodiment, the forearm **18**A has an attachment component **36** configured to couple the suction/irrigation line **34** to the forearm **18**A. In this particular exemplary embodiment, the attachment component **36** is an attachment collar **36** configured to be positioned around the forearm **18**A and coupled to the line **34** such that the collar **36** helps to keep the line **34** coupled to the forearm **18**A. At its distal end, the dual suction/irrigation line **34** is operably coupled to the cautery scissors **26**A.

As shown in FIGS. **2**A and **2**B, the connector **12** has a laparoscope lumen **38** defined in the connector **12**. The lumen **38** is configured to receive any standard laparoscopic imaging device. Further, each of the two coupleable connectors **12**A, **12**B defines an insertion rod lumen **40**A, **40**B. Each lumen **40**A, **40**B is configured to receive an insertion rod **42**A, **42**B.

In accordance with one implementation, each of the power and communications lines **30**A, **30**B, the cautery lines **32**A, **32**B, and the dual suction/irrigation line **34** are all coupled with or disposed in the connector **12** such that a seal is maintained between the connector **12** and the access port (not shown) mounted to the patient. That is, as best shown in FIG. **6**, the connector **12** (and the two connector bodies **12**A, **12**B), according to one embodiment, has grooves or channels **70** defined along the outer surface of the two bodies **12**A, **12**B such that the various lines and cables (including the power and communications lines **30**A, **30**B, the cautery lines **32**A, **32**B, the suction/irrigation line **34**, and any other lines or cables that might be incorporated into the device) are positioned in those grooves or channels **70**. The positioning of the lines or cables in the grooves or channels **70** helps to maintain a smooth outer perimeter around the outer surface of the connector **12**, thereby ensuring a successful fluidic seal with the access port when the connector **12** is positioned therethrough. It is understood that the access port can be any known port for use with laparoscopic surgical tools, including the port devices described in U.S. patent application Ser. No. 13/738,706, filed on Jan. 10, 2013, which is hereby incorporated herein by reference in its entirety. In certain exemplary embodiments, the access port can be readily removed, cleaned and sterilized.

According to one implementation, the arms **14**A, **14**B are configured to receive a fluid sealing component over the arms **14**A, **14**B. That is, as best shown in FIG. **1**, each of the coupleable connectors **12**A, **12**B, has a channel **44**A, **44**B defined around the connectors **12**A, **12**B and each of the arms **14**A, **14**B has a channel **46**A, **46**B defined around a distal portion of the forearms **18**A, **18**B. Fluid sealing protective sleeves (not shown), such as those, for example, described in U.S. application Ser. No. 13/573,849, filed on Oct. 9, 2012, which is hereby incorporated by reference herein in its entirety, are positioned over each arm **14**A, **14**B and the ends of each sleeve are positioned in one of the channels **44**A, **44**B, **46**A, **46**B such that the sleeves are coupled to the arms **14**A, **14**B such that the sleeves create a fluidic seal around each arm **14**A, **14**B, whereby moisture and liquid are prevented from ingressing into the arms **14**A, **14**B.

Each of the joints described above is operably coupled to a motor via a geartrain (not shown). Further, each joint is also operably coupled to a microcontroller. In addition, each joint is operably coupled to at least one position sensor. According to one embodiment, each joint is coupled to both a relative position sensor and an absolute position sensor. According to another embodiment, each joint has at least a relative position sensor.

As best shown in FIGS. **2**C and **2**D, the configuration of the connector **12** and the arms **14**A, **14**B in this embodiment provide a minimal cross-sectional area for the device **10**, thereby allowing for easy insertion of the device **10** through a small incision and into a small cavity of a patient. That is, the coupling of the arms **14**A, **14**B to the connector **12** via the coupling links **8**A, **8**B, along with the ability to position the arms **14**A, **14**B as shown in FIGS. **2**C and **2**D, results in a narrower device **10** that can fit through smaller incisions in comparison to devices that are wider/have larger cross-sections. In use, the arms **14**A, **14**B of the device **10** can be positioned as shown in these figures prior to insertion into a patient's cavity. The device **10** can then be positioned through an incision in a single linear motion. In one embodiment, the device **10** is inserted one arm at a time. That is, the two coupleable bodies **12**A, **12**B with arms attached are positioned in the patient's cavity prior to coupling the two bodies **12**A, **12**B together. Alternatively, the device **10** is inserted as a single unit, with the two bodies **12**A, **12**B already coupled together.

