Office de la Propriété Intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2877690 A1 2014/01/03

(21) 2 877 690

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) A1

(86) **Date de dépôt PCT/PCT Filing Date:** 2013/06/14
(87) **Date publication PCT/PCT Publication Date:** 2014/01/03
(85) **Entrée phase nationale/National Entry:** 2014/12/22
(86) **N° demande PCT/PCT Application No.:** US 2013/045828
(87) **N° publication PCT/PCT Publication No.:** 2014/004120
(30) **Priorité/Priority:** 2012/06/29 (US13/538,711)

(51) **Cl.Int./Int.Cl.** ***A61B 17/32*** (2006.01),
A61B 17/29 (2006.01)

(71) **Demandeur/Applicant:**
ETHICON ENDO-SURGERY, INC., US

(72) **Inventeurs/Inventors:**
VAKHARIA, OMAR J., US;
MESSERLY, JEFFREY D., US;
STEFANCHIK, DAVID, US;
SMOLIK, STEVEN P., US

(74) **Agent:** NORTON ROSE FULBRIGHT CANADA LLP/S.E.N.C.R.L., S.R.L.

(54) **Titre : INSTRUMENTS CHIRURGICAUX A ULTRASONS AVEC ENSEMBLES MACHOIRES POSITIONNEES DISTALEMENT**
(54) **Title: ULTRASONIC SURGICAL INSTRUMENTS WITH DISTALLY POSITIONED JAW ASSEMBLIES**

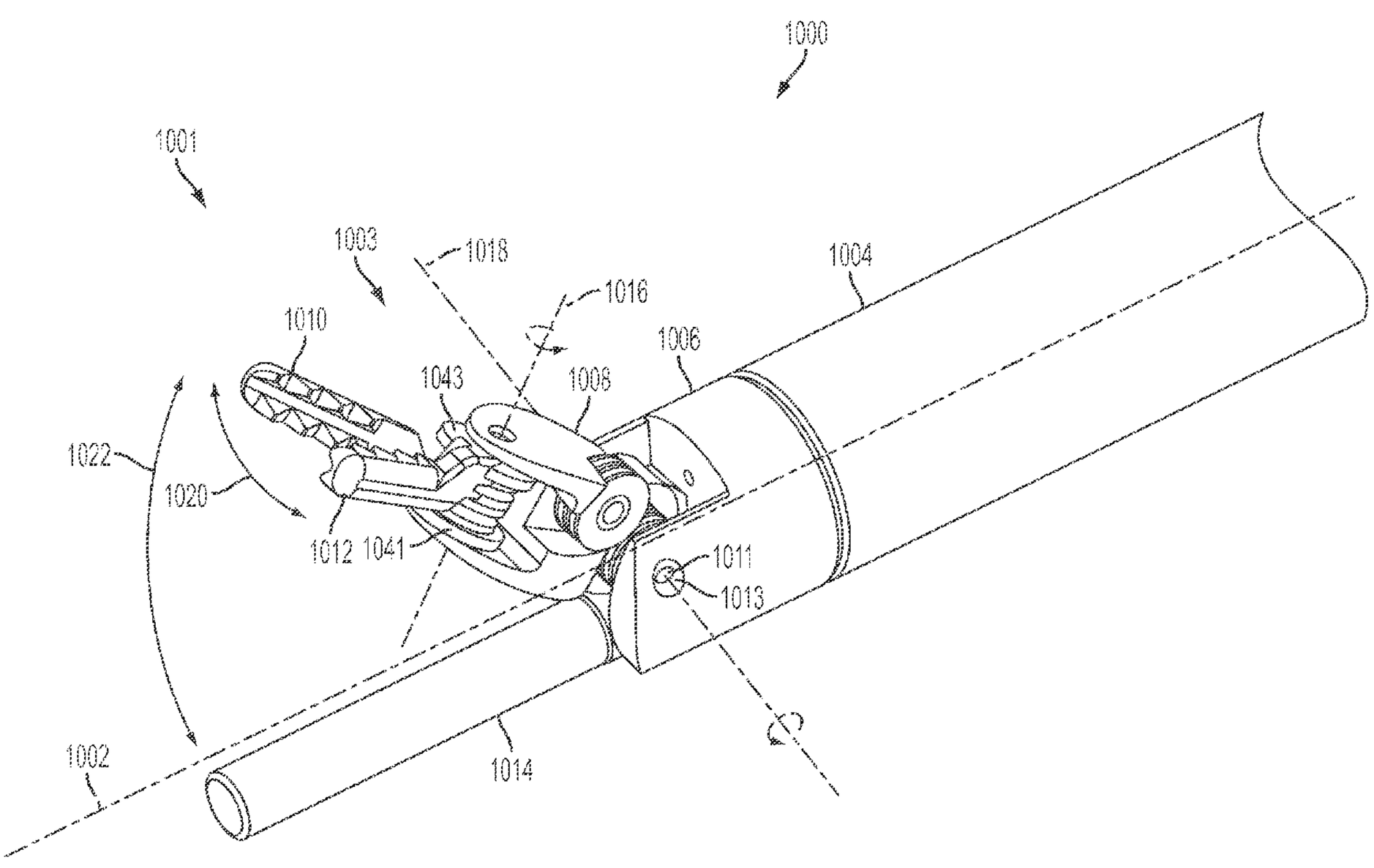

FIG. 37

(57) **Abrégé/Abstract:**
Various embodiments are directed to surgical instruments comprising an end effector, a shaft and a jaw assembly. The end effector may comprise an ultrasonic blade extending distally substantially parallel to a longitudinal axis. The shaft may extend proximally from the end effector along the longitudinal axis. The jaw assembly may comprise first and second jaw members. The jaw assembly may be pivotable about a first axis substantially perpendicular to the longitudinal axis from a first position where the first and second jaw members are substantially parallel to the ultrasonic blade to a second position. Additionally, the first and second jaw members may be pivotable about a second axis substantially perpendicular to the first axis.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
3 January 2014 (03.01.2014)

WIPO | PCT

(10) International Publication Number
WO 2014/004120 A1

(51) **International Patent Classification**:
A61B 17/32 (2006.01) *A61B 17/29* (2006.01)

(21) **International Application Number**:
PCT/US2013/045828

(22) **International Filing Date**:
14 June 2013 (14.06.2013)

(25) **Filing Language**: English

(26) **Publication Language**: English

(30) **Priority Data**:
13/538,711 29 June 2012 (29.06.2012) US

(71) **Applicant**: **ETHICON ENDO-SURGERY, INC.** [US/US]; 4545 Creek Road, #97, Cincinnati, Ohio 45242 (US).

(72) **Inventors**: **VAKHARIA, Omar J.**; 2036 Bershire Club Drive, Cincinnati, Ohio 45230 (US). **MESSERLY, Jeffrey D.**; 2181 Telegraph Court, Cincinnati, Ohio 45244 (US). **STEFANCHIK, David**; 5792 Cabernet Court, Morrow, Ohio 45152 (US). **SMOLIK, Steven P.**; 7588 Tepperwood Drive, West Chester, Ohio 45069 (US).

(74) **Agents**: **JOHNSON, Philip S.** et al.; Johnson & Johnson, One Johnson & Johnson Plaza, New Brunswick, New Jersey 08933 (US).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

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

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

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

(54) Title: ULTRASONIC SURGICAL INSTRUMENTS WITH DISTALLY POSITIONED JAW ASSEMBLIES

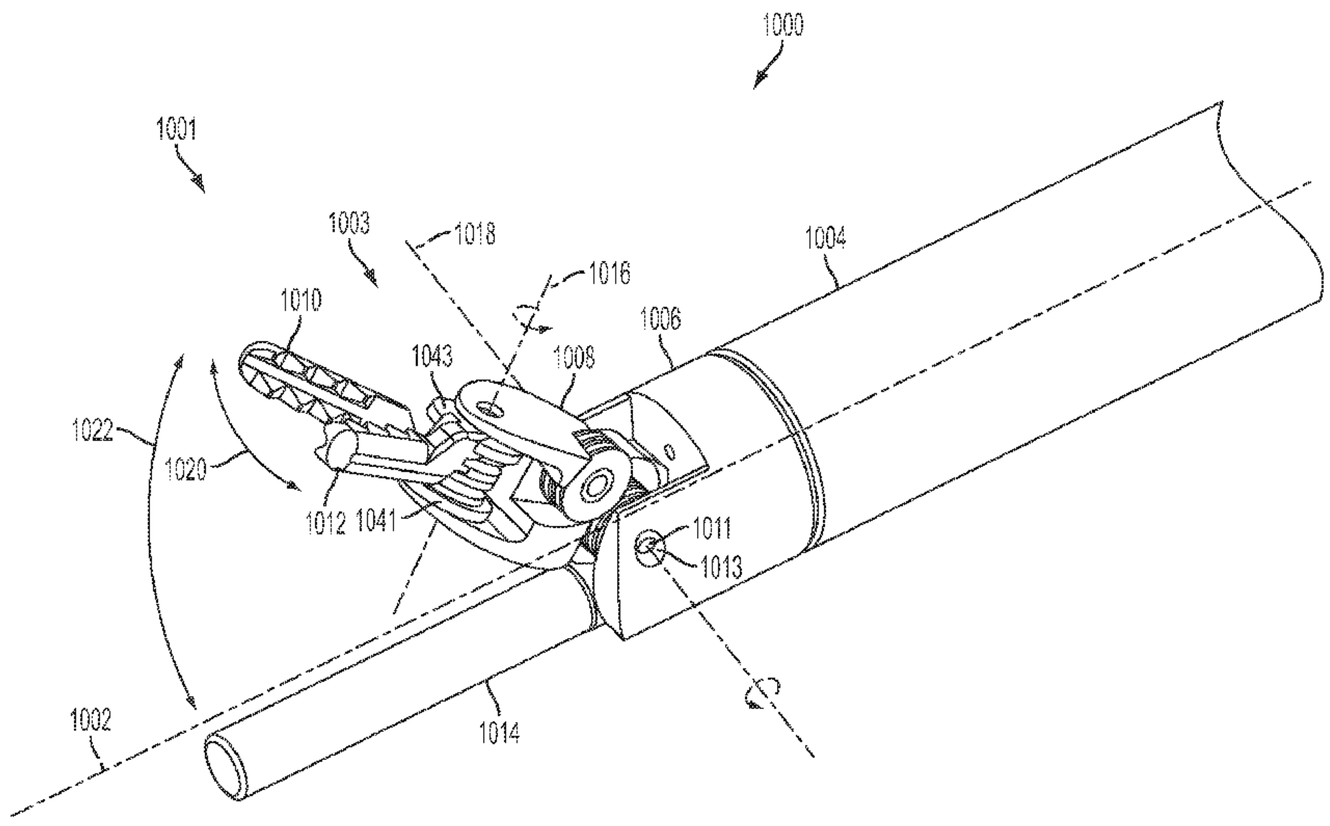

FIG. 37

(57) Abstract: Various embodiments are directed to surgical instruments comprising an end effector, a shaft and a jaw assembly. The end effector may comprise an ultrasonic blade extending distally substantially parallel to a longitudinal axis. The shaft may extend proximally from the end effector along the longitudinal axis. The jaw assembly may comprise first and second jaw members. The jaw assembly may be pivotable about a first axis substantially perpendicular to the longitudinal axis from a first position where the first and second jaw members are substantially parallel to the ultrasonic blade to a second position. Additionally, the first and second jaw members may be pivotable about a second axis substantially perpendicular to the first axis.

WO 2014/004120 A1

TITLE

ULTRASONIC SURGICAL INSTRUMENTS WITH DISTALLY POSITIONED JAW ASSEMBLIES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application is related to the following, concurrently-filed U.S. Patent Applications, which are incorporated herein by reference in their entirety:

[0002] U.S. Application Serial No. _____, entitled "Haptic Feedback Devices for Surgical Robot," Attorney Docket No. END7042USNP/110388;

[0003] U.S. Application Serial No. _____, entitled "Lockout Mechanism for Use with Robotic Electrosurgical Device," Attorney Docket No. END7043USNP/110389;

[0004] U.S. Application Serial No. _____, entitled "Closed Feedback Control for Electrosurgical Device," Attorney Docket No. END7044USNP/110390;

[0005] U.S. Application Serial No. _____, entitled "Surgical Instruments with Articulating Shafts," Attorney Docket No. END6423USNP/110392;

[0006] U.S. Application Serial No. _____, entitled "Ultrasonic Surgical Instruments with Distally Positioned Transducers," Attorney Docket No. END6819USNP/110393;

[0007] U.S. Application Serial No. _____, entitled "Surgical Instruments with Articulating Shafts," Attorney Docket No. END7047USNP/110394;

[0008] U.S. Application Serial No. _____, entitled "Surgical Instruments with Articulating Shafts," Attorney Docket No. END7049USNP/110396;

[0009] U.S. Application Serial No. _____, entitled "Ultrasonic Surgical Instruments with Control Mechanisms," Attorney Docket No. END7050USNP/110397; and

[0010] U.S. Application Serial No. _____, entitled "Surgical Instruments With Fluid Management System" Attorney Docket No. END7051USNP/110399.

BACKGROUND

[0011] Various embodiments are directed to surgical instruments including ultrasonic instruments distally positioned jaw assemblies.

[0012] Ultrasonic surgical devices, such as ultrasonic scalpels, are used in many applications in surgical procedures by virtue of their unique performance characteristics. Depending upon specific device configurations and operational parameters, ultrasonic surgical devices can provide substantially simultaneous transection of tissue and homeostasis by coagulation, desirably minimizing patient trauma. An ultrasonic surgical device comprises a proximally-positioned ultrasonic transducer and an instrument coupled to the ultrasonic transducer having a distally-mounted end effector comprising an ultrasonic blade to cut and seal tissue. The end effector is typically coupled either to a handle and/or a robotic surgical implement via a shaft. The blade is acoustically coupled to the transducer via a waveguide extending through the shaft. Ultrasonic surgical devices of this nature can be configured for open surgical use, laparoscopic, or endoscopic surgical procedures including robotic-assisted procedures.

[0013] Ultrasonic energy cuts and coagulates tissue using temperatures lower than those used in electrosurgical procedures. Vibrating at high frequencies (*e.g.*, 55,500 times per second), the ultrasonic blade denatures protein in the tissue to form a sticky coagulum. Pressure exerted on tissue by the blade surface collapses blood vessels and allows the coagulum to form a hemostatic seal. A surgeon can control the cutting speed and coagulation by the force applied to the tissue by the end effector, the time over which the force is applied and the selected excursion level of the end effector.

[0014] It is often desirable for clinicians to articulate a distal portion of the instrument shaft in order to direct the application of ultrasonic and/or RF energy. Such articulation is challenging and often limited in embodiments where an ultrasonic waveguide extends from a proximally-positioned transducer to the distally-positioned ultrasonic blade.

DRAWINGS

[0015] The features of the various embodiments are set forth with particularity in the appended claims. The various embodiments, however, both as to organization and methods of operation, together with advantages thereof, may best be understood by reference to the following description, taken in conjunction with the accompanying drawings as follows:

[0016] FIG. 1 illustrates one embodiment of a surgical system including a surgical instrument and an ultrasonic generator.

[0017] FIG. 2 illustrates one embodiment of the surgical instrument shown in FIG. 1.

[0018] FIG. 3 illustrates one embodiment of an ultrasonic end effector.

[0019] FIG. 4 illustrates another embodiment of an ultrasonic end effector.