FIGS. **5**C and **5**D depict a close-up of the right connector **12**A, according to one embodiment. It is understood that the internal components of the right connector **12**A as described herein are substantially similar to the equivalent components in the left connector **12**B, so the following description shall encompass those equivalent components as well. As best shown in FIG. **5**D, the right connector **12**A has a connector motor **160** that is operably coupled to a bevel motor gear **162**. The bevel motor gear **162** is operably coupled to a bevel driven gear **164**, which constitutes joint **20**A discussed above. The drive gear **164** is supported in this embodiment by two bearings **166** and is operably coupled to the right coupling link **8**A, which is also described above. In one implementation, a magnetic absolute position encoder **168** (also shown in FIG. **5**C) and an encoder magnet **170** are operably coupled to the driven gear **164**, and are thereby configured to provide information about the position of the gear **164**. As best shown in FIG. **5**C, a motor control board **172** is positioned in the housing of the connector **12**A.

In accordance with one embodiment, the right and left upper arms **16**A, **16**B, including the coupling links **8**A, **8**B, have configurations that are identical or substantially similar and are simply minor versions of each other. Alternatively, they can have some different components as necessary for the specific end effectors that might be coupled to the forearms **18**A, **18**B.

FIGS. **7**A, **7**B, and **7**C depict a right upper arm **16**A, according to one embodiment. It is understood that the internal components of the right upper arm **16**A as described herein are substantially similar to the equivalent components in the left upper arm **16**B, so the following description shall encompass those equivalent components as well. The upper arm **16**A has two motors **200**, **202**. The first motor **200** is configured to actuate the shoulder shaft **204** to rotate in relation to the coupling link **8**A, thereby rotating around axis B. The second motor **202** is configured to actuate the elbow shaft **206** to rotate in relation to the forearm **18**A, thereby rotating around axis C.

As best shown in FIG. **7**B, the first motor **200** is operably coupled to motor gear **208**, which is operably coupled to the driven gear **210**. The driven gear **210** is operably coupled to the shoulder shaft **204** such that rotation of the driven gear **210** causes rotation of the shoulder shaft **204**. The shaft **204** is supported by bearings **216**A, **216**B. The motor **202** is operably coupled to motor gear **212**, which is operably coupled to the driven gear **214**. The driven gear **214** is operably coupled to the elbow shaft **206** such that rotation of the driven gear **214** causes rotation of the elbow shaft **206**. The shaft **206** is supported by bearings **218**A, **218**B.

Each of the shafts **204**, **206** is operably coupled to an encoder magnet **222**A, **222**B, each of which is operably coupled to an absolute position magnetic encoder **220**A, **220**B. The encoders **220**A, **220**B work in a fashion similar to the position encoders described above. At least one motor control board **224** is positioned in the housing of the upper arm **16**A as best shown in FIG. **7**C.

In contrast, in this implementation as shown in FIGS. **1** and **2**A, the right and left forearms **18**A, **18**B are not identical. That is, the right forearm **18**A has an end effector **26**A further comprising cautery scissors **26**A. According to one embodiment, the cautery scissors **26**A is a "quick-change" mono-polar cautery scissors **26**A. That is, the cautery scissors **26**A can be coupled to or removed from the forearm **18**A without the need to assemble or disassemble any other components. More specifically, in this exemplary embodiment, a commercially-available cautery scissors **26**A called the ReNew Laparoscopic Endocut Scissors Tip™, which is available from Microline Surgical, Inc., located in Beverly, Mass., is removeably coupled to the forearm **18**A. Alternatively, any known easily removeable end effector or any known mechanism or method for providing easy coupling and uncoupling of the end effector **26**A can be used. In a further alternative, the end effector **26**A can be any known end effector for use with an arm of a robotic surgical device.

One exemplary embodiment is depicted in FIGS. **8**A-**8**D. FIGS. **8**A-**8**D depict several views of the right forearm **18**A according to one implementation. FIG. **8**C is a cross-sectional cutaway view of the forearm **18**A that is perpendicular to the plane of the line CC-CC of FIG. **8**A, while FIG. **8**D is a cross-sectional cutaway view of the forearm along line CC-CC of FIG. **8**A. The forearm **18**A has two motors **80**, **82**. As best shown in FIG. **8**C, the motor **80** is operably coupled to the end effector **26**A such that the motor **80** actuates the end effector **26**A to move between its open and closed positions. As best shown in FIG. **8**D, the motor **82** is operably coupled to the end effector **26**A such that the motor **82** actuates the end effector **26**A to "roll," which is rotation around an axis parallel to the longitudinal length of the arm **18**A.