[0020] FIG. 5 illustrates an exploded view of one embodiment of the surgical instrument shown in FIG. 1.

[0021] FIG. 6 illustrates a cut-away view of one embodiment of the surgical instrument shown in FIG. 1.

[0022] FIG. 7 illustrates various internal components of one embodiment of the surgical instrument shown in FIG. 1

[0023] FIG. 8 illustrates a top view of one embodiment of a surgical system including a surgical instrument and an ultrasonic generator.

[0024] FIG. 9 illustrates one embodiment of a rotation assembly included in one example embodiment of the surgical instrument of FIG. 1.

[0025] FIG. 10 illustrates one embodiment of a surgical system including a surgical instrument having a single element end effector.

[0026] FIG. 11 illustrates a block diagram of one embodiment of a robotic surgical system.

[0027] FIG. 12 illustrates one embodiment of a robotic arm cart.

[0028] FIG. 13 illustrates one embodiment of the robotic manipulator of the robotic arm cart of FIG. 12.

[0029] FIG. 14 illustrates one embodiment of a robotic arm cart having an alternative set-up joint structure.

[0030] FIG. 15 illustrates one embodiment of a controller that may be used in conjunction with a robotic arm cart, such as the robotic arm carts of FIGS. 11-14.

[0031] FIG. 16 illustrates one embodiment of an ultrasonic surgical instrument adapted for use with a robotic system.

FIG. 25 illustrates one embodiment of an electrosurgical instrument adapted for use with a robotic system.

[0032] FIG. 17 illustrates one embodiment of an instrument drive assembly that may be coupled to a surgical manipulators to receive and control the surgical instrument shown in FIG. 16.

[0033] FIG. 18 illustrates another view of the instrument drive assembly embodiment of FIG. 26 including the surgical instrument of FIG. 16.

[0034] FIGS. 19-21 illustrate additional views of the adapter portion of the instrument drive assembly embodiment of FIG. 26.

[0035] FIGS. 22-24 illustrate one embodiment of the instrument mounting portion of FIG. 16 showing components for translating motion of the driven elements into motion of the surgical instrument.

[0036] FIGS. 25-27 illustrate an alternate embodiment of the instrument mounting portion of FIG. 16 showing an alternate example mechanism for translating rotation of the driven elements into rotational motion about the axis of the shaft and an alternate example mechanism for generating reciprocating translation of one or more members along the axis of the shaft.

[0037] FIGS. 28-32 illustrate an alternate embodiment of the instrument mounting portion FIGS. 16 showing another alternate example mechanism for translating rotation of the driven elements into rotational motion about the axis of the shaft.

[0038] FIGS. 33-36A illustrate an alternate embodiment of the instrument mounting portion showing an alternate example mechanism for differential translation of members along the axis of the shaft (*e.g.*, for articulation).

[0039] FIGS. 36B-36C illustrate one embodiment of a tool mounting portion comprising internal power and energy sources.

[0040] FIGS. 37-38 illustrates one embodiment of a distal portion of a surgical instrument comprising a distally positioned jaw assembly.

[0041] FIG. 39 illustrates a head-on view of one embodiment of the distal portion of the surgical instrument of FIGS. 37-38.

[0042] FIGS. 40-41 illustrate one embodiment of the distal portion of the surgical instrument of FIGS. 37-38 coupled to an instrument mounting portion for use with a robotic surgical system.

[0043] FIGS. 42-44 illustrate one embodiment of the distal portion of the surgical instrument of FIGS. 37-38 showing additional control mechanisms.

[0044] FIG. 45A illustrates one embodiment of the instrument mounting portion showing an example mechanism for actuating various control lines of the surgical instrument of FIGS. 37-38.

[0045] FIG. 45B illustrates a side view of one embodiment of the routers.

[0046] FIGS. 46-47 illustrate one embodiment of the distal portion of the surgical instrument of FIGS. 37-38 with a retractable ultrasonic blade.

[0047] FIG. 48 illustrates one embodiment of the distal portion of the surgical instrument of FIGS. 37-38 coupled to an instrument mounting portion of a robotic surgical system configured to extend and retract the ultrasonic blade.

[0048] FIG. 49 illustrates an alternate embodiment of the distal portion of the surgical instrument of FIGS. 37-38 coupled to an instrument mounting portion of a robotic surgical system with an external transducer.

[0049] FIG. 50 illustrates an additional view of the distal portion of the surgical instrument of FIGS. 37-38 as illustrated in FIG. 49.

[0050] FIG. 51 illustrates one embodiment of the jaw assembly comprising a clamp pad.

[0051] FIGS. 52-56 illustrate one embodiment of a distal portion of a surgical instrument comprising a jaw assembly with a U-shaped jaw member.

DESCRIPTION

[0052] Various embodiments described herein are directed to surgical instruments comprising distally positioned, articulatable jaw assemblies. The jaw assemblies may be utilized in lieu of or in addition to shaft articulation. For example, the jaw assemblies may be utilized to grasp tissue and move it towards an ultrasonic blade, RF electrodes or other component for treating tissue.

[0053] According to one example embodiments, a surgical instrument may comprise an end effector with an ultrasonic blade extending distally therefrom. The jaw assembly may be articulatable and may pivot about at least two axes. A first axis, or wrist pivot axis, may be substantially perpendicular to a longitudinal axis of the instrument shaft. The jaw assembly may pivot about the wrist pivot axis from a first position where the jaw assembly is substantially parallel to the ultrasonic blade to a second position where the jaw assembly is not substantially parallel to the ultrasonic blade. In addition, the jaw assembly may comprise first and second jaw members that are pivotable about a second axis or jaw pivot axis. The jaw pivot axis may be substantially perpendicular to the wrist pivot axis. In some embodiments, the jaw pivot axis

itself may pivot as the jaw assembly pivots about the wrist pivot axis. The first and second jaw members may be pivotably relative to one another about the jaw pivot axis such that the first and second jaw members may "open" and "close." Additionally, in some embodiments, the first and second jaw members are also pivotable about the jaw pivot axis together such that the direction of the first and second jaw members may change.

[0054] In various embodiments, the jaw assembly is controlled by a series of lines and/or cables that extend proximally from the jaw assembly to a manual handle and/or instrument mounting portion of a robotic surgical system. First and second lines may control pivoting of the jaw assembly about the wrist pivot axis. A first line may be coupled to the jaw assembly at a position offset from the wrist pivot axis. A second line may be coupled to the jaw assembly at a second position offset from the wrist pivot axis and substantially opposite the first position. Differential translation of the first and second lines may cause pivoting of the jaw assembly about the wrist pivot axis. For example, proximal translation of one of the lines may cause the jaw assembly to pivot away from the longitudinal axis of the shaft towards the proximally translated line. In some embodiments, the jaw assembly may comprise a pulley positioned about the wrist pivot axis. The first and second lines may be first and second ends of a single line wrapped around the pulley.

[0055] The first and second jaw members may be similarly controlled. For example, in some embodiments, each jaw member is coupled to two control lines that extend proximally from the jaw assembly through the shaft to the manual handle and/or instrument mounting portion of the robotic surgical system. The control lines for each jaw member may be offset from one another about the jaw pivot axis such that proximal translation of one control line pivots the jaw about the jaw pivot axis in a first direction and proximal translation of the other control line pivots the jaw about the jaw pivot axis in a second direction opposite the first. In some embodiments the first and second jaw members comprise pulleys positioned about the jaw pivot axis and the first and second control lines for each jaw member are ends of a single control line wrapped around the respective pulleys. In some embodiments, the jaw members are separately controllable. For example, the jaw members may open and close about the jaw pivot axis and may additional pivot together about the jaw pivot axis.

[0056] Reference will now be made in detail to several embodiments, including embodiments showing example implementations of manual and robotic surgical instruments with

end effectors comprising ultrasonic and/or electrosurgical elements. Wherever practicable similar or like reference numbers may be used in the figures and may indicate similar or like functionality. The figures depict example embodiments of the disclosed surgical instruments and/or methods of use for purposes of illustration only. One skilled in the art will readily recognize from the following description that alternative example embodiments of the structures and methods illustrated herein may be employed without departing from the principles described herein.

[0057] FIG. 1 is a right side view of one embodiment of an ultrasonic surgical instrument 10. In the illustrated embodiment, the ultrasonic surgical instrument 10 may be employed in various surgical procedures including endoscopic or traditional open surgical procedures. In one example embodiment, the ultrasonic surgical instrument 10 comprises a handle assembly 12, an elongated shaft assembly 14, and an ultrasonic transducer 16. The handle assembly 12 comprises a trigger assembly 24, a distal rotation assembly 13, and a switch assembly 28. The elongated shaft assembly 14 comprises an end effector assembly 26, which comprises elements to dissect tissue or mutually grasp, cut, and coagulate vessels and/or tissue, and actuating elements to actuate the end effector assembly 26. The handle assembly 12 is adapted to receive the ultrasonic transducer 16 at the proximal end. The ultrasonic transducer 16 is mechanically engaged to the elongated shaft assembly 14 and portions of the end effector assembly 26. The ultrasonic transducer 16 is electrically coupled to a generator 20 via a cable 22. Although the majority of the drawings depict a multiple end effector assembly 26 for use in connection with laparoscopic surgical procedures, the ultrasonic surgical instrument 10 may be employed in more traditional open surgical procedures and in other embodiments, may be configured for use in endoscopic procedures. For the purposes herein, the ultrasonic surgical instrument 10 is described in terms of an endoscopic instrument; however, it is contemplated that an open and/or laparoscopic version of the ultrasonic surgical instrument 10 also may include the same or similar operating components and features as described herein.

[0058] In various embodiments, the generator 20 comprises several functional elements, such as modules and/or blocks. Different functional elements or modules may be configured for driving different kinds of surgical devices. For example, an ultrasonic generator module 21 may drive an ultrasonic device, such as the ultrasonic surgical instrument 10. In some example embodiments, the generator 20 also comprises an electrosurgery/RF generator module

23 for driving an electrosurgical device (or an electrosurgical embodiment of the ultrasonic surgical instrument 10). In the example embodiment illustrated in FIG. 1, the generator 20 includes a control system 25 integral with the generator 20, and a foot switch 29 connected to the generator via a cable 27. The generator 20 may also comprise a triggering mechanism for activating a surgical instrument, such as the instrument 10. The triggering mechanism may include a power switch (not shown) as well as a foot switch 29. When activated by the foot switch 29, the generator 20 may provide energy to drive the acoustic assembly of the surgical instrument 10 and to drive the end effector 18 at a predetermined excursion level. The generator 20 drives or excites the acoustic assembly at any suitable resonant frequency of the acoustic assembly and/or derives the therapeutic/sub-therapeutic electromagnetic/RF energy.

[0059] In one embodiment, the electrosurgical/RF generator module 23 may be implemented as an electrosurgery unit (ESU) capable of supplying power sufficient to perform bipolar electrosurgery using radio frequency (RF) energy. In one embodiment, the ESU can be a bipolar ERBE ICC 350 sold by ERBE USA, Inc. of Marietta, Ga. In bipolar electrosurgery applications, as previously discussed, a surgical instrument having an active electrode and a return electrode can be utilized, wherein the active electrode and the return electrode can be positioned against, or adjacent to, the tissue to be treated such that current can flow from the active electrode to the return electrode through the tissue. Accordingly, the electrosurgical/RF module 23 generator may be configured for therapeutic purposes by applying electrical energy to the tissue T sufficient for treating the tissue (e.g., cauterization). For example, in some embodiments, the active and/or return electrode may be positioned on the jaw assembly described herein.

[0060] In one embodiment, the electrosurgical/RF generator module 23 may be configured to deliver a subtherapeutic RF signal to implement a tissue impedance measurement module. In one embodiment, the electrosurgical/RF generator module 23 comprises a bipolar radio frequency generator as described in more detail below. In one embodiment, the electrosurgical/RF generator module 12 may be configured to monitor electrical impedance Z, of tissue T and to control the characteristics of time and power level based on the tissue T by way of a return electrode provided on a clamp member of the end effector assembly 26. Accordingly, the electrosurgical/RF generator module 23 may be configured for subtherapeutic purposes for measuring the impedance or other electrical characteristics of the tissue T. Techniques and

circuit configurations for measuring the impedance or other electrical characteristics of tissue T are discussed in more detail in commonly assigned U.S. Patent Publication No. 2011/0015631, titled "Electrosurgical Generator for Ultrasonic Surgical Instrument," the disclosure of which is herein incorporated by reference in its entirety.

[0061] A suitable ultrasonic generator module 21 may be configured to functionally operate in a manner similar to the GEN300 sold by Ethicon Endo-Surgery, Inc. of Cincinnati, Ohio as is disclosed in one or more of the following U.S. patents, all of which are incorporated by reference herein: U.S. Pat. No. 6,480,796 (Method for Improving the Start Up of an Ultrasonic System Under Zero Load Conditions); U.S. Pat. No. 6,537,291 (Method for Detecting Blade Breakage Using Rate and/or Impedance Information); U.S. Pat. No. 6,662,127 (Method for Detecting Presence of a Blade in an Ultrasonic System); U.S. Pat. No. 6,977,495 (Detection Circuitry for Surgical Handpiece System); U.S. Pat. No. 7,077,853 (Method for Calculating Transducer Capacitance to Determine Transducer Temperature); U.S. Pat. No. 7,179,271 (Method for Driving an Ultrasonic System to Improve Acquisition of Blade Resonance Frequency at Startup); and U.S. Pat. No. 7,273,483 (Apparatus and Method for Alerting Generator Function in an Ultrasonic Surgical System).

[0062] It will be appreciated that in various embodiments, the generator 20 may be configured to operate in several modes. In one mode, the generator 20 may be configured such that the ultrasonic generator module 21 and the electrosurgical/RF generator module 23 may be operated independently.

[0063] For example, the ultrasonic generator module 21 may be activated to apply ultrasonic energy to the end effector assembly 26 and subsequently, either therapeutic sub-therapeutic RF energy may be applied to the end effector assembly 26 by the electrosurgical/RF generator module 23. As previously discussed, the sub-therapeutic electrosurgical/RF energy may be applied to tissue clamped between claim elements of the end effector assembly 26 to measure tissue impedance to control the activation, or modify the activation, of the ultrasonic generator module 21. Tissue impedance feedback from the application of the sub-therapeutic energy also may be employed to activate a therapeutic level of the electrosurgical/RF generator module 23 to seal the tissue (e.g., vessel) clamped between claim elements of the end effector assembly 26.

[0064] In another embodiment, the ultrasonic generator module 21 and the electrosurgical/RF generator module 23 may be activated simultaneously. In one example, the ultrasonic generator module 21 is simultaneously activated with a sub-therapeutic RF energy level to measure tissue impedance simultaneously while the ultrasonic blade of the end effector assembly 26 cuts and coagulates the tissue (or vessel) clamped between the clamp elements of the end effector assembly 26. Such feedback may be employed, for example, to modify the drive output of the ultrasonic generator module 21. In another example, the ultrasonic generator module 21 may be driven simultaneously with electrosurgical/RF generator module 23 such that the ultrasonic blade portion of the end effector assembly 26 is employed for cutting the damaged tissue while the electrosurgical/RF energy is applied to electrode portions of the end effector clamp assembly 26 for sealing the tissue (or vessel).

[0065] When the generator 20 is activated via the triggering mechanism, electrical energy is continuously applied by the generator 20 to a transducer stack or assembly of the acoustic assembly. In another embodiment, electrical energy is intermittently applied (e.g., pulsed) by the generator 20. A phase-locked loop in the control system of the generator 20 may monitor feedback from the acoustic assembly. The phase lock loop adjusts the frequency of the electrical energy sent by the generator 20 to match the resonant frequency of the selected longitudinal mode of vibration of the acoustic assembly. In addition, a second feedback loop in the control system 25 maintains the electrical current supplied to the acoustic assembly at a pre-selected constant level in order to achieve substantially constant excursion at the end effector 18 of the acoustic assembly. In yet another embodiment, a third feedback loop in the control system 25 monitors impedance between electrodes located in the end effector assembly 26. Although FIGS. 1-9 show a manually operated ultrasonic surgical instrument, it will be appreciated that ultrasonic surgical instruments may also be used in robotic applications, for example, as described herein as well as combinations of manual and robotic applications.

[0066] In ultrasonic operation mode, the electrical signal supplied to the acoustic assembly may cause the distal end of the end effector 18, to vibrate longitudinally in the range of, for example, approximately 20 kHz to 250 kHz. According to various embodiments, the blade 22 may vibrate in the range of about 54 kHz to 56 kHz, for example, at about 55.5 kHz. In other embodiments, the blade 22 may vibrate at other frequencies including, for example, about 31 kHz or about 80 kHz. The excursion of the vibrations at the blade can be controlled by, for

example, controlling the amplitude of the electrical signal applied to the transducer assembly of the acoustic assembly by the generator 20. As noted above, the triggering mechanism of the generator 20 allows a user to activate the generator 20 so that electrical energy may be continuously or intermittently supplied to the acoustic assembly. The generator 20 also has a power line for insertion in an electro-surgical unit or conventional electrical outlet. It is contemplated that the generator 20 can also be powered by a direct current (DC) source, such as a battery. The generator 20 can comprise any suitable generator, such as Model No. GEN04, and/or Model No. GEN11 available from Ethicon Endo-Surgery, Inc.

[0067] FIG. 2 is a left perspective view of one example embodiment of the ultrasonic surgical instrument 10 showing the handle assembly 12, the distal rotation assembly 13, the elongated shaft assembly 14, and the end effector assembly 26. In the illustrated embodiment the elongated shaft assembly 14 comprises a distal end 52 dimensioned to mechanically engage the end effector assembly 26 and a proximal end 50 that mechanically engages the handle assembly 12 and the distal rotation assembly 13. The proximal end 50 of the elongated shaft assembly 14 is received within the handle assembly 12 and the distal rotation assembly 13. More details relating to the connections between the elongated shaft assembly 14, the handle assembly 12, and the distal rotation assembly 13 are provided in the description of FIGS. 5 and 7.

[0068] In the illustrated embodiment, the trigger assembly 24 comprises a trigger 32 that operates in conjunction with a fixed handle 34. The fixed handle 34 and the trigger 32 are ergonomically formed and adapted to interface comfortably with the user. The fixed handle 34 is integrally associated with the handle assembly 12. The trigger 32 is pivotally movable relative to the fixed handle 34 as explained in more detail below with respect to the operation of the ultrasonic surgical instrument 10. The trigger 32 is pivotally movable in direction 33A toward the fixed handle 34 when the user applies a squeezing force against the trigger 32. A spring element 98 (FIG. 5) causes the trigger 32 to pivotally move in direction 33B when the user releases the squeezing force against the trigger 32.

[0069] In one example embodiment, the trigger 32 comprises an elongated trigger hook 36, which defines an aperture 38 between the elongated trigger hook 36 and the trigger 32. The aperture 38 is suitably sized to receive one or multiple fingers of the user therethrough. The trigger 32 also may comprise a resilient portion 32a molded over the trigger 32 substrate. The

overmolded resilient portion 32a is formed to provide a more comfortable contact surface for control of the trigger 32 in outward direction 33B. In one example embodiment, the overmolded resilient portion 32a may be provided over a portion of the elongated trigger hook 36. The proximal surface of the elongated trigger hook 32 remains uncoated or coated with a non-resilient substrate to enable the user to easily slide their fingers in and out of the aperture 38. In another embodiment, the geometry of the trigger forms a fully closed loop which defines an aperture suitably sized to receive one or multiple fingers of the user therethrough. The fully closed loop trigger also may comprise a resilient portion molded over the trigger substrate.

[0070] In one example embodiment, the fixed handle 34 comprises a proximal contact surface 40 and a grip anchor or saddle surface 42. The saddle surface 42 rests on the web where the thumb and the index finger are joined on the hand. The proximal contact surface 40 has a pistol grip contour that receives the palm of the hand in a normal pistol grip with no rings or apertures. The profile curve of the proximal contact surface 40 may be contoured to accommodate or receive the palm of the hand. A stabilization tail 44 is located towards a more proximal portion of the handle assembly 12. The stabilization tail 44 may be in contact with the uppermost web portion of the hand located between the thumb and the index finger to stabilize the handle assembly 12 and make the handle assembly 12 more controllable.

[0071] In one example embodiment, the switch assembly 28 may comprise a toggle switch 30. The toggle switch 30 may be implemented as a single component with a central pivot 304 located within inside the handle assembly 12 to eliminate the possibility of simultaneous activation. In one example embodiment, the toggle switch 30 comprises a first projecting knob 30a and a second projecting knob 30b to set the power setting of the ultrasonic transducer 16 between a minimum power level (*e.g.*, MIN) and a maximum power level (*e.g.*, MAX). In another embodiment, the rocker switch may pivot between a standard setting and a special setting. The special setting may allow one or more special programs to be implemented by the device. The toggle switch 30 rotates about the central pivot as the first projecting knob 30a and the second projecting knob 30b are actuated. The one or more projecting knobs 30a, 30b are coupled to one or more arms that move through a small arc and cause electrical contacts to close or open an electric circuit to electrically energize or de-energize the ultrasonic transducer 16 in accordance with the activation of the first or second projecting knobs 30a, 30b. The toggle switch 30 is coupled to the generator 20 to control the activation of the ultrasonic transducer 16.

The toggle switch 30 comprises one or more electrical power setting switches to activate the ultrasonic transducer 16 to set one or more power settings for the ultrasonic transducer 16. The forces required to activate the toggle switch 30 are directed substantially toward the saddle point 42, thus avoiding any tendency of the instrument to rotate in the hand when the toggle switch 30 is activated.

[0072] In one example embodiment, the first and second projecting knobs 30a, 30b are located on the distal end of the handle assembly 12 such that they can be easily accessible by the user to activate the power with minimal, or substantially no, repositioning of the hand grip, making it suitable to maintain control and keep attention focused on the surgical site (*e.g.*, a monitor in a laparoscopic procedure) while activating the toggle switch 30. The projecting knobs 30a, 30b may be configured to wrap around the side of the handle assembly 12 to some extent to be more easily accessible by variable finger lengths and to allow greater freedom of access to activation in awkward positions or for shorter fingers.

[0073] In the illustrated embodiment, the first projecting knob 30a comprises a plurality of tactile elements 30c, *e.g.*, textured projections or "bumps" in the illustrated embodiment, to allow the user to differentiate the first projecting knob 30a from the second projecting knob 30b. It will be appreciated by those skilled in the art that several ergonomic features may be incorporated into the handle assembly 12. Such ergonomic features are described in U.S. Pat. App. Pub. No. 2009/0105750 entitled "Ergonomic Surgical Instruments" which is incorporated by reference herein in its entirety.

[0074] In one example embodiment, the toggle switch 30 may be operated by the hand of the user. The user may easily access the first and second projecting knobs 30a, 30b at any point while also avoiding inadvertent or unintentional activation at any time. The toggle switch 30 may readily operated with a finger to control the power to the ultrasonic assembly 16 and/or to the ultrasonic assembly 16. For example, the index finger may be employed to activate the first contact portion 30a to turn on the ultrasonic assembly 16 to a maximum (MAX) power level. The index finger may be employed to activate the second contact portion 30b to turn on the ultrasonic assembly 16 to a minimum (MIN) power level. In another embodiment, the rocker switch may pivot the instrument 10 between a standard setting and a special setting. The special setting may allow one or more special programs to be implemented by the instrument 10. The toggle switch 30 may be operated without the user having to look at the first or second projecting

knob 30a, 30b. For example, the first projecting knob 30a or the second projecting knob 30b may comprise a texture or projections to tactilely differentiate between the first and second projecting knobs 30a, 30b without looking.

[0075] In one example embodiment, the distal rotation assembly 13 is rotatable without limitation in either direction about a longitudinal axis "T." The distal rotation assembly 13 is mechanically engaged to the elongated shaft assembly 14. The distal rotation assembly 13 is located on a distal end of the handle assembly 12. The distal rotation assembly 13 comprises a cylindrical hub 46 and a rotation knob 48 formed over the hub 46. The hub 46 mechanically engages the elongated shaft assembly 14. The rotation knob 48 may comprise fluted polymeric features and may be engaged by a finger (*e.g.*, an index finger) to rotate the elongated shaft assembly 14. The hub 46 may comprise a material molded over the primary structure to form the rotation knob 48. The rotation knob 48 may be overmolded over the hub 46. The hub 46 comprises an end cap portion 46a that is exposed at the distal end. The end cap portion 46a of the hub 46 may contact the surface of a trocar during laparoscopic procedures. The hub 46 may be formed of a hard durable plastic such as polycarbonate to alleviate any friction that may occur between the end cap portion 46a and the trocar. The rotation knob 48 may comprise "scallops" or flutes formed of raised ribs 48a and concave portions 48b located between the ribs 48a to provide a more precise rotational grip. In one example embodiment, the rotation knob 48 may comprise a plurality of flutes (*e.g.*, three or more flutes). In other embodiments, any suitable number of flutes may be employed. The rotation knob 48 may be formed of a softer polymeric material overmolded onto the hard plastic material. For example, the rotation knob 48 may be formed of pliable, resilient, flexible polymeric materials including Versaflex® TPE alloys made by GLS Corporation, for example. This softer overmolded material may provide a greater grip and more precise control of the movement of the rotation knob 48. It will be appreciated that any materials that provide adequate resistance to sterilization, are biocompatible, and provide adequate frictional resistance to surgical gloves may be employed to form the rotation knob 48.

[0076] In one example embodiment, the handle assembly 12 is formed from two (2) housing portions or shrouds comprising a first portion 12a and a second portion 12b. From the perspective of a user viewing the handle assembly 12 from the distal end towards the proximal end, the first portion 12a is considered the right portion and the second portion 12b is considered the left portion. Each of the first and second portions 12a, 12b includes a plurality of interfaces

69 (FIG. 5) dimensioned to mechanically align and engage each another to form the handle assembly 12 and enclosing the internal working components thereof. The fixed handle 34, which is integrally associated with the handle assembly 12, takes shape upon the assembly of the first and second portions 12a and 12b of the handle assembly 12. A plurality of additional interfaces (not shown) may be disposed at various points around the periphery of the first and second portions 12a and 12b of the handle assembly 12 for ultrasonic welding purposes, *e.g.*, energy direction/deflection points. The first and second portions 12a and 12b (as well as the other components described below) may be assembled together in any fashion known in the art. For example, alignment pins, snap-like interfaces, tongue and groove interfaces, locking tabs, adhesive ports, may all be utilized either alone or in combination for assembly purposes.

[0077] In one example embodiment, the elongated shaft assembly 14 comprises a proximal end 50 adapted to mechanically engage the handle assembly 12 and the distal rotation assembly 13; and a distal end 52 adapted to mechanically engage the end effector assembly 26. The elongated shaft assembly 14 comprises an outer tubular sheath 56 and a reciprocating tubular actuating member 58 located within the outer tubular sheath 56. The proximal end of the tubular reciprocating tubular actuating member 58 is mechanically engaged to the trigger 32 of the handle assembly 12 to move in either direction 60A or 60B in response to the actuation and/or release of the trigger 32. The pivotably moveable trigger 32 may generate reciprocating motion along the longitudinal axis "T." Such motion may be used, for example, to actuate the jaws or clamping mechanism of the end effector assembly 26. A series of linkages translate the pivotal rotation of the trigger 32 to axial movement of a yoke coupled to an actuation mechanism, which controls the opening and closing of the jaws of the clamping mechanism of the end effector assembly 26. The distal end of the tubular reciprocating tubular actuating member 58 is mechanically engaged to the end effector assembly 26. In the illustrated embodiment, the distal end of the tubular reciprocating tubular actuating member 58 is mechanically engaged to a clamp arm assembly 64, which is pivotable about a pivot point 70, to open and close the clamp arm assembly 64 in response to the actuation and/or release of the trigger 32. For example, in the illustrated embodiment, the clamp arm assembly 64 is movable in direction 62A from an open position to a closed position about a pivot point 70 when the trigger 32 is squeezed in direction 33A. The clamp arm assembly 64 is movable in direction 62B

from a closed position to an open position about the pivot point 70 when the trigger 32 is released or outwardly contacted in direction 33B.

[0078] In one example embodiment, the end effector assembly 26 is attached at the distal end 52 of the elongated shaft assembly 14 and includes a clamp arm assembly 64 and a blade 66. The jaws of the clamping mechanism of the end effector assembly 26 are formed by clamp arm assembly 64 and the blade 66. The blade 66 is ultrasonically actuatable and is acoustically coupled to the ultrasonic transducer 16. The trigger 32 on the handle assembly 12 is ultimately connected to a drive assembly, which together, mechanically cooperate to effect movement of the clamp arm assembly 64. Squeezing the trigger 32 in direction 33A moves the clamp arm assembly 64 in direction 62A from an open position, wherein the clamp arm assembly 64 and the blade 66 are disposed in a spaced relation relative to one another, to a clamped or closed position, wherein the clamp arm assembly 64 and the blade 66 cooperate to grasp tissue therebetween. The clamp arm assembly 64 may comprise a clamp pad 69 to engage tissue between the blade 66 and the clamp arm 64. Releasing the trigger 32 in direction 33B moves the clamp arm assembly 64 in direction 62B from a closed relationship, to an open position, wherein the clamp arm assembly 64 and the blade 66 are disposed in a spaced relation relative to one another.

[0079] The proximal portion of the handle assembly 12 comprises a proximal opening 68 to receive the distal end of the ultrasonic assembly 16. The ultrasonic assembly 16 is inserted in the proximal opening 68 and is mechanically engaged to the elongated shaft assembly 14.

[0080] In one example embodiment, the elongated trigger hook 36 portion of the trigger 32 provides a longer trigger lever with a shorter span and rotation travel. The longer lever of the elongated trigger hook 36 allows the user to employ multiple fingers within the aperture 38 to operate the elongated trigger hook 36 and cause the trigger 32 to pivot in direction 33B to open the jaws of the end effector assembly 26. For example, the user may insert three fingers (*e.g.*, the middle, ring, and little fingers) in the aperture 38. Multiple fingers allows the surgeon to exert higher input forces on the trigger 32 and the elongated trigger hook326 to activate the end effector assembly 26. The shorter span and rotation travel creates a more comfortable grip when closing or squeezing the trigger 32 in direction 33A or when opening the trigger 32 in the outward opening motion in direction 33B lessening the need to extend the fingers further outward. This substantially lessens hand fatigue and strain associated with the outward opening

motion of the trigger 32 in direction 33B. The outward opening motion of the trigger may be spring-assisted by spring element 98 (FIG. 5) to help alleviate fatigue. The opening spring force is sufficient to assist the ease of opening, but not strong enough to adversely impact the tactile feedback of tissue tension during spreading dissection.