Focusing on FIG. **8**C, the motor **80** actuates the end effector **26**A to open and close in the following fashion. The motor **80** has a motor gear **84** that is operably coupled to a driven gear **86**. The driven gear **86** is operably coupled to a connector component **88** such that the connector component **88** rotates when the driven gear **86** rotates. Connector component **88** is supported by two bearings (not shown). The connector component **88** has a threaded inner lumen **88**A and is operably coupled to a translation component **90**. More specifically, the translation component **90** has a proximal threaded projection **90**A that is threadably coupled to the threaded inner lumen **88**A such that rotation of the connector component **88** causes axial movement of the translation component **90**. In addition, as best shown in FIG. **8**D, the translation component **90** has a projection **90**B extending from an outer circumference of the component **90** such that the projection **90**B is positioned in a slot **92** that constrains the translation component **90** from rotating. As such, when the driven gear **86** rotates and thus causes the connector component **88** to rotate, the rotation of the connector component **88** causes the translation component **90** to move axially along the longitudinal axis of the arm **18**A.

The translation component **90** defines a lumen **90**C at its distal end that is configured to receive the coupling component **94**, as best shown in FIG. **8**C. Further, the lumen **90**C contains at least one bearing **96** that is positioned between the translation component **90** and the coupling component **94** such that the translation component **90** and the coupling component **94** are rotationally independent of each other. That is, the coupling component **94** can rotate inside the lumen **90**C of the translation component **90** while the translation component **90** does not rotate. The coupling component **94** has a threaded lumen **94**A configured to receive a rod (or pin) **98** that has external threads on its proximal end that are threadably coupled to the threaded lumen **94**A of the coupling component **94**. The distal end of the rod **98** is slidably positioned in the end effector housing **100** such that the rod **98** can slide axially back and forth in relation to the housing **100**. The rod **98** is operably coupled to the first and second blades **102**A, **102**B of the scissors **26**A via linkages (not shown) such that the axial movement of the rod **98** causes the blades **102**A, **102**B to pivot around the pivot axis **104**, thereby causing the blades **102**A, **102**B to open and close. More specifically, in one embodiment, movement of the rod **98** in a distal direction (toward the scissors **26**A) causes the blades **102**A, **102**B to move away from each other such that the scissors **26**A move toward an open position, while proximal movement of the rod **98** causes the scissors **26**A to move toward a closes position.

Focusing on FIG. **8**D, the motor **82** actuates the end effector **26**A to roll in the following fashion. The motor **82** has a motor gear **104** that is operably coupled to a driven gear **106**. The driven gear **106** is operably coupled to a roll shaft **108** such that the roll shaft **108** rotates when the driven gear **106** rotates. The at least one bearing **112** disposed around the roll shaft **108** allows the roll shaft **108** to rotate in relation to the forearm **18**A. The roll shaft **108** is operably coupled to rotational connector **110**, such that roll shaft is constrained linearly and rotationally. Housing **100** is threadably coupled to rotational connector **110**, such that the two components are operably coupled, again constrained linearly and rotationally. In certain embodiments, roll shaft **108** does not have any threads. As such, the roll shaft **108**, the housing **100**, and the rotational connector **110** are all coupled together such that they are capable of rotating together. Thus, actuation of the motor **82** results in rotation of the housing **100** and thus rotation of the end effector **26**A. According to one embodiment, the forearm **18**A also has at least one position sensor to provide information to an external controller (not shown) or a microcontroller regarding the position of the end effector **26**A.

The electrical connection required for the cautery feature of the end effector **26**A is maintained in the following fashion. An electrical contact pin **114** is slidably positioned within the lumen **88**A of the connector component **88** and is electrically coupled at its proximal end to the cautery line **32**A discussed elsewhere herein (and depicted in FIGS. **1** and **2**B). The lumen **88**A contains bifurcated leaf springs which maintain electrical contact and provide long life to mechanism. This was accomplished by taking an off the shelf socket connector and press fitting the socket portion into part **88**. At its distal end, the pin **114** is electrically coupled to the translation component **90**, which is electrically coupled through the other coupling components discussed above to the blades **102**A, **102**B of the end effector **26**A, thereby allowing for electrical coupling of the cautery line **32**A to the end effector **26**A.

The left forearm **18**B has an end effector **26**B that is a cautery grasper **26**B, as shown in FIGS. **9**A and **9**B. According to one embodiment, the cautery grasper **26**B is an integrated bi-polar cautery grasper **26**B. In this context, "integrated" is intended to mean that the grasper **26**B is an integral part of the forearm **18**B such that replacement of the grasper **26**B with another end effector would require disassembly of the forearm **18**B. Alternatively, the grasper **26**B is not an integral part of the forearm **18**B but rather is easily removable and interchangeable with other end effectors. For example, in one embodiment, the end effector **26**B is a "quick change" end effector **26**B similar to the right end effector **26**A as described above.

FIGS. **9**A and **9**B depict the left forearm **18**B according to one implementation. FIG. **9**A is a cross-sectional cutaway view of the forearm **18**B along line DD-DD of FIG. **2**D, while FIG. **9**B is a cross-sectional cutaway view of the forearm along a line that is perpendicular to the plane of line DD-DD of FIG. **2**D. The forearm **18**B has two motors **120**, **122**. As best shown in FIG. **9**A, the motor **120** is operably coupled to the end effector **26**B such that the motor **120** actuates the end effector **26**B to "roll," which is rotation around an axis parallel to the longitudinal length of the arm **18**B. As best shown in FIG. **9**B, the motor **122** is operably coupled to the end effector **26**B such that the motor **122** actuates the end effector **26**B to move between its open and closed positions.

Focusing on FIG. **9**A, the motor **120** actuates the end effector **26**B to roll in the following fashion. The motor **120** has a motor gear **124** that is operably coupled to a driven gear **126**. The driven gear **126** is operably coupled to a end effector housing **128** such that the housing **128** rotates when the driven gear **126** rotates. As such, actuation of the motor **120** causes rotation of the end effector **26**B. The at least one bearing **130** positioned around a proximal portion of the driven gear **126** to allow the gear **126** and the housing **128** to rotate in relation to the arm **18**B. An O-Ring **132** forms a seal around the housing **128**, but does not support the shaft and does not aid in its rotation or constraint. Applying a radial loaded to the O-ring **132** could potentially compromise the seal which is its primary and sole function.

Focusing on FIG. **9**B, the motor **122** actuates the end effector **26**B to open and close in the following fashion. The motor **122** has a motor gear **134** that is operably coupled to a driven gear **136**. The driven gear **136** is operably coupled to a connector component **138**, which is threadably coupled to an inner lumen **136**A of the driven gear **136** such that the connector component **138** translates when the driven gear **136** rotates. The connector component **138** is operably coupled to connector rods **140**A, **140**B, which are operably coupled at their proximal ends to a slip ring **142** (as best shown in FIG. **9**A). The connector component **138**, rods **140**A, **140**B, and slip ring **142** are coupled to each other rotationally and axially such that rotation of the connector component **138** causes rotation of both the rods **140**A, **140**B and the slip ring **142**. Further, as the driven gear **136**—rotates, the assembly of the coupled components **138**, **140**A, **140**B, **142** moves axially in relation to the driven gear **136**. The assembly **138**, **140**A, **140**B, **142** is also coupled to the end effector housing **128** such that housing **128** rotates when the assembly **138**, **140**A, **140**B, **142** rotates. However, the assembly **138**, **140**A, **140**B, **142** can move axially independently of the housing **128**. Each of the rods **140**A, **140**B is operably coupled to one of the fingers **148**A, **148**B of the grasper **26**B via a linkage (not shown) within the housing **128**. As the rods **140**A, **140**B move axially, they move the linkages, thereby causing the fingers **148**A, **148**B to move between their open and closed positions. The driven gear **136** thus causes translation, not rotation of the assembly **138**, **140**, **142**. Its rotation is contrained by the housing **128**, which in turn is constrained by the driven gear **126**, which in turn is rotationally constrained by motor gear **124**, which is in turn constrained by motor **120**. Therefore, it is the motor **120** that provides the rotational constraint in a similar fashion to the projection **90**B in FIG. **8**D. In contrast to the right arm, the linear motion and the rotational motion of this mechanism is coupled. When a user wishes to roll the tool and maintain a constant open or closed position, both motors **120**, **122** must be actuated and match speed. When a user wishes to open or close the tool, the motor **122** must be actuated and hold position to constrain the rotation.