[0081] For example, during a surgical procedure either the index finger may be used to control the rotation of the elongated shaft assembly 14 to locate the jaws of the end effector assembly 26 in a suitable orientation. The middle and/or the other lower fingers may be used to squeeze the trigger 32 and grasp tissue within the jaws. Once the jaws are located in the desired position and the jaws are clamped against the tissue, the index finger can be used to activate the toggle switch 30 to adjust the power level of the ultrasonic transducer 16 to treat the tissue. Once the tissue has been treated, the user the may release the trigger 32 by pushing outwardly in the distal direction against the elongated trigger hook 36 with the middle and/or lower fingers to open the jaws of the end effector assembly 26. This basic procedure may be performed without the user having to adjust their grip of the handle assembly 12.

[0082] FIGS. 3-4 illustrate the connection of the elongated shaft assembly 14 relative to the end effector assembly 26. As previously described, in the illustrated embodiment, the end effector assembly 26 comprises a clamp arm assembly 64 and a blade 66 to form the jaws of the clamping mechanism. The blade 66 may be an ultrasonically actuatable blade acoustically coupled to the ultrasonic transducer 16. The trigger 32 is mechanically connected to a drive assembly. Together, the trigger 32 and the drive assembly mechanically cooperate to move the clamp arm assembly 64 to an open position in direction 62A wherein the clamp arm assembly 64 and the blade 66 are disposed in spaced relation relative to one another, to a clamped or closed position in direction 62B wherein the clamp arm assembly 64 and the blade 66 cooperate to grasp tissue therebetween. The clamp arm assembly 64 may comprise a clamp pad 69 to engage tissue between the blade 66 and the clamp arm 64. The distal end of the tubular reciprocating tubular actuating member 58 is mechanically engaged to the end effector assembly 26. In the illustrated embodiment, the distal end of the tubular reciprocating tubular actuating member 58 is mechanically engaged to the clamp arm assembly 64, which is pivotable about the pivot point 70, to open and close the clamp arm assembly 64 in response to the actuation and/or release of the trigger 32. For example, in the illustrated embodiment, the clamp arm assembly 64 is movable from an open position to a closed position in direction 62B about a pivot point 70 when

the trigger 32 is squeezed in direction 33A. The clamp arm assembly 64 is movable from a closed position to an open position in direction 62A about the pivot point 70 when the trigger 32 is released or outwardly contacted in direction 33B.

[0083] As previously discussed, the clamp arm assembly 64 may comprise electrodes electrically coupled to the electrosurgical/RF generator module 23 to receive therapeutic and/or sub-therapeutic energy, where the electrosurgical/RF energy may be applied to the electrodes either simultaneously or non simultaneously with the ultrasonic energy being applied to the blade 66. Such energy activations may be applied in any suitable combinations to achieve a desired tissue effect in cooperation with an algorithm or other control logic.

[0084] FIG. 5 is an exploded view of the ultrasonic surgical instrument 10 shown in FIG. 2. In the illustrated embodiment, the exploded view shows the internal elements of the handle assembly 12, the handle assembly 12, the distal rotation assembly 13, the switch assembly 28, and the elongated shaft assembly 14. In the illustrated embodiment, the first and second portions 12a, 12b mate to form the handle assembly 12. The first and second portions 12a, 12b each comprises a plurality of interfaces 69 dimensioned to mechanically align and engage one another to form the handle assembly 12 and enclose the internal working components of the ultrasonic surgical instrument 10. The rotation knob 48 is mechanically engaged to the outer tubular sheath 56 so that it may be rotated in circular direction 54 up to 360°. The outer tubular sheath 56 is located over the reciprocating tubular actuating member 58, which is mechanically engaged to and retained within the handle assembly 12 via a plurality of coupling elements 72. The coupling elements 72 may comprise an O-ring 72a, a tube collar cap 72b, a distal washer 72c, a proximal washer 72d, and a thread tube collar 72e. The reciprocating tubular actuating member 58 is located within a reciprocating yoke 84, which is retained between the first and second portions 12a, 12b of the handle assembly 12. The yoke 84 is part of a reciprocating yoke assembly 88. A series of linkages translate the pivotal rotation of the elongated trigger hook 32 to the axial movement of the reciprocating yoke 84, which controls the opening and closing of the jaws of the clamping mechanism of the end effector assembly 26 at the distal end of the ultrasonic surgical instrument 10. In one example embodiment, a four-link design provides mechanical advantage in a relatively short rotation span, for example.

[0085] In one example embodiment, an ultrasonic transmission waveguide 78 is disposed inside the reciprocating tubular actuating member 58. The distal end 52 of the

ultrasonic transmission waveguide 78 is acoustically coupled (*e.g.*, directly or indirectly mechanically coupled) to the blade 66 and the proximal end 50 of the ultrasonic transmission waveguide 78 is received within the handle assembly 12. The proximal end 50 of the ultrasonic transmission waveguide 78 is adapted to acoustically couple to the distal end of the ultrasonic transducer 16 as discussed in more detail below. The ultrasonic transmission waveguide 78 is isolated from the other elements of the elongated shaft assembly 14 by a protective sheath 80 and a plurality of isolation elements 82, such as silicone rings. The outer tubular sheath 56, the reciprocating tubular actuating member 58, and the ultrasonic transmission waveguide 78 are mechanically engaged by a pin 74. The switch assembly 28 comprises the toggle switch 30 and electrical elements 86a,b to electrically energize the ultrasonic transducer 16 in accordance with the activation of the first or second projecting knobs 30a, 30b.

[0086] In one example embodiment, the outer tubular sheath 56 isolates the user or the patient from the ultrasonic vibrations of the ultrasonic transmission waveguide 78. The outer tubular sheath 56 generally includes a hub 76. The outer tubular sheath 56 is threaded onto the distal end of the handle assembly 12. The ultrasonic transmission waveguide 78 extends through the opening of the outer tubular sheath 56 and the isolation elements 82 isolate the ultrasonic transmission waveguide 24 from the outer tubular sheath 56. The outer tubular sheath 56 may be attached to the waveguide 78 with the pin 74. The hole to receive the pin 74 in the waveguide 78 may occur nominally at a displacement node. The waveguide 78 may screw or snap into the hand piece handle assembly 12 by a stud. Flat portions on the hub 76 may allow the assembly to be torqued to a required level. In one example embodiment, the hub 76 portion of the outer tubular sheath 56 is preferably constructed from plastic and the tubular elongated portion of the outer tubular sheath 56 is fabricated from stainless steel. Alternatively, the ultrasonic transmission waveguide 78 may comprise polymeric material surrounding it to isolate it from outside contact.

[0087] In one example embodiment, the distal end of the ultrasonic transmission waveguide 78 may be coupled to the proximal end of the blade 66 by an internal threaded connection, preferably at or near an antinode. It is contemplated that the blade 66 may be attached to the ultrasonic transmission waveguide 78 by any suitable means, such as a welded joint or the like. Although the blade 66 may be detachable from the ultrasonic transmission

waveguide 78, it is also contemplated that the single element end effector (*e.g.*, the blade 66) and the ultrasonic transmission waveguide 78 may be formed as a single unitary piece.

[0088] In one example embodiment, the trigger 32 is coupled to a linkage mechanism to translate the rotational motion of the trigger 32 in directions 33A and 33B to the linear motion of the reciprocating tubular actuating member 58 in corresponding directions 60A and 60B. The trigger 32 comprises a first set of flanges 98 with openings formed therein to receive a first yoke pin 92a. The first yoke pin 92a is also located through a set of openings formed at the distal end of the yoke 84. The trigger 32 also comprises a second set of flanges 96 to receive a first end 92a of a link 92. A trigger pin 90 is received in openings formed in the link 92 and the second set of flanges 96. The trigger pin 90 is received in the openings formed in the link 92 and the second set of flanges 96 and is adapted to couple to the first and second portions 12a, 12b of the handle assembly 12 to form a trigger pivot point for the trigger 32. A second end 92b of the link 92 is received in a slot 384 formed in a proximal end of the yoke 84 and is retained therein by a second yoke pin 94b. As the trigger 32 is pivotally rotated about the pivot point 190 formed by the trigger pin 90, the yoke translates horizontally along longitudinal axis "T" in a direction indicated by arrows 60A,B.

[0089] FIG. 8 illustrates one example embodiment of an ultrasonic surgical instrument 10. In the illustrated embodiment, a cross-sectional view of the ultrasonic transducer 16 is shown within a partial cutaway view of the handle assembly 12. One example embodiment of the ultrasonic surgical instrument 10 comprises the ultrasonic signal generator 20 coupled to the ultrasonic transducer 16, comprising a hand piece housing 99, and an ultrasonically actuatable single or multiple element end effector assembly 26. As previously discussed, the end effector assembly 26 comprises the ultrasonically actuatable blade 66 and the clamp arm 64. The ultrasonic transducer 16, which is known as a "Langevin stack", generally includes a transduction portion 100, a first resonator portion or end-bell 102, and a second resonator portion or fore-bell 104, and ancillary components. The total construction of these components is a resonator. The ultrasonic transducer 16 is preferably an integral number of one-half system wavelengths ($n\lambda/2$; where "n" is any positive integer; *e.g.*, n = 1, 2, 3…) in length as will be described in more detail later. An acoustic assembly 106 includes the ultrasonic transducer 16, a nose cone 108, a velocity transformer 118, and a surface 110.

[0090] In one example embodiment, the distal end of the end-bell 102 is connected to the proximal end of the transduction portion 100, and the proximal end of the fore-bell 104 is connected to the distal end of the transduction portion 100. The fore-bell 104 and the end-bell 102 have a length determined by a number of variables, including the thickness of the transduction portion 100, the density and modulus of elasticity of the material used to manufacture the end-bell 102 and the fore-bell 22, and the resonant frequency of the ultrasonic transducer 16. The fore-bell 104 may be tapered inwardly from its proximal end to its distal end to amplify the ultrasonic vibration amplitude as the velocity transformer 118, or alternately may have no amplification. A suitable vibrational frequency range may be about 20Hz to 32kHz and a well-suited vibrational frequency range may be about 30-10kHz. A suitable operational vibrational frequency may be approximately 55.5kHz, for example.

[0091] In one example embodiment, the piezoelectric elements 112 may be fabricated from any suitable material, such as, for example, lead zirconate-titanate, lead meta-niobate, lead titanate, barium titanate, or other piezoelectric ceramic material. Each of positive electrodes 114, negative electrodes 116, and the piezoelectric elements 112 has a bore extending through the center. The positive and negative electrodes 114 and 116 are electrically coupled to wires 120 and 122, respectively. The wires 120 and 122 are encased within the cable 22 and electrically connectable to the ultrasonic signal generator 20.

[0092] The ultrasonic transducer 16 of the acoustic assembly 106 converts the electrical signal from the ultrasonic signal generator 20 into mechanical energy that results in primarily a standing acoustic wave of longitudinal vibratory motion of the ultrasonic transducer 16 and the blade 66 portion of the end effector assembly 26 at ultrasonic frequencies. In another embodiment, the vibratory motion of the ultrasonic transducer may act in a different direction. For example, the vibratory motion may comprise a local longitudinal component of a more complicated motion of the tip of the elongated shaft assembly 14. A suitable generator is available as model number GEN11, from Ethicon Endo-Surgery, Inc., Cincinnati, Ohio. When the acoustic assembly 106 is energized, a vibratory motion standing wave is generated through the acoustic assembly 106. The ultrasonic surgical instrument 10 is designed to operate at a resonance such that an acoustic standing wave pattern of predetermined amplitude is produced. The amplitude of the vibratory motion at any point along the acoustic assembly 106 depends upon the location along the acoustic assembly 106 at which the vibratory motion is measured. A

minimum or zero crossing in the vibratory motion standing wave is generally referred to as a node (*i.e.*, where motion is minimal), and a local absolute value maximum or peak in the standing wave is generally referred to as an anti-node (*e.g.*, where local motion is maximal). The distance between an anti-node and its nearest node is one-quarter wavelength ($\lambda/4$).

[0093] The wires 120 and 122 transmit an electrical signal from the ultrasonic signal generator 20 to the positive electrodes 114 and the negative electrodes 116. The piezoelectric elements 112 are energized by the electrical signal supplied from the ultrasonic signal generator 20 in response to an actuator 224, such as a foot switch, for example, to produce an acoustic standing wave in the acoustic assembly 106. The electrical signal causes disturbances in the piezoelectric elements 112 in the form of repeated small displacements resulting in large alternating compression and tension forces within the material. The repeated small displacements cause the piezoelectric elements 112 to expand and contract in a continuous manner along the axis of the voltage gradient, producing longitudinal waves of ultrasonic energy. The ultrasonic energy is transmitted through the acoustic assembly 106 to the blade 66 portion of the end effector assembly 26 via a transmission component or an ultrasonic transmission waveguide portion 78 of the elongated shaft assembly 14.

[0094] In one example embodiment, in order for the acoustic assembly 106 to deliver energy to the blade 66 portion of the end effector assembly 26, all components of the acoustic assembly 106 must be acoustically coupled to the blade 66. The distal end of the ultrasonic transducer 16 may be acoustically coupled at the surface 110 to the proximal end of the ultrasonic transmission waveguide 78 by a threaded connection such as a stud 124.

[0095] In one example embodiment, the components of the acoustic assembly 106 are preferably acoustically tuned such that the length of any assembly is an integral number of one-half wavelengths ($n\lambda/2$), where the wavelength λ is the wavelength of a pre-selected or operating longitudinal vibration drive frequency f_d of the acoustic assembly 106. It is also contemplated that the acoustic assembly 106 may incorporate any suitable arrangement of acoustic elements.

[0096] In one example embodiment, the blade 66 may have a length substantially equal to an integral multiple of one-half system wavelengths ($n\lambda/2$). A distal end of the blade 66 may be disposed near an antinode in order to provide the maximum longitudinal excursion of the distal end. When the transducer assembly is energized, the distal end of the blade 66 may be configured to move in the range of, for example, approximately 10 to 500 microns peak-to-peak,

and preferably in the range of about 30 to 64 microns at a predetermined vibrational frequency of 55kHz, for example.

[0097] In one example embodiment, the blade 66 may be coupled to the ultrasonic transmission waveguide 78. The blade 66 and the ultrasonic transmission waveguide 78 as illustrated are formed as a single unit construction from a material suitable for transmission of ultrasonic energy. Examples of such materials include Ti6Al4V (an alloy of Titanium including Aluminum and Vanadium), Aluminum, Stainless Steel, or other suitable materials. Alternately, the blade 66 may be separable (and of differing composition) from the ultrasonic transmission waveguide 78, and coupled by, for example, a stud, weld, glue, quick connect, or other suitable known methods. The length of the ultrasonic transmission waveguide 78 may be substantially equal to an integral number of one-half wavelengths ($n\lambda/2$), for example. The ultrasonic transmission waveguide 78 may be preferably fabricated from a solid core shaft constructed out of material suitable to propagate ultrasonic energy efficiently, such as the titanium alloy discussed above (*i.e.*, Ti6Al4V) or any suitable aluminum alloy, or other alloys, for example.

[0098] In one example embodiment, the ultrasonic transmission waveguide 78 comprises a longitudinally projecting attachment post at a proximal end to couple to the surface 110 of the ultrasonic transmission waveguide 78 by a threaded connection such as the stud 124. The ultrasonic transmission waveguide 78 may include a plurality of stabilizing silicone rings or compliant supports 82 (FIG. 5) positioned at a plurality of nodes. The silicone rings 82 dampen undesirable vibration and isolate the ultrasonic energy from an outer protective sheath 80 (FIG. 5) assuring the flow of ultrasonic energy in a longitudinal direction to the distal end of the blade 66 with maximum efficiency.

[0099] FIG. 9 illustrates one example embodiment of the proximal rotation assembly 128. In the illustrated embodiment, the proximal rotation assembly 128 comprises the proximal rotation knob 134 inserted over the cylindrical hub 135. The proximal rotation knob 134 comprises a plurality of radial projections 138 that are received in corresponding slots 130 formed on a proximal end of the cylindrical hub 135. The proximal rotation knob 134 defines an opening 142 to receive the distal end of the ultrasonic transducer 16. The radial projections 138 are formed of a soft polymeric material and define a diameter that is undersized relative to the outside diameter of the ultrasonic transducer 16 to create a friction interference fit when the distal end of the ultrasonic transducer 16. The polymeric radial projections 138 protrude radially

into the opening 142 to form "gripper" ribs that firmly grip the exterior housing of the ultrasonic transducer 16. Therefore, the proximal rotation knob 134 securely grips the ultrasonic transducer 16.

[0100] The distal end of the cylindrical hub 135 comprises a circumferential lip 132 and a circumferential bearing surface 140. The circumferential lip engages a groove formed in the housing 12 and the circumferential bearing surface 140 engages the housing 12. Thus, the cylindrical hub 135 is mechanically retained within the two housing portions (not shown) of the housing 12. The circumferential lip 132 of the cylindrical hub 135 is located or "trapped" between the first and second housing portions 12a, 12b and is free to rotate in place within the groove. The circumferential bearing surface 140 bears against interior portions of the housing to assist proper rotation. Thus, the cylindrical hub 135 is free to rotate in place within the housing. The user engages the flutes 136 formed on the proximal rotation knob 134 with either the finger or the thumb to rotate the cylindrical hub 135 within the housing 12.

[0101] In one example embodiment, the cylindrical hub 135 may be formed of a durable plastic such as polycarbonate. In one example embodiment, the cylindrical hub 135 may be formed of a siliconized polycarbonate material. In one example embodiment, the proximal rotation knob 134 may be formed of pliable, resilient, flexible polymeric materials including Versaflex® TPE alloys made by GLS Corporation, for example. The proximal rotation knob 134 may be formed of elastomeric materials, thermoplastic rubber known as Santoprene®, other thermoplastic vulcanizates (TPVs), or elastomers, for example. The embodiments, however, are not limited in this context.

[0102] FIG. 10 illustrates one example embodiment of a surgical system 200 including a surgical instrument 210 having single element end effector 278. The system 200 may include a transducer assembly 216 coupled to the end effector 278 and a sheath 256 positioned around the proximal portions of the end effector 278 as shown. The transducer assembly 216 and end effector 278 may operate in a manner similar to that of the transducer assembly 16 and end effector 18 described above to produce ultrasonic energy that may be transmitted to tissue via blade 226'

[0103] Over the years, a variety of minimally invasive robotic (or "telesurgical") systems have been developed to increase surgical dexterity as well as to permit a surgeon to operate on a patient in an intuitive manner. Robotic surgical systems can be used with many

different types of surgical instruments including, for example, ultrasonic instruments, as described herein. Example robotic systems include those manufactured by Intuitive Surgical, Inc., of Sunnyvale, California, U.S.A. Such systems, as well as robotic systems from other manufacturers, are disclosed in the following U.S. Patents which are each herein incorporated by reference in their respective entirety: U.S. Pat. No. 5,792,135, entitled "Articulated Surgical Instrument For Performing Minimally Invasive Surgery With Enhanced Dexterity and Sensitivity", U.S. Patent No. 6,231,565, entitled "Robotic Arm DLUs For Performing Surgical Tasks", U.S. Patent No. 6,783,524, entitled "Robotic Surgical Tool With Ultrasound Cauterizing and Cutting Instrument", U.S. Patent No. 6,364,888, entitled "Alignment of Master and Slave In a Minimally Invasive Surgical Apparatus", U.S. Patent No. 7,524,320, entitled "Mechanical Actuator Interface System For Robotic Surgical Tools", U.S. Patent No. 7,691,098, entitled Platform Link Wrist Mechanism", U.S. Patent No. 7,806,891, entitled "Repositioning and Reorientation of Master/Slave Relationship in Minimally Invasive Telesurgery", and U.S. Patent No. 7,824,401, entitled "Surgical Tool With Wristed Monopolar Electrosurgical End Effectors". Many of such systems, however, have in the past been unable to generate the magnitude of forces required to effectively cut and fasten tissue.

[0104] FIGS. 11-26 illustrate example embodiments of robotic surgical systems. In some embodiments, the disclosed robotic surgical systems may utilize the ultrasonic or electrosurgical instruments described herein. Those skilled in the art will appreciate that the illustrated robotic surgical systems are not limited to only those instruments described herein, and may utilize any compatible surgical instruments. Those skilled in the art will further appreciate that while various embodiments described herein may be used with the described robotic surgical systems, the disclosure is not so limited, and may be used with any compatible robotic surgical system.

[0105] FIGS. 11-16 illustrate the structure and operation of several example robotic surgical systems and components thereof. FIG. 11 shows a block diagram of an example robotic surgical system 1000. The system 1000 comprises at least one controller 508 and at least one arm cart 510. The arm cart 510 may be mechanically coupled to one or more robotic manipulators or arms, indicated by box 512. Each of the robotic arms 512 may comprise one or more surgical instruments 514 for performing various surgical tasks on a patient 504. Operation of the arm cart 510, including the arms 512 and instruments 514 may be directed by a clinician

502 from a controller 508. In some embodiments, a second controller 508′, operated by a second clinician 502′ may also direct operation of the arm cart 510 in conjunction with the first clinician 502′. For example, each of the clinicians 502, 502′ may control different arms 512 of the cart or, in some cases, complete control of the arm cart 510 may be passed between the clinicians 502, 502′. In some embodiments, additional arm carts (not shown) may be utilized on the patient 504. These additional arm carts may be controlled by one or more of the controllers 508, 508′. The arm cart(s) 510 and controllers 508, 508′ may be in communication with one another via a communications link 516, which may be any suitable type of wired or wireless communications link carrying any suitable type of signal (*e.g.*, electrical, optical, infrared, *etc.*) according to any suitable communications protocol. Example implementations of robotic surgical systems, such as the system 1000, are disclosed in U.S. Patent No. 7,524,320 which has been herein incorporated by reference. Thus, various details of such devices will not be described in detail herein beyond that which may be necessary to understand various embodiments of the claimed device.

[0106] FIG. 12 shows one example embodiment of a robotic arm cart 520. The robotic arm cart 520 is configured to actuate a plurality of surgical instruments or instruments, generally designated as 522 within a work envelope 519. Various robotic surgery systems and methods employing master controller and robotic arm cart arrangements are disclosed in U.S. Patent No. 6,132,368, entitled "Multi-Component Telepresence System and Method", the full disclosure of which is incorporated herein by reference. In various forms, the robotic arm cart 520 includes a base 524 from which, in the illustrated embodiment, three surgical instruments 522 are supported. In various forms, the surgical instruments 522 are each supported by a series of manually articulatable linkages, generally referred to as set-up joints 526, and a robotic manipulator 528. These structures are herein illustrated with protective covers extending over much of the robotic linkage. These protective covers may be optional, and may be limited in size or entirely eliminated in some embodiments to minimize the inertia that is encountered by the servo mechanisms used to manipulate such devices, to limit the volume of moving components so as to avoid collisions, and to limit the overall weight of the cart 520. Cart 520 will generally have dimensions suitable for transporting the cart 520 between operating rooms. The cart 520 may be configured to typically fit through standard operating room doors and onto standard hospital elevators. In various forms, the cart 520 would preferably have a weight and

include a wheel (or other transportation) system that allows the cart 520 to be positioned adjacent an operating table by a single attendant.

[0107] FIG. 13 shows one example embodiment of the robotic manipulator 528 of the robotic arm cart 520. In the example shown in FIG. 13, the robotic manipulators 528 may include a linkage 530 that constrains movement of the surgical instrument 522. In various embodiments, linkage 530 includes rigid links coupled together by rotational joints in a parallelogram arrangement so that the surgical instrument 522 rotates around a point in space 532, as more fully described in issued U.S. Pat. No. 5,817,084, the full disclosure of which is herein incorporated by reference. The parallelogram arrangement constrains rotation to pivoting about an axis 534a, sometimes called the pitch axis. The links supporting the parallelogram linkage are pivotally mounted to set-up joints 526 (FIG. 12) so that the surgical instrument 522 further rotates about an axis 534b, sometimes called the yaw axis. The pitch and yaw axes 534a, 534b intersect at the remote center 536, which is aligned along a shaft 538 of the surgical instrument 522. The surgical instrument 522 may have further degrees of driven freedom as supported by manipulator 540, including sliding motion of the surgical instrument 522 along the longitudinal instrument axis "LT-LT". As the surgical instrument 522 slides along the instrument axis LT-LT relative to manipulator 540 (arrow 534c), remote center 536 remains fixed relative to base 542 of manipulator 540. Hence, the entire manipulator 540 is generally moved to re-position remote center 536. Linkage 530 of manipulator 540 is driven by a series of motors 544. These motors 544 actively move linkage 530 in response to commands from a processor of a control system. As will be discussed in further detail below, motors 544 are also employed to manipulate the surgical instrument 522.

[0108] FIG. 14 shows one example embodiment of a robotic arm cart 520′ having an alternative set-up joint structure. In this example embodiment, a surgical instrument 522 is supported by an alternative manipulator structure 528' between two tissue manipulation instruments. Those of ordinary skill in the art will appreciate that various embodiments of the claimed device may incorporate a wide variety of alternative robotic structures, including those described in U.S. Pat. No. 5,878,193, the full disclosure of which is incorporated herein by reference. Additionally, while the data communication between a robotic component and the processor of the robotic surgical system is primarily described herein with reference to communication between the surgical instrument 522 and the controller, it should be understood

that similar communication may take place between circuitry of a manipulator, a set-up joint, an endoscope or other image capture device, or the like, and the processor of the robotic surgical system for component compatibility verification, component-type identification, component calibration (such as off-set or the like) communication, confirmation of coupling of the component to the robotic surgical system, or the like.

[0109] FIG. 15 shows one example embodiment of a controller 518 that may be used in conjunction with a robotic arm cart, such as the robotic arm carts 520, 520′ depicted in FIGS. 12-14. The controller 518 generally includes master controllers (generally represented as 519 in FIG. 15) which are grasped by the clinician and manipulated in space while the clinician views the procedure via a stereo display 521. A surgeon feed back meter 515 may be viewed via the display 521 and provide the surgeon with a visual indication of the amount of force being applied to the cutting instrument or dynamic clamping member. The master controllers 519 generally comprise manual input devices which preferably move with multiple degrees of freedom, and which often further have a handle or trigger for actuating instruments (for example, for closing grasping saws, applying an electrical potential to an electrode, or the like).

[0110] FIG. 16 shows one example embodiment of an ultrasonic surgical instrument 522 adapted for use with a robotic surgical system. For example, the surgical instrument 522 may be coupled to one of the surgical manipulators 528, 528′ described hereinabove. As can be seen in FIG. 16, the surgical instrument 522 comprises a surgical end effector 548 that comprises an ultrasonic blade 550 and clamp arm 552, which may be coupled to an elongated shaft assembly 554 that, in some embodiments, may comprise an articulation joint 556. FIG. 17 shows one example embodiment of an instrument drive assembly 546 that may be coupled to one of the surgical manipulators 528, 528′ to receive and control the surgical instrument 522. The instrument drive assembly 546 may also be operatively coupled to the controller 518 to receive inputs from the clinician for controlling the instrument 522. For example, actuation (*e.g.*, opening and closing) of the clamp arm 552, actuation (*e.g.*, opening and closing) of the jaws 551A, 551B, actuation of the ultrasonic blade 550, extension of the knife 555 and actuation of the energy delivery surfaces 553A, 553B, *etc.* may be controlled through the instrument drive assembly 546 based on inputs from the clinician provided through the controller 518. The surgical instrument 522 is operably coupled to the manipulator by an instrument mounting portion, generally designated as 558. The surgical instruments 522 further include an interface

560 which mechanically and electrically couples the instrument mounting portion 558 to the manipulator.

[0111] FIG. 18 shows another view of the instrument drive assembly of FIG. 17 including the ultrasonic surgical instrument 522. The instrument mounting portion 558 includes an instrument mounting plate 562 that operably supports a plurality of (four are shown in FIG. 17) rotatable body portions, driven discs or elements 564, that each include a pair of pins 566 that extend from a surface of the driven element 564. One pin 566 is closer to an axis of rotation of each driven elements 564 than the other pin 566 on the same driven element 564, which helps to ensure positive angular alignment of the driven element 564. The driven elements 564 and pints 566 may be positioned on an adapter side 567 of the instrument mounting plate 562.

[0112] Interface 560 also includes an adaptor portion 568 that is configured to mountingly engage the mounting plate 562 as will be further discussed below. The adaptor portion 568 may include an array of electrical connecting pins 570, which may be coupled to a memory structure by a circuit board within the instrument mounting portion 558. While interface 560 is described herein with reference to mechanical, electrical, and magnetic coupling elements, it should be understood that a wide variety of telemetry modalities might be used, including infrared, inductive coupling, or the like.

[0113] FIGS. 19-21 show additional views of the adapter portion 568 of the instrument drive assembly 546 of FIG. 17. The adapter portion 568 generally includes an instrument side 572 and a holder side 574 (FIG. 19). In various embodiments, a plurality of rotatable bodies 576 are mounted to a floating plate 578 which has a limited range of movement relative to the surrounding adaptor structure normal to the major surfaces of the adaptor 568. Axial movement of the floating plate 578 helps decouple the rotatable bodies 576 from the instrument mounting portion 558 when the levers 580 along the sides of the instrument mounting portion housing 582 are actuated (See FIG. 16) Other mechanisms/arrangements may be employed for releasably coupling the instrument mounting portion 558 to the adaptor 568. In at least one form, rotatable bodies 576 are resiliently mounted to floating plate 578 by resilient radial members which extend into a circumferential indentation about the rotatable bodies 576. The rotatable bodies 576 can move axially relative to plate 578 by deflection of these resilient structures. When disposed in a first axial position (toward instrument side 572) the rotatable bodies 576 are free to rotate without angular limitation. However, as the rotatable bodies 576 move axially toward

instrument side 572, tabs 584 (extending radially from the rotatable bodies 576) laterally engage detents on the floating plates so as to limit angular rotation of the rotatable bodies 576 about their axes. This limited rotation can be used to help drivingly engage the rotatable bodies 576 with drive pins 586 of a corresponding instrument holder portion 588 of the robotic system, as the drive pins 586 will push the rotatable bodies 576 into the limited rotation position until the pins 586 are aligned with (and slide into) openings 590.