According to one embodiment, the forearm **18**B also has a set of position sensors to provide information to an external controller (not shown) or a microcontroller regarding the position of the end effector **26**B. In the implementation as shown in FIG. **9**A, an array of LEDs **144** and a set of position sensors **146** are positioned in the forearm **18**B such that the axial position of the end effector **26**B can be determined based on the position of the slip ring **142**. More specifically, the array of LEDs **144** are positioned on one side of the ring **142** and the sensors **146** are positioned on the other side such that the position of the slip ring **142** can be determined based on which sensors **146** are sensing light emitted from LEDs **144** (and which sensors **146** are not). This information about the position of the slip ring **142** can be used to determine the position of the end effector **26**B.

As best shown in FIG. **10**, in certain exemplary embodiments of the present invention **300**, the onboard microcontrollers, or PCBs **302**, are operably connected with uniform flex tapes **304**. In certain embodiments, the various PCBs are identical and the flex tapes are universally adaptable.

In certain exemplary embodiments of the forearm, **18** as shown in FIGS. **11**A-**11**F and **12**, the surgical device further comprises a linear slip ring assembly **402** (best shown in FIGS. **11**A-**11**F) for use with an end effector, such as a bipolar cautery end effector, or "tool assembly" **460** which is shown generally in FIG. **12**. In these embodiments, the bi-polar cautery end effector having two grasper fingers operates by coupling the two grasper fingers to separate electrical channels. The linear slip ring assembly **402** has an opening **402**A that receives the tool assembly **460** (depicted in FIGS. **11**F and **12**) so as to provide electrical and mechanical communication between the tool assembly and the linear slip ring, and thereby couple the two grasper fingers to a power source. In certain embodiments, this is an external power source.

In certain implementations, the linear slip ring assembly **402** is a novel two-channel linear slip ring assembly **402** capable of allowing both rotating motion and translating motion of the tool assembly **460** disposed therein. The linear slip ring assembly also contains two electrical channels (as described below) that are isolated from one another throughout the assembly and connect to the linear slip ring **402** so as to pass bi-polar cautery power to the grasper fingers as they roll and open or close.

In exemplary embodiments, the linear slip ring assembly **402** has a first stator pair **408** and second stator pair **410**. The first and second stator pairs **408**, **410** are each spring loaded onto the housing **412** by U-springs **414**, **416** and are operably coupled with the corresponding slip ring rotors **452**, **454** of the tool assembly **460** (shown in FIG. **12**). The slip ring rotors **452**, **454** are capable of both translational and continuous rotation of the end effector. An insulator **418** separates the slip ring rotors **452**, **454** to maintain electrical isolation.

Focusing on FIG. **12**, in operation, exemplary end effector embodiments **440** having the linear slip ring assembly **440**A further comprise a tool assembly **460** having a roll gear **442**, which is permanently bonded to the tool housing **444**. In operation, by rotating the roll gear **442**, the tool housing assembly, **460** as described previously, all of the tool rotates. This rotation includes the grasper **448**, the roll gear **442**, the leadscrew **450**, and the slip ring rotators **452**, **454**. In these embodiments, the roll gear **442** is fixed in place axially in the forearm assembly **440** and operably coupled to the roll motor **456**. In these implementations, the roll gear **442** is not free to move linearly, and can only move rotationally. Actuating the roll motor **456** thus causes the entire tool assembly **460** to rotate.

In exemplary embodiments, a linear motor **462** is coupled to an internally threaded driven gear (shown in reference to FIG. **9**B as the driven gear **136**). This driven gear **136** is in turn threadably coupled to the connector component, or "leadscrew" **450** (shown in FIG. **9**B as the connector component **138**). The driven leadscrew drives the leadscrew **450** linearly so as to open and close the grasper **448**.

Further, the leadscrew **450** and roll gear **442** are coupled together. In operation, in order to achieve pure roll, both the roll gear **442** and the driven leadscrew must rotate at the same speed. This is done so that there is no relative angular velocity between the leadscrew **450** and the leadscrew gear. By way of example, if the roll gear **442** were to spin (and the tool **460** spin with it), while the driven leadscrew gear maintained position, the leadscrew **450** would be spinning within the leadscrew gear and causing translation, in the depicted embodiment the opening or closing of the grasper **448**.