[0114] Openings 590 on the instrument side 572 and openings 590 on the holder side 574 of rotatable bodies 576 are configured to accurately align the driven elements 564 (FIGS. 18, 28) of the instrument mounting portion 558 with the drive elements 592 of the instrument holder 588. As described above regarding inner and outer pins 566 of driven elements 564, the openings 590 are at differing distances from the axis of rotation on their respective rotatable bodies 576 so as to ensure that the alignment is not 33 degrees from its intended position. Additionally, each of the openings 590 may be slightly radially elongated so as to fittingly receive the pins 566 in the circumferential orientation. This allows the pins 566 to slide radially within the openings 590 and accommodate some axial misalignment between the instrument 522 and instrument holder 588, while minimizing any angular misalignment and backlash between the drive and driven elements. Openings 590 on the instrument side 572 may be offset by about 90 degrees from the openings 590 (shown in broken lines) on the holder side 574, as can be seen most clearly in FIG. 21.

[0115] Various embodiments may further include an array of electrical connector pins 570 located on holder side 574 of adaptor 568, and the instrument side 572 of the adaptor 568 may include slots 594 (FIG. 21) for receiving a pin array (not shown) from the instrument mounting portion 558. In addition to transmitting electrical signals between the surgical instrument 522, 523 and the instrument holder 588, at least some of these electrical connections may be coupled to an adaptor memory device 596 (FIG. 20) by a circuit board of the adaptor 568.

[0116] A detachable latch arrangement 598 may be employed to releasably affix the adaptor 568 to the instrument holder 588. As used herein, the term "instrument drive assembly" when used in the context of the robotic system, at least encompasses various embodiments of the adapter 568 and instrument holder 588 and which has been generally designated as 546 in FIG. 17. For example, as can be seen in FIG. 17, the instrument holder 588 may include a first latch

pin arrangement 600 that is sized to be received in corresponding clevis slots 602 provided in the adaptor 568. In addition, the instrument holder 588 may further have second latch pins 604 that are sized to be retained in corresponding latch clevises 606 in the adaptor 568. *See* FIG. 20. In at least one form, a latch assembly 608 is movably supported on the adapter 568 and is biasable between a first latched position wherein the latch pins 600 are retained within their respective latch clevis 606 and an unlatched position wherein the second latch pins 604 may be into or removed from the latch clevises 606. A spring or springs (not shown) are employed to bias the latch assembly into the latched position. A lip on the instrument side 572 of adaptor 568 may slidably receive laterally extending tabs of instrument mounting housing 582.

[0117] As described the driven elements 564 may be aligned with the drive elements 592 of the instrument holder 588 such that rotational motion of the drive elements 592 causes corresponding rotational motion of the driven elements 564. The rotation of the drive elements 592 and driven elements 564 may be electronically controlled, for example, via the robotic arm 612, in response to instructions received from the clinician 502 via a controller 508. The instrument mounting portion 558 may translate rotation of the driven elements 564 into motion of the surgical instrument 522, 523.

[0118] FIGS. 22-24 show one example embodiment of the instrument mounting portion 558 showing components for translating motion of the driven elements 564 into motion of the surgical instrument 522. FIGS. 22-24 show the instrument mounting portion with a shaft 538 having a surgical end effector 610 at a distal end thereof. The end effector 610 may be any suitable type of end effector for performing a surgical task on a patient. For example, the end effector may be configured to provide ultrasonic energy to tissue at a surgical site. The shaft 538 may be rotatably coupled to the instrument mounting portion 558 and secured by a top shaft holder 646 and a bottom shaft holder 648 at a coupler 650 of the shaft 538.

[0119] In one example embodiment, the instrument mounting portion 558 comprises a mechanism for translating rotation of the various driven elements 564 into rotation of the shaft 538, differential translation of members along the axis of the shaft (*e.g.*, for articulation), and reciprocating translation of one or more members along the axis of the shaft 538 (*e.g.*, for extending and retracting tissue cutting elements such as 555, overtubes and/or other components). In one example embodiment, the rotatable bodies 612 (*e.g.*, rotatable spools) are coupled to the driven elements 564. The rotatable bodies 612 may be formed integrally with the

driven elements 564. In some embodiments, the rotatable bodies 612 may be formed separately from the driven elements 564 provided that the rotatable bodies 612 and the driven elements 564 are fixedly coupled such that driving the driven elements 564 causes rotation of the rotatable bodies 612. Each of the rotatable bodies 612 is coupled to a gear train or gear mechanism to provide shaft articulation and rotation and clamp jaw open/close and knife actuation.

[0120] In one example embodiment, the instrument mounting portion 558 comprises a mechanism for causing differential translation of two or more members along the axis of the shaft 538. In the example provided in FIGS. 22-24, this motion is used to manipulate articulation joint 556. In the illustrated embodiment, for example, the instrument mounting portion 558 comprises a rack and pinion gearing mechanism to provide the differential translation and thus the shaft articulation functionality. In one example embodiment, the rack and pinion gearing mechanism comprises a first pinion gear 614 coupled to a rotatable body 612 such that rotation of the corresponding driven element 564 causes the first pinion gear 614 to rotate. A bearing 616 is coupled to the rotatable body 612 and is provided between the driven element 564 and the first pinion gear 614. The first pinion gear 614 is meshed to a first rack gear 618 to convert the rotational motion of the first pinion gear 614 into linear motion of the first rack gear 618 to control the articulation of the articulation section 556 of the shaft assembly 538 in a left direction 620L. The first rack gear 618 is attached to a first articulation band 622 (FIG. 22) such that linear motion of the first rack gear 618 in a distal direction causes the articulation section 556 of the shaft assembly 538 to articulate in the left direction 620L. A second pinion gear 626 is coupled to another rotatable body 612 such that rotation of the corresponding driven element 564 causes the second pinion gear 626 to rotate. A bearing 616 is coupled to the rotatable body 612 and is provided between the driven element 564 and the second pinion gear 626. The second pinion gear 626 is meshed to a second rack gear 628 to convert the rotational motion of the second pinion gear 626 into linear motion of the second rack gear 628 to control the articulation of the articulation section 556 in a right direction 620R. The second rack gear 628 is attached to a second articulation band 624 (FIG. 23) such that linear motion of the second rack gear 628 in a distal direction causes the articulation section 556 of the shaft assembly 538 to articulate in the right direction 620R. Additional bearings may be provided between the rotatable bodies and the corresponding gears. Any suitable bearings may be provided to support and stabilize the mounting and reduce rotary friction of shaft and gears, for example.

[0121] In one example embodiment, the instrument mounting portion 558 further comprises a mechanism for translating rotation of the driven elements 564 into rotational motion about the axis of the shaft 538. For example, the rotational motion may be rotation of the shaft 538 itself. In the illustrated embodiment, a first spiral worm gear 630 coupled to a rotatable body 612 and a second spiral worm gear 632 coupled to the shaft assembly 538. A bearing 616 (figure 17) is coupled to a rotatable body 612 and is provided between a driven element 564 and the first spiral worm gear 630. The first spiral worm gear 630 is meshed to the second spiral worm gear 632, which may be coupled to the shaft assembly 538 and/or to another component of the instrument 522, 523 for which longitudinal rotation is desired. Rotation may be caused in a clockwise (CW) and counter-clockwise (CCW) direction based on the rotational direction of the first and second spiral worm gears 630, 632. Accordingly, rotation of the first spiral worm gear 630 about a first axis is converted to rotation of the second spiral worm gear 632 about a second axis, which is orthogonal to the first axis. As shown in FIGS. 22-23, for example, a CW rotation of the second spiral worm gear 632 results in a CW rotation of the shaft assembly 538 in the direction indicated by 634CW. A CCW rotation of the second spiral worm gear 632 results in a CCW rotation of the shaft assembly 538 in the direction indicated by 634CCW. Additional bearings may be provided between the rotatable bodies and the corresponding gears. Any suitable bearings may be provided to support and stabilize the mounting and reduce rotary friction of shaft and gears, for example.

[0122] In one example embodiment, the instrument mounting portion 558 comprises a mechanism for generating reciprocating translation of one or more members along the axis of the shaft 538. Such translation may be used, for example to drive a tissue cutting element, such as 555, drive an overtube for closure and/or articulation of the end effector 610, *etc.* In the illustrated embodiment, for example, a rack and pinion gearing mechanism may provide the reciprocating translation. A first gear 636 is coupled to a rotatable body 612 such that rotation of the corresponding driven element 564 causes the first gear 636 to rotate in a first direction. A second gear 638 is free to rotate about a post 640 formed in the instrument mounting plate 562. The first gear 636 is meshed to the second gear 638 such that the second gear 638 rotates in a direction that is opposite of the first gear 636. In one example embodiment, the second gear 638 is a pinion gear meshed to a rack gear 642, which moves in a liner direction. The rack gear 642 is coupled to a translating block 644, which may translate distally and proximally with the rack

gear 642. The translation block 644 may be coupled to any suitable component of the shaft assembly 538 and/or the end effector 610 so as to provide reciprocating longitudinal motion. For example, the translation block 644 may be mechanically coupled to the tissue cutting element 555 of the RF surgical device 523. In some embodiments, the translation block 644 may be coupled to an overtube, or other component of the end effector 610 or shaft 538.

[0123] FIGS. 25-27 illustrate an alternate embodiment of the instrument mounting portion 558 showing an alternate example mechanism for translating rotation of the driven elements 564 into rotational motion about the axis of the shaft 538 and an alternate example mechanism for generating reciprocating translation of one or more members along the axis of the shaft 538. Referring now to the alternate rotational mechanism, a first spiral worm gear 652 is coupled to a second spiral worm gear 654, which is coupled to a third spiral worm gear 656. Such an arrangement may be provided for various reasons including maintaining compatibility with existing robotic systems 1000 and/or where space may be limited. The first spiral worm gear 652 is coupled to a rotatable body 612. The third spiral worm gear 656 is meshed with a fourth spiral worm gear 658 coupled to the shaft assembly 538. A bearing 760 is coupled to a rotatable body 612 and is provided between a driven element 564 and the first spiral worm gear 738. Another bearing 760 is coupled to a rotatable body 612 and is provided between a driven element 564 and the third spiral worm gear 652. The third spiral worm gear 652 is meshed to the fourth spiral worm gear 658, which may be coupled to the shaft assembly 538 and/or to another component of the instrument 522 for which longitudinal rotation is desired. Rotation may be caused in a CW and a CCW direction based on the rotational direction of the spiral worm gears 656, 658. Accordingly, rotation of the third spiral worm gear 656 about a first axis is converted to rotation of the fourth spiral worm gear 658 about a second axis, which is orthogonal to the first axis. As shown in FIGS. 26 and 27, for example, the fourth spiral worm gear 658 is coupled to the shaft 538, and a CW rotation of the fourth spiral worm gear 658 results in a CW rotation of the shaft assembly 538 in the direction indicated by 634CW. A CCW rotation of the fourth spiral worm gear 658 results in a CCW rotation of the shaft assembly 538 in the direction indicated by 634CCW. Additional bearings may be provided between the rotatable bodies and the corresponding gears. Any suitable bearings may be provided to support and stabilize the mounting and reduce rotary friction of shaft and gears, for example.

[0124] Referring now to the alternate example mechanism for generating reciprocating translation of one or more members along the axis of the shaft 538, the instrument mounting portion 558 comprises a rack and pinion gearing mechanism to provide reciprocating translation along the axis of the shaft 538 (*e.g.*, translation of a tissue cutting element 555 of the RF surgical device 523). In one example embodiment, a third pinion gear 660 is coupled to a rotatable body 612 such that rotation of the corresponding driven element 564 causes the third pinion gear 660 to rotate in a first direction. The third pinion gear 660 is meshed to a rack gear 662, which moves in a linear direction. The rack gear 662 is coupled to a translating block 664. The translating block 664 may be coupled to a component of the device 522, 523, such as, for example, the tissue cutting element 555 of the RF surgical device and/or an overtube or other component which is desired to be translated longitudinally.

[0125] FIGS. 28-32 illustrate an alternate embodiment of the instrument mounting portion 558 showing another alternate example mechanism for translating rotation of the driven elements 564 into rotational motion about the axis of the shaft 538. In FIGS. 28-32, the shaft 538 is coupled to the remainder of the mounting portion 558 via a coupler 676 and a bushing 678. A first gear 666 coupled to a rotatable body 612, a fixed post 668 comprising first and second openings 672, first and second rotatable pins 674 coupled to the shaft assembly, and a cable 670 (or rope). The cable is wrapped around the rotatable body 612. One end of the cable 670 is located through a top opening 672 of the fixed post 668 and fixedly coupled to a top rotatable pin 674. Another end of the cable 670 is located through a bottom opening 672 of the fixed post 668 and fixedly coupled to a bottom rotating pin 674. Such an arrangement is provided for various reasons including maintaining compatibility with existing robotic systems 1000 and/or where space may be limited. Accordingly, rotation of the rotatable body 612 causes the rotation about the shaft assembly 538 in a CW and a CCW direction based on the rotational direction of the rotatable body 612 (*e.g.*, rotation of the shaft 538 itself). Accordingly, rotation of the rotatable body 612 about a first axis is converted to rotation of the shaft assembly 538 about a second axis, which is orthogonal to the first axis. As shown in FIGS. 28-29, for example, a CW rotation of the rotatable body 612 results in a CW rotation of the shaft assembly 538 in the direction indicated by 634CW. A CCW rotation of the rotatable body 612 results in a CCW rotation of the shaft assembly 538 in the direction indicated by 634CCW. Additional bearings may be provided between the rotatable bodies and the corresponding gears. Any

suitable bearings may be provided to support and stabilize the mounting and reduce rotary friction of shaft and gears, for example.

[0126] FIGS. 33-36A illustrate an alternate embodiment of the instrument mounting portion 558 showing an alternate example mechanism for differential translation of members along the axis of the shaft 538 (*e.g.*, for articulation). For example, as illustrated in FIGS. 33-36A, the instrument mounting portion 558 comprises a double cam mechanism 680 to provide the shaft articulation functionality. In one example embodiment, the double cam mechanism 680 comprises first and second cam portions 680A, 680B. First and second follower arms 682, 684 are pivotally coupled to corresponding pivot spools 686. As the rotatable body 612 coupled to the double cam mechanism 680 rotates, the first cam portion 680A acts on the first follower arm 682 and the second cam portion 680B acts on the second follower arm 684. As the cam mechanism 680 rotates the follower arms 682, 684 pivot about the pivot spools 686. The first follower arm 682 may be attached to a first member that is to be differentially translated (*e.g.*, the first articulation band 622). The second follower arm 684 is attached to a second member that is to be differentially translated (*e.g.*, the second articulation band 624). As the top cam portion 680A acts on the first follower arm 682, the first and second members are differentially translated. In the example embodiment where the first and second members are the respective articulation bands 622 and 624, the shaft assembly 538 articulates in a left direction 620L. As the bottom cam portion 680B acts of the second follower arm 684, the shaft assembly 538 articulates in a right direction 620R. In some example embodiments, two separate bushings 688, 690 are mounted beneath the respective first and second follower arms 682, 684 to allow the rotation of the shaft without affecting the articulating positions of the first and second follower arms 682, 684. For articulation motion, these bushings reciprocate with the first and second follower arms 682, 684 without affecting the rotary position of the jaw 902. FIG. 36A shows the bushings 688, 690 and the dual cam assembly 680, including the first and second cam portions 680B, 680B, with the first and second follower arms 682, 684 removed to provide a more detailed and clearer view.

[0127] In various embodiments, the instrument mounting portion 558 may additionally comprise internal energy sources for driving electronics and provided desired ultrasonic and/or RF frequency signals to surgical tools. FIGS. 36B-36C illustrate one embodiment of a tool mounting portion 558′ comprising internal power and energy sources. For example, surgical

instruments (*e.g.*, instrument 522) mounted utilizing the tool mounting portion 558′ need not be wired to an external generator or other power source. Instead, the functionality of the generator 20 described herein may be implemented on board the mounting portion 558.

[0128] As illustrated in FIGS. 36B-36C, the instrument mounting portion 558′ may comprise a distal portion 702. The distal portion 702 may comprise various mechanisms for coupling rotation of drive elements 612 to end effectors of the various surgical instruments 522, for example, as described herein above. Proximal of the distal portion 702, the instrument mounting portion 558′ comprises an internal direct current (DC) energy source and an internal drive and control circuit 704. In the illustrated embodiment, the energy source comprises a first and second battery 706, 708. In other respects, the tool mounting portion 558′ is similar to the various embodiments of the tool mounting portion 558 described herein above. The control circuit 704 may operate in a manner similar to that described above with respect to generator 20. For example, the control circuit 704 may provide an ultrasonic and/or electrosurgical drive signal in a manner similar to that described above with respect to generator 20.

[0129] FIGS. 37-38 illustrates one embodiment of a distal portion 1000 of a surgical instrument comprising a distally positioned jaw assembly 1003. The distal portion 1000 also comprises an ultrasonic blade 1014 and a shaft 1004 extending along a longitudinal axis 1002. A clevis 1006 coupled to a distal portion of the shaft 1004 pivotably receives the jaw assembly 1003. For example, a wrist member 1008 of the jaw assembly 1003 may be pivotably coupled to the clevis 1018 about a first axis or wrist pivot axis 1018. Pivoting of the jaw assembly 1003 about the wrist pivot axis 1018 may cause the jaw assembly 1003 to pivot in the directions indicated by arrow 1022. The wrist member 1008 may be coupled to the clevis 1006 utilizing any suitable pivotable connector or connector assembly. For example, in some embodiments, the wrist member 1008 may be coupled to clevis 1006 with a pin 1011 that may ride within a hole 1013 defined by the clevis 1006.

[0130] First and second jaw members 1010, 1012 may be pivotably coupled to the wrist member 1008 and configured to pivot about a second axis, or jaw pivot axis 1016. Pivoting of the jaw members 1010, 1012 about the jaw pivot axis 1016 may cause the respective jaw members 1010, 1012 to pivot in the directions indicated by arrow 1020. The jaw members 1010, 1012 may be pivotable about the jaw pivot axis 1016 relative to one another and absolutely. For example, the jaw members 1010, 1012 may pivot relative to one another from open positions,

where the jaw members 1010, 1012 are separated from one another as shown in FIG. 37, to a closed position where the jaw members 1010, 1012 are substantially parallel to one another (and optionally in contact with one another). For example, tissue may be grasped between the jaw members 1010, 1012 when they are at or near the closed position. In some embodiments, one or both of the jaw members 1010, 1012 is also absolutely pivotably about the jaw pivot axis 1016. This may allow the general orientation of the jaw assembly 1003 to pivot about the axis 1016 (from left to right in the orientation illustrated in FIG. 37).

[0131] FIG. 39 illustrates a head-on view of one embodiment of the distal portion 1000 of the surgical instrument of FIGS. 37-38. In FIG. 39, various control pulleys 1026, 1028, 1030, 1032 are illustrated, along with openings 1031, 1032 in the clevis 1006 for control lines to pass through. Additional details of the various control lines and control pulleys are provided herein below. FIG. 39 also illustrates additional details of the jaw members 1010, 1012. In the embodiment shown in FIG. 39, for example, the jaw members 1010, 1012 define teeth 1024. In some embodiments, the teeth 1024 interlock when the jaw members 1010, 1012 are in a closed position relative to one another. In other embodiments, however, the teeth 1024 do not interlock when the jaw members 1010, 1012 are in a closed position relative to one another.

[0132] FIGS. 40-41 illustrate one embodiment of the distal portion 1000 of the surgical instrument of FIGS. 37-38 coupled to an instrument mounting portion 1034 for use with a robotic surgical system, such as the system 500 described herein above. The shaft 1004 may be coupled to the instrument mounting portion 1034. The instrument mounting portion 1034 may contain various mechanisms and interfaces for actuating the ultrasonic blade 1014, articulating the jaw assembly 1003 and, in some embodiments, retracting and extending the ultrasonic blade 1014, for example, as described herein below.

[0133] FIGS. 42-44 illustrate one embodiment of the distal portion 1000 of the surgical instrument of FIGS. 37-38 showing additional control mechanisms. Each of the jaw members 1010, 1012 may comprise respective pulleys 1041, 1043 centered on the jaw pivot axis 1016. Rotation of the pulleys 1041, 1043 may cause corresponding pivoting of the respective jaw members 1010, 1012. Rotation of the pulleys 1041, 1043 (and corresponding pivoting of the jaw members 1010, 1012) may be brought about utilizing control lines 1038, 1040, 1048, 1050. For example, control line 1040 may be coupled to and/or wrapped around pulley 1043 such that proximal translation of the control line 1040 causes the jaw member 1012 to pivot about the jaw

pivot axis 1016 towards the control line 1040 (*e.g.*, out of the page from the perspective shown in FIGS. 42-43). Pivoting of the jaw member 1012 in the opposition direction (*e.g.*, into the page from the perspective shown in FIGS. 42-43) may be actuated utilizing a control line 1048 also coupled to and/or wrapped around the pulley 1043. Proximal translation of the control line 1048 may cause the jaw member 1012 to pivot towards the control line 1048. When the control line 1048 is coupled to the pulley 1043, it may be coupled at a position substantially opposite the position where the control line 1040 is coupled to the pulley 1043. Also, in some embodiments, control lines 1048, 1040 may be opposite ends of a single cable wrapped around the pulley 1043.

[0134] Similarly, control line 1038 may be coupled to and/or wrapped around pulley 1041 such that proximal translation of the control line 1038 causes the jaw member 1010 to pivot about the jaw pivot axis 1016 towards the control line 1038 (*e.g.*, again out of the page from the perspective shown in FIGS. 42-43). Control line 1050 may also be coupled to and/or wrapped around pulley 1041 such that proximal translation of the control line 1050 causes the jaw member 1010 to pivot about the jaw pivot axis towards the control line 1050 (*e.g.*, into the page from the perspective shown in FIGS. 42-43). Control lines 1038, 1050 may be separately coupled to the pulley 1041 or, in some embodiments, may represent separate ends of a single cable or other line wrapped around the pulley 1041. It will be appreciated that as the jaw assembly 1003 pivots about the wrist pivot axis 1018, the orientation of the control lines 1038, 1040, 1048, 1050 relative to the pulleys 1041, 1043 may change.

[0135] To prevent the control lines from becoming strained and/or disengaged with the pulleys 1041, 1043, various idler pulleys 1026, 1028, 1036, 1042, 1046, 1044, 1030, 1032 (FIG. 39) may be included to route the control lines 1038, 1040, 1048, 1050 to the shaft 1004. Also, in some embodiments, the control lines are routed to the shaft 1004 via holes in the clevis 1006. FIG. 39 illustrates example holes 1031, 1032 that may be utilized by cables 1048, 1050, respectively.

[0136] Pivoting of the wrist member 1008 (and thereby the jaw assembly 1003) may also be actuated utilizing control lines. For example, referring to FIGS. 42 and 44, a control line 1052 is visible coupled to the wrist member 1008 at a position offset from the wrist pivot axis 1018. Proximal translation of the control line 1052 may pull the jaw assembly 1003 away from the ultrasonic blade 1014, for example, up from the perspective shown in FIG. 42 and out of the page from the perspective shown in FIG. 44. A similar control line 1053 may be coupled to a

lower portion of the wrist member 1008 such that proximal translation of the control line 1053 causes the jaw assembly 1003 to pivot towards the ultrasonic blade 1014 (*e.g.*, down from the perspective shown in FIG. 42 and into the page from the perspective shown in FIG. 44). The control lines 1052, 1053, in some embodiments, may be ends of a single cable or control line wrapped through and coupled to the wrist member 1008. Also, in some embodiments, the control line 1053 may be omitted. Pivoting of the jaw assembly 1003 towards the ultrasonic blade 1014 may be brought about by distal translation of the control member 1052.

[0137] The various control lines 1038, 1040, 1048, 1050, 1052, 1053 may extend proximally through the shaft 1004 where they may be actuated at a handle or an instrument mounting portion of a robotic surgical system, such as the instrument mounting portion 1034 described herein. As described above, differential translation of control line pairs (1038/1050, 1040/1048, 1052, 1053) may cause articulation of the various components of the jaw assembly 1003. Differential translation of control lines may be brought about in any suitable manual and/or automated manner, for example, as described above.

[0138] FIG. 45A illustrates one embodiment of the instrument mounting portion 1034 showing an example mechanism for actuating various control lines of the surgical instrument of FIGS. 37-38. The various control lines 1038, 1040, 1048, 1050, 1052, 1053 may extend proximally through the shaft 1004 and enter the instrument mounting portion 1034. The various control lines may be routed by routers 1056 to various spools 1039, 1041, 1043 mounted on the rotatable bodies described above. FIG. 45B illustrates a side view of one embodiment of the routers 1056. For example, the router 1056 shown in FIG. 45B comprises a plurality of grooves 1058 for receiving and routing the various control lines. More or fewer grooves may be included in routers 1056, for example, based on the number of control lines that they are configured to route.

[0139] Referring back to FIG. 45A, in some embodiments, control lines 1038 and 1050 may be routed to spool 1039. According to the pictured configuration, clockwise rotation of the spool 1039 causes proximal translation of the control line 1038 and distal translation of the control line 1050. This, as described above, may cause the jaw member 1010 to pivot about the jaw pivot axis 1016 to the left from the perspective of FIG. 44 and out of the page from the perspective of FIGS. 42-43. Counterclockwise rotation of the spool 1039 causes distal translation of the control line 1038 and proximal translation of the control line 1050. This, again

as described above, may cause the jaw member 1010 to pivot about the jaw pivot axis 1016 to the right from the perspective of FIG. 44 and into the page from the perspective of FIGS. 42-43. Control lines 1040 and 1048 may be routed to spool 1040. Clockwise and counterclockwise rotation of the spool 1041 may differentially translate control lines 1040 and 1048, causing the jaw member 1012 to pivot about the jaw pivot axis 1016 similar to the jaw member 1010 described above. The control lines 1052 and 1053 may be similarly coupled to spool 1043 to control pivoting of the jaw assembly 1003 about the wrist pivot axis 1016 upon clockwise and counterclockwise rotation of the spool 1043.

[0140] According to various embodiments, the surgical instrument of FIGS. 37-38 may be implemented with a retractable ultrasonic blade 1014. For example, the ultrasonic blade 1014 may be retractable in a proximal direction such that it is partially or completely within the shaft 1004 and/or clevis 1006. This may increase the range of motion of the jaw assembly 1003 about the wrist pivot axis 1018. FIGS. 46-47 illustrate one embodiment of the distal portion 1000 of the surgical instrument of FIGS. 37-38 with a retractable ultrasonic blade 1014. Referring now to FIG. 46, the blade 1014 is shown retracted in the proximal direction indicated by arrow 1060 within the shaft 1004. As can be seen, this increases the range of motion of the jaw assembly 1003 to pivot about the wrist pivot axis 1018. For example, as illustrated in FIG. 46, the jaw assembly 1003 may pivot to and past a location where it would have otherwise contacted the ultrasonic blade 1014. This may increase the range in which the jaw assembly 1003 is able to grasp tissue. In use, the jaw assembly 1003 may grasp tissue while pivoted to the position shown in FIG. 46. The jaw assembly 1003 may then be pivoted back to and/or beyond the position shown in FIG. 47 so that the blade 1014 may be extended distally to act on the grasped tissue.

[0141] The ultrasonic blade 1014 may be coupled to an ultrasonic waveguide 1058 that may extend proximally through the shaft 1004 to an ultrasonic transducer, such as the transducer 16 described above. In some embodiments, translation of the ultrasonic blade 1014 may be brought about by translation of the blade 1014, waveguide 1058 and transducer assembly. FIG. 48 illustrates one embodiment of the distal portion 1000 of the surgical instrument of FIGS. 37-38 coupled to an instrument mounting portion 1034 of a robotic surgical system configured to extend and retract the ultrasonic blade 1014. As illustrated, the waveguide 1058 extends proximally from the ultrasonic blade 1014 through the shaft 1004 to the instrument mounting portion where it is coupled to an ultrasonic transducer assembly 1064 located within the

instrument mounting portion 1034. A rack gear 1062 is coupled to the waveguide 1058 and may be positioned to be engaged by a round gear coupled to one of the rotating bodies 612 of the instrument mounting portion 1034. For example, FIG. 45 illustrates the rack gear 1062 coupled to a gear 1047, which is, in turn, coupled to a gear 1045 that rotates with the rotating body 612. Alternate rotation of the rotating body 612 may cause rotation of the respective gears 1045, 1047 that may, in turn, cause distal and proximal translation of the rack gear 1062. As the rack gear 1062 is coupled to the waveguide 1058, distal and proximal translation of the rack gear 1062 may also cause distal and proximal translation of the waveguide 1058, blade 1014 and transducer 1064.

[0142] In the embodiment illustrated in FIG. 48, the transducer 1064 is positioned within the instrument mounting portion 1034. A flexible/extendible cable 1066 may be coupled the transducer 1064 and ultimately to an external cable 1067. As the transducer translates distally and proximally with the waveguide 1058 and blade 1014, the cable 1066 may alternately slacken and tighten so as to maintain its connection to the external cable 1067. FIG. 49 illustrates an alternate embodiment of the distal portion 1000 of the surgical instrument of FIGS. 37-38 coupled to an instrument mounting portion of a robotic surgical system with an external transducer 1070. As illustrated, the transducer extends beyond the instrument mounting portion 1034. FIG. 49 also illustrates the track gear 1062 coupled to the waveguide 1058 that may act (in conjunction with one of the rotatable members 612) to translate the waveguide 1058, blade 1014 (not shown in FIG. 49) and transducer 1070 proximally and distally. FIG. 50 illustrates an additional view of the distal portion 1000 of the surgical instrument of FIGS. 37-38 as illustrated in FIG. 49.

[0143] FIG. 51 illustrates one embodiment of the jaw assembly 1003 comprising a clamp pad 1072. The clamp pad 1072 may comprise one or more components coupled to at least one face of the wrist member 1008 and/or one of the jaw members 1010, 1012. For example, FIG. 51 illustrates a face 1074 of the wrist member 1008 directed towards the ultrasonic blade 1014 and a face 1076 of the jaw member 1012 directed towards the ultrasonic blade 1014. One or more of these faces may be coupled to a clamp pad 1072. The clamp pad 1072 may be similar to the clamp arm assembly 64 described herein. For example, the clamp pad 1072 may be configured to be in physical contact with the ultrasonic blade 1014 without substantially affecting the operation of the blade 1014. In the way, a clinician may utilize the jaw assembly

1003 to clamp tissue to the blade 1014 in a manner similar to that described above with respect to clamp arm assembly 64.