Similarly, in order to achieve pure opening or closing of the grasper **448**, the roll gear **442** must hold position while the driven leadscrew gear rotates and drives the leadscrew **450** linearly. If the roll gear **442** were free to spin while the driven leadscrew gear operates, no relative motion between the leadscrew **450** and leadscrew gear would occur and thus there would be no linear translation, and thus no opening or closing of the grasper **448**.

In these exemplary embodiments, the cautery slip ring rotors **452**, **454** are permanently coupled mechanically to the leadscrew **450** along an axis, but remain isolated **418** electrically from the leadscrew **450**, such that the cautery slip ring rotors **452**, **454** translate with the leadscrew **450** and rotated when entire tool **460** rotates.

Thus, in certain exemplary embodiments, the entire tool **460** is rotationally coupled. The proximal portion **470** (including the leadscrew **450** and the cautery slip ring rotors **452**, **454**) can translate with respect to the distal portion **480** (including the roll gear gear **442**, the tool housing **440** and the grasper **448**). This translation drives the grasper **448** open and closed. Further, and as discussed in relation to FIG. **11**A-F, each of the cautery slip ring rotors **452**, **454** is electrically coupled to one grasper jaw **448**A, **448**B. As previously discussed in reference to FIG. **11**A-**11**F, each of the cautery slip ring rotors **452**, **454** are also electrically coupled to a stator pair **408**, **410**, and is electrically isolated from every other element in the system.

According to another implementation, the surgical device forearm **18** further comprises a linear encoder, as is depicted in FIGS. **11**A-F and discussed further herein in reference to **13**A-D. Linear encoders serve as absolute position sensors by assessing the absolute position of the end effector or forearm. In these embodiments, the forearm **18** further comprises a pixel array **420** and LED array **422**, as best shown in FIGS. **11**A & **11**B, which function together to determine the position of aspects of the surgical device. By way of example, in these embodiments, this functions is performed by broadcasting and receiving a signal—such as LED light—to determine the position of those aspects by assessing shadows or breaks in the LED light. Data from the magnetic absolute position encoder (discussed in relation to FIGS. **5**C and **7**B herein) and the linear position encoder can both be used as feedback sensors in the control algorithm. In certain implementations, the absolute linear position optical encoder is coupled to the gripper translation assembly and the custom relative rotary position optical encoder is coupled to the motor shaft, and both are used as the feedback sensors in the control algorithm. This is discussed further herein in relation to FIG. **13**A-**13**D.

In the implementation shown in FIG. **11**A-**11**F, an array of LEDs **422** and the pixel array **420** are positioned on the housing **412** such that the axial position of the end effector (not shown) can be determined based on the position of the projection from the LED array **422**. More specifically, the array of LEDs on one side of the housing and the pixel array **420** are positioned on opposite sides of the housing **412** such that the position of the LED projection can be determined based on which sensors are sensing light emitted from LEDs (and which sensors are not) based on the position of the end effector disposed within that channel.

In certain embodiments, the motor control boards are integrated into the forearm housing, best shown as reference numbers **80** in FIGS. **8**C and **122** in FIG. **9**B. The linear position encoder is attached to the back of the tool drive motor. In certain embodiments, the surgical device comprises a rotary relative position encoder having a fan with a plurality of equally spaced blades operationally coupled to the dependant motor. As the dependant motor spins, these blades break a beam between an infrared sensor and receiver, thereby counting rotations of the motor.

Again, according to certain additional implementations, the surgical device has a linear encoder **500**, as depicted in FIG. **13**A-D. In these implementations, the LED emitter **522** is a PCB further comprising an array of LEDs. In these implementations, the receiver array **520** is also a PCB, and further comprises a linear array of light sensitive pixels. In certain implementations, the receiver array **520** comprises a COTS integrated circuit. In such exemplary embodiments, each element of output of the linear array **522** is continuously sampled by the receiver array **520** and the voltage level is recorded. By way of example, in these implementations, the voltage level is directly proportional to the amount of light collected by the pixel during the last sample period, such that increases in receive light correlates to increases in voltage, so as to communicate feedback concerning the absolute position of the surgical device and end effector.

In the exemplary embodiments of the linear encoder **500** depicted in FIGS. **13**A-**13**D, the receiver array **520** and the LED emitter **522** are supported by a support piece **524** with at least one window (one labeled **526**, others not shown), and a slit **528**. According to one embodiment, the support piece **524** is made of machined delrin. The window **526** or windows allow light to pass from the LED emitter **522** to the receiver **520**. The support piece **524** can accommodate a leadscrew **530**. In certain implementations, the leadscrew **530** further comprises a slotted extrusion **532** which translates linearly to the slit **528**. A gap in the extrusion **532** allows light to pass from the LED emitter **522** to the receiver **520**. As the leadscrew **530** translates, the slot in extrusion **532** moves correspondingly, thereby casting a shadow on the receiver everywhere except in the location of the slot. In this way, absolute position of the leadscrew **530** is determined.

In certain implementations, a second extrusion **552** slides in a slot **550** in the second support piece **540**. This slot **550** has a tighter fit than between the slotted extrusion **532** and slot **528**. In this way the second support piece **540** can act as the rotational constraint for the leadscrew **530**. In this implementation, the second extrusion **552** causes friction (or "rubs") against the second support piece **540** and slot **550**. Conversely, the slotted extrusion **532** does not rub in slot **528**. This implementation prevents material build up, deformation, or other deterioration of the sensor unit.

Thus, certain embodiments of the present invention provide redundant position sensing. For example, each forearm may have a relative position sensor. In these embodiments, each forearm also may further comprise an absolute position encoder. As would be apparent to those of skill in the art, the coupling of the absolute and relative position sensing allows for both homing of the device and the addition of safety features.

While multiple embodiments are disclosed, still other embodiments of the present invention will become apparent to those skilled in the art from the following detailed description, which shows and describes illustrative embodiments of the invention. As will be realized, the invention is capable of modifications in various obvious aspects, all without departing from the spirit and scope of the present invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not restrictive.

Although the present invention has been described with reference to preferred embodiments, persons skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

What is claimed is:

1. A robotic device, comprising:

a. a connector comprising:
  i. a first coupleable body comprising at least one first connector motor;
  ii. a second coupleable body comprising at least one second connector motor; and
  iii. a lumen defined within the connector and sized to accept a laparoscopic imaging device;

b. a first segmented robotic arm in operational communication with the first coupleable body and first connector motor, the first segmented robotic arm comprising:
  i. a first upper arm in operable and rotational communication with the first coupleable body, the first upper arm comprising a first upper arm housing containing:
    A. a plurality of first upper arm motors; and
    B. a first upper arm motor control board;
  ii. a first forearm in operable and rotational communication with the first upper arm, the first forearm having a first forearm housing containing:
    A. a plurality of first forearm motors;
    B. a first forearm motor control board; and
    C. a first end effector housing defined in the first forearm housing;

c. a second segmented robotic arm in operational communication with the second coupleable body and second connector motor, the second segmented robotic arm comprising:
  i. a second upper arm in operable and rotational communication with the second coupleable body, the second upper arm comprising a second upper arm housing containing:
    A. a plurality of second upper arm motors; and
    B. a second upper arm motor control board;
  ii. a second forearm in operable and rotational communication with the second upper arm, the second forearm having a second forearm housing containing:
    A. a plurality of second forearm motors;
    B. a second forearm motor control board; and
    C. a second end effector housing defined in the second forearm housing;

d. a first end effector in operational communication with the first segmented robotic arm via the first end effector housing; and

e. a second end effector in operational communication with the second segmented robotic arm via the second end effector housing,

wherein:
  i. the first coupleable body further comprises a notch;
  ii. the second coupleable body further comprises a projection; and
  iii. the notch and the projection are designed to be operationally communicable.

2. The surgical device of claim **1**, further comprising an LED array disposed within the first forearm housing.

3. The surgical device of claim **1**, further comprising an absolute position sensor disposed within the first forearm housing.

4. A modular surgical device comprising:

a. a connector comprising:
  i. a first coupleable body enclosing at least one motor control board;

ii. a second coupleable body;

iii. two or more connector motors disposed within the first or second coupleable body and in operational communication with the at least one motor control board;

iv. a lumen defined within the connector and sized to accept a laparoscopic imaging device,

wherein the first coupleable body is constructed and arranged to be coupled to the second coupleable body;

b. a first segmented robotic arm in operational communication with at least one of the two or more connector motors, the first segmented robotic arm comprising:

i. a first upper arm comprising a first upper arm housing containing:

A. a plurality of first upper arm motors; and

B. a first upper arm motor control board;

ii. a first forearm in operable and rotational communication with the first upper arm, the first forearm having a first forearm housing containing:

A. a plurality of first forearm motors;

B. a first forearm motor control board; and

C. a first end effector housing defined in the first forearm housing;

c. a second segmented robotic arm in operational communication with at least one of the two or more connector motors, the second segmented robotic arm comprising:

i. a second upper arm comprising a second upper arm housing containing:

A. a plurality of second upper arm motors; and

B. a second upper arm motor control board;

ii. a second forearm in operable and rotational communication with the second upper arm, the second forearm having a second forearm housing containing:

A. a plurality of second forearm motors;

B. a second forearm motor control board; and

C. a second end effector housing defined in the second forearm housing;

d. a first end effector in operational communication with the first segmented robotic arm via the first end effector housing;

e. a second end effector in operational communication with the second segmented robotic arm via the second end effector housing; and

f. first and second connection lines, one for each segmented robotic arm,

thereby allowing for independent operation of the segmented robotic arms.

5. The surgical device of claim **4**, further comprising at least one irrigation line.

6. The surgical device of claim **4**, wherein the connector comprises a first coupling body and a second coupling body.

7. The surgical device of claim **6**, wherein the first coupleable body and second coupleable body are mateable to form a single body.

8. The surgical device of claim **7**, wherein the first coupleable body comprises a first mating feature and the second coupleable body comprises a second mating feature.

9. The surgical device of claim **8**, wherein the first mating feature is a notch and the second mating feature is a projection.

10. A modular surgical device comprising:

a. a connector comprising:

i. a first body portion comprising at least one motor control board in electrical communication with two or more connector motors disposed within the first body portion;

ii. a second body portion; and

iii. a lumen defined within the connector and sized to accept a laparoscopic imaging device,

wherein the first body portion is constructed and arranged to be coupled to the second body portion;

b. a first segmented robotic arm in operational communication with at least one of the two or more connector motors, the first segmented robotic arm comprising:

i. a first upper arm comprising a first upper arm housing containing:

A. a plurality of first upper arm motors; and

B. a first upper arm motor control board;

ii. a first forearm in operable and rotational communication with the first upper arm, the first forearm having a first forearm housing containing:

A. a plurality of first forearm motors;

B. a first forearm motor control board; and

C. a first end effector housing defined in the first forearm housing;

c. a second segmented robotic arm in operational communication with at least one of the two or more connector motors, the second segmented robotic arm comprising:

i. a second upper arm comprising a second upper arm housing containing:

A. a plurality of second upper arm motors; and

B. a second upper arm motor control board;

ii. a second forearm in operable and rotational communication with the second upper arm, the second forearm having a second forearm housing containing:

A. a plurality of second forearm motors;

B. a second forearm motor control board; and

C. a second end effector housing defined in the second forearm housing;

d. a first end effector in operational communication with the first segmented robotic arm via the first end effector housing; and

e. a second end effector in operational communication with the second segmented robotic arm via the second end effector housing,

wherein the first and second body portions and segmented robotic arms are constructed and arranged so as to operate independently in an uncoupled state.

11. The surgical device of claim **10**, wherein the first end effector is chosen from a group consisting of a grasping component, a cauterizing component, a suturing component, an imaging component, an irrigation component, a suction component, an operational arm component, a sensor component, and a lighting component.

12. The surgical device of claim **10**, wherein the second end effector is chosen from a group consisting of a grasping component, a cauterizing component, a suturing component, an imaging component, an irrigation component, a suction component, an operational arm component, a sensor component, and a lighting component.

13. The surgical device of claim **10**, wherein the robotic device further comprises at least one absolute position sensor.

14. The surgical device of claim **13**, wherein the at least one absolute position sensor is selected from the group consisting of a magnetic absolute position encoder and a linear encoder.

15. The surgical device of claim **10**, further comprising a pixel array and an LED array.

* * * * *

patsnap

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当前申请(专利权)人(译)	虚拟切口CORPORATION		
[标]发明人	WILSON JOHN SHASHO JEFF KUMAR NISHANT MAHIN MATT SANTORO CHRIS MUMM ERIK HERMAN JASON FARRITOR SHANE		
发明人	WILSON, JOHN SHASHO, JEFF KUMAR, NISHANT MAHIN, MATT SANTORO, CHRIS MUMM, ERIK HERMAN, JASON FARRITOR, SHANE		
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摘要(译)

本文公开的实施例涉及各种医疗设备部件，包括可以被结合到机器人和/或体内医疗设备中的部件。 某些实施例包括用于体内医疗程序的各种模块化医疗设备。