[0144] FIGS. 52-55 illustrate one embodiment of a distal portion 1101 of a surgical instrument comprising a jaw assembly 1100. The distal portion 1101 may additionally comprise a shaft portion 1110, a clevis 1102 and an ultrasonic blade 1106. As described herein above, the ultrasonic blade 1106 may be in mechanical communication with an ultrasonic waveguide (not shown in FIG. 52) that may extend proximally to a transducer, such as the transducer 16 of FIG. 1. In some embodiments, the ultrasonic bladed 1106 may be retractable, as described herein above.

[0145] The jaw assembly 1100 may comprise a jaw member 1102 and an opposable U-shaped jaw member 1104. The jaw members 1102, 1104 may be pivotably coupled to the clevis 1102 that may be, in turn, coupled to a shaft 1110. The jaw members 1102, 1104 may be separately pivotable about an axis 1109 in a manner similar to that described above by which the jaw members 1010, 1012 are separately pivotable about the axis 1016. For example, the jaw members 1102, 1104 may be separately pivoted about the axis 1109 to an open position where the jaw members 1102, 1104 are pivoted away from one another. The jaw members 1102, 1104 may also be separately pivoted about the axis 1109 to a closed position where the jaw members 1102, 1104 are near and/or in contact with one another, for example, as shown in FIGS. 53 and 55. In various embodiments the jaw members 1102, 1104 may be at either an open or closed position at various angles relative to a longitudinal axis 1002 of the shaft. For example, FIG. 52 shows the jaw members 1102, 1104 in an open position pivoted away from the longitudinal axis 1002. FIG. 53 shows the jaw members 1102, 1104 in a closed position substantially parallel to the ultrasonic blade 1106. The axis 1109 may be substantially parallel to the longitudinal axis 1002.

[0146] In various embodiments, the jaw members 1102, 1104 may be utilized to capture tissue and maneuver the captured tissue towards the ultrasonic blade 1106 for cutting and/or coagulation. For example, the U-shaped jaw member 1104 may comprise a pair of times 1104a, 1104b. The tines 1104a, 1104b may define an opening 1105 between the times 1104a, 1104b. The jaw member 1102 and ultrasonic blade 1106 may be aligned with the opening. In this way, the jaw members 1102, 1104 may be pivoted to an open position with at least the jaw member 1102 away from the longitudinal axis 1002 to capture tissue, such as tissue 1114 shown

in FIG. 55. In some embodiments, the jaw member 1102 may fit at least into the opening 1105 between the tines 1104a, 1104b. Accordingly, the jaw member 1102 may push a portion of the tissue 1114 through the opening 1105 where it may contact the ultrasonic blade 1106 for cutting and/or coagulation, as shown in FIG. 55.

[0147] The jaw members 1102, 1104 may be controlled in any suitable manner. For example, referring to FIG. 56, a pulley 1116 may be positioned about the axis 1109 and coupled to the jaw member 1104. A similar pulley 1118 may be positioned about the axis 1109 and coupled to the jaw member 1106. Cables 1120, 1122 may be coupled around the respective pulleys 1104, 1106 in a manner similar to that described herein above with respect to pulleys 1041, 1043 and cables 1038, 1040. Differential movement of the cable 1120 may cause the jaw member 1104 to pivot about the axis 1109, as described above. Similarly, differential movement of the cable 1120 may cause the jaw member 1104 to pivot about the axis 1109 also as described above. Referring now to FIG. 54, the shaft 1112 may define a cavity 1115. The respective cables 1120, 1122 may extend proximally from the jaw assembly 1100 through the cavity 1115. The cables 1120, 1122 may be controlled in any suitable manner. For example, the cables may be controlled by an instrument mounting portion, similar to the instrument mounting portion shown in FIG. 45 and/or by a hand-held controller, such as the handle 12 described herein above.

[0148] *Non-Limiting Embodiments*

[0149] Various embodiments are directed to surgical instruments comprising an end effector, a shaft and a jaw assembly. The end effector may comprise an ultrasonic blade extending distally substantially parallel to a longitudinal axis. The shaft may extend proximally from the end effector along the longitudinal axis. The jaw assembly may comprise first and second jaw members. The jaw assembly may be pivotable about a first axis substantially perpendicular to the longitudinal axis from a first position where the first and second jaw members are substantially parallel to the ultrasonic blade to a second position. Additionally, the first and second jaw members may be pivotable about a second axis substantially perpendicular to the first axis.

[0150] In some embodiments, the jaw assembly comprises a wrist member, a first jaw member and a second jaw member. The wrist member may be pivotable about a wrist pivot axis substantially perpendicular to the longitudinal axis from a first position where the wrist member is substantially parallel to the ultrasonic blade to a second position where the wrist member is

pivoted away from the ultrasonic blade. The first jaw member may extend distally from and be pivotably coupled to the wrist member. The first jaw member may also be pivotable about a jaw pivot axis substantially perpendicular to the wrist pivot axis. The second jaw member may extend distally from and also be pivotably coupled to the wrist member. The second jaw member may also be pivotable about the jaw pivot axis. The first and second jaw members may be further pivotable about the jaw pivot axis relative to one another from an open position where the first and second jaw members are pivoted away from one another to a closed position where the first and second jaw members are pivoted towards one another.

[0151] Applicant also owns the following patent applications that are each incorporated by reference in their respective entireties:

[0152] U.S. Patent Application Serial No. 13/536,271, filed on June 28, 2012 and entitled "Flexible Drive Member," (Attorney Docket No. END7131USNP/120135);

[0153] U.S. Patent Application Serial No. 13/536,288, filed on June 28, 2012 and entitled "Multi-Functional Powered Surgical Device with External Dissection Features," (Attorney Docket No. END7132USNP/120136);

[0154] U.S. Patent Application Serial No. 13/536,295, filed on June 28, 2012 and entitled "Rotary Actuatable Closure Arrangement for Surgical End Effector," (Attorney Docket No. END7134USNP/120138);

[0155] U.S. Patent Application Serial No. 13/536,326, filed on June 28, 2012 and entitled "Surgical End Effectors Having Angled Tissue-Contacting Surfaces," (Attorney Docket No. END7135USNP/120139);

[0156] U.S. Patent Application Serial No. 13/536,303, filed on June 28, 2012 and entitled "Interchangeable End Effector Coupling Arrangement," (Attorney Docket No. END7136USNP/120140);

[0157] U.S. Patent Application Serial No. 13/536,393, filed on June 28, 2012 and entitled "Surgical End Effector Jaw and Electrode Configurations," (Attorney Docket No. END7137USNP/120141);

[0158] U.S. Patent Application Serial No. 13/536,362, filed on June 28, 2012 and entitled "Multi-Axis Articulating and Rotating Surgical Tools," (Attorney Docket No. END7138USNP/120142); and

[0159] U.S. Patent Application Serial No. 13/536,417, filed on June 28, 2012 and entitled "Electrode Connections for Rotary Driven Surgical Tools," (Attorney Docket No. END7149USNP/120153).

[0160] It will be appreciated that the terms "proximal" and "distal" are used throughout the specification with reference to a clinician manipulating one end of an instrument used to treat a patient. The term "proximal" refers to the portion of the instrument closest to the clinician and the term "distal" refers to the portion located furthest from the clinician. It will further be appreciated that for conciseness and clarity, spatial terms such as "vertical," "horizontal," "up," or "down" may be used herein with respect to the illustrated embodiments. However, surgical instruments may be used in many orientations and positions, and these terms are not intended to be limiting or absolute.

[0161] Various embodiments of surgical instruments and robotic surgical systems are described herein. It will be understood by those skilled in the art that the various embodiments described herein may be used with the described surgical instruments and robotic surgical systems. The descriptions are provided for example only, and those skilled in the art will understand that the disclosed embodiments are not limited to only the devices disclosed herein, but may be used with any compatible surgical instrument or robotic surgical system.

[0162] Reference throughout the specification to "various embodiments," "some embodiments," "one example embodiment," or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one example embodiment. Thus, appearances of the phrases "in various embodiments," "in some embodiments," "in one example embodiment," or "in an embodiment" in places throughout the specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics illustrated or described in connection with one example embodiment may be combined, in whole or in part, with features, structures, or characteristics of one or more other embodiments without limitation.

[0163] While various embodiments herein have been illustrated by description of several embodiments and while the illustrative embodiments have been described in considerable detail, it is not the intention of the applicant to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications may readily appear to those skilled in the art. For example, each of the disclosed embodiments may be employed in

endoscopic procedures, laparoscopic procedures, as well as open procedures, without limitations to its intended use.

[0164] It is to be understood that at least some of the figures and descriptions herein have been simplified to illustrate elements that are relevant for a clear understanding of the disclosure, while eliminating, for purposes of clarity, other elements. Those of ordinary skill in the art will recognize, however, that these and other elements may be desirable. However, because such elements are well known in the art, and because they do not facilitate a better understanding of the disclosure, a discussion of such elements is not provided herein.

[0165] While several embodiments have been described, it should be apparent, however, that various modifications, alterations and adaptations to those embodiments may occur to persons skilled in the art with the attainment of some or all of the advantages of the disclosure. For example, according to various embodiments, a single component may be replaced by multiple components, and multiple components may be replaced by a single component, to perform a given function or functions. This application is therefore intended to cover all such modifications, alterations and adaptations without departing from the scope and spirit of the disclosure as defined by the appended claims.

[0166] Any patent, publication, or other disclosure material, in whole or in part, that is said to be incorporated by reference herein is incorporated herein only to the extent that the incorporated materials does not conflict with existing definitions, statements, or other disclosure material set forth in this disclosure. As such, and to the extent necessary, the disclosure as explicitly set forth herein supersedes any conflicting material incorporated herein by reference. Any material, or portion thereof, that is said to be incorporated by reference herein, but which conflicts with existing definitions, statements, or other disclosure material set forth herein will only be incorporated to the extent that no conflict arises between that incorporated material and the existing disclosure material.

CLAIMS

What is claimed is:

1. A surgical instrument comprising:

an end effector comprising an ultrasonic blade extending distally substantially parallel to a longitudinal axis;

a shaft extending proximally from the end effector along the longitudinal axis; and

a jaw assembly, wherein the jaw assembly comprises:

a wrist member pivotable about a wrist pivot axis substantially perpendicular to the longitudinal axis from a first position where the wrist member is substantially parallel to the ultrasonic blade to a second position where the wrist member is pivoted away from the ultrasonic blade;

a first jaw member extending distally from and pivotably coupled to the wrist member, wherein the first jaw member is pivotable about a jaw pivot axis substantially perpendicular to the wrist pivot axis;

a second jaw member extending distally from and pivotably coupled to the wrist member, wherein the second jaw member is pivotable about the jaw pivot axis, and wherein the first and second jaw members are further pivotable about the jaw pivot axis relative to one another from an open position where the first and second jaw members are pivoted away from one another to a closed position where the first and second jaw members are pivoted towards one another.

2. The instrument of claim 1, further comprising:

first and second control lines extending proximally from the first jaw member through the shaft, wherein differential translation of the first and second control lines causes the first jaw member to pivot about the jaw pivot axis; and

third and fourth control lines extending proximally from the second jaw member through the shaft, wherein differential translation of the third and fourth control lines causes the second jaw member to pivot about the jaw pivot axis.

3. The instrument of claim 2, wherein the first jaw member comprises a pulley positioned about the jaw pivot axis and wherein the first and second first jaw control line extend around the pulley.

4. The instrument of claim 3, wherein the first and second control lines are ends of a single control line positioned around the pulley.

5. The instrument of claim 1, wherein the first and second jaw members are pivotable about the jaw pivot axis individually and collectively.

6. The instrument of claim 1, further comprising a first wrist member control line coupled to the wrist member and extending proximally through the shaft, wherein proximal translation of the first wrist control line pivots the wrist member proximally about the wrist pivot axis towards the first wrist member.

7. The instrument of claim 1, wherein the ultrasonic blade is translatable in a direction parallel to the longitudinal axis from an extended position to a retracted position.

8. The instrument of claim 1, wherein a range of motion of the wrist member about the wrist pivot axis is increased when the ultrasonic blade is in the retracted position.

9. The instrument of claim 1, wherein at least one of the wrist member, the first jaw member, and the second jaw member define a face directed towards the ultrasonic blade, and further comprising a clamp pad material coupled to the face.

10. A surgical instrument comprising:

an end effector comprising an ultrasonic blade extending distally substantially parallel to a longitudinal axis;

a shaft extending proximally from the end effector along the longitudinal axis; and

a jaw assembly comprising first and second jaw members, wherein the jaw assembly is pivotable about a first axis substantially perpendicular to the longitudinal axis from a first

position where the first and second jaw members are substantially parallel to the ultrasonic blade to a second position, and wherein the first and second jaw members are pivotable about a second axis substantially perpendicular to the first axis.

11. The surgical instrument of claim 10, wherein the first and second jaw members are pivotable relative to each other about the second axis from a closed position where the first and second jaw members are substantially parallel to each other to an open position.

12. The surgical instrument of claim 10, wherein the jaw assembly further comprises a wrist member pivotable about the first axis, wherein the first and second jaw members are pivotably coupled to the wrist member about the second axis.

13. The instrument of claim 10, further comprising:

first and second control lines extending proximally from the first jaw member through the shaft, wherein differential translation of the first and second control lines causes the first jaw member to pivot about the second axis; and

third and fourth control lines extending proximally from the second jaw member through the shaft, wherein differential translation of the third and fourth control lines causes the second jaw member to pivot about the second axis.

14. The instrument of claim 13, wherein the first jaw member comprises a pulley positioned about the jaw pivot axis and wherein the first and second first jaw control line extend around the pulley.

15. The instrument of claim 14, wherein the first jaw member comprises a pulley positioned about the jaw pivot axis and wherein the first and second first jaw control line extend around the pulley.

16. The instrument of claim 10, wherein the first and second jaw members are pivotable about the second axis individually and together.

17. The instrument of claim 10, further comprising a first axis control line coupled to the jaw assembly and extending proximally through the shaft, wherein proximal translation of the first axis control line pivots the jaw assembly proximally about the wrist pivot axis towards the first wrist member.

18. The instrument of claim 10, wherein the ultrasonic blade is translatable in a direction parallel to the longitudinal axis from an extended position to a retracted position.

19. The instrument of claim 10, wherein a range of motion of the jaw assembly about the first axis is increased when the ultrasonic blade is in the retracted position.

20. The instrument of claim 10, wherein the jaw assembly defines a face directed towards the ultrasonic blade, and further comprising a clamp pad material coupled to the face.

21. A surgical instrument comprising:

an end effector comprising an ultrasonic blade extending distally substantially parallel to a longitudinal axis;

a shaft extending proximally from the end effector along the longitudinal axis; and

a jaw assembly, wherein the jaw assembly comprises:

a first jaw member pivotable about a first axis substantially perpendicular to the longitudinal axis;

a second jaw member also pivotable about the first axis, wherein the second jaw member defines first and second tines, wherein the first and second jaw members are pivotable about the first axis to at least one open position where the first and second jaw members are separated from one another to at least one open position where the first and second jaw members are pivoted towards one another, and wherein the first and second tines define an opening aligned with the first jaw member and the ultrasonic blade.

22. The surgical instrument of claim 21, wherein the first jaw member comprises a pulley positioned about the first axis and wherein the instrument further comprises a first cable positioned around the pulley to pivot the first jaw member about the first axis.

23. The surgical instrument of claim 21, wherein the second jaw member comprises a pulley positioned about the first axis and wherein the instrument further comprises a second cable positioned around the pulley to pivot the second jaw member about the first axis.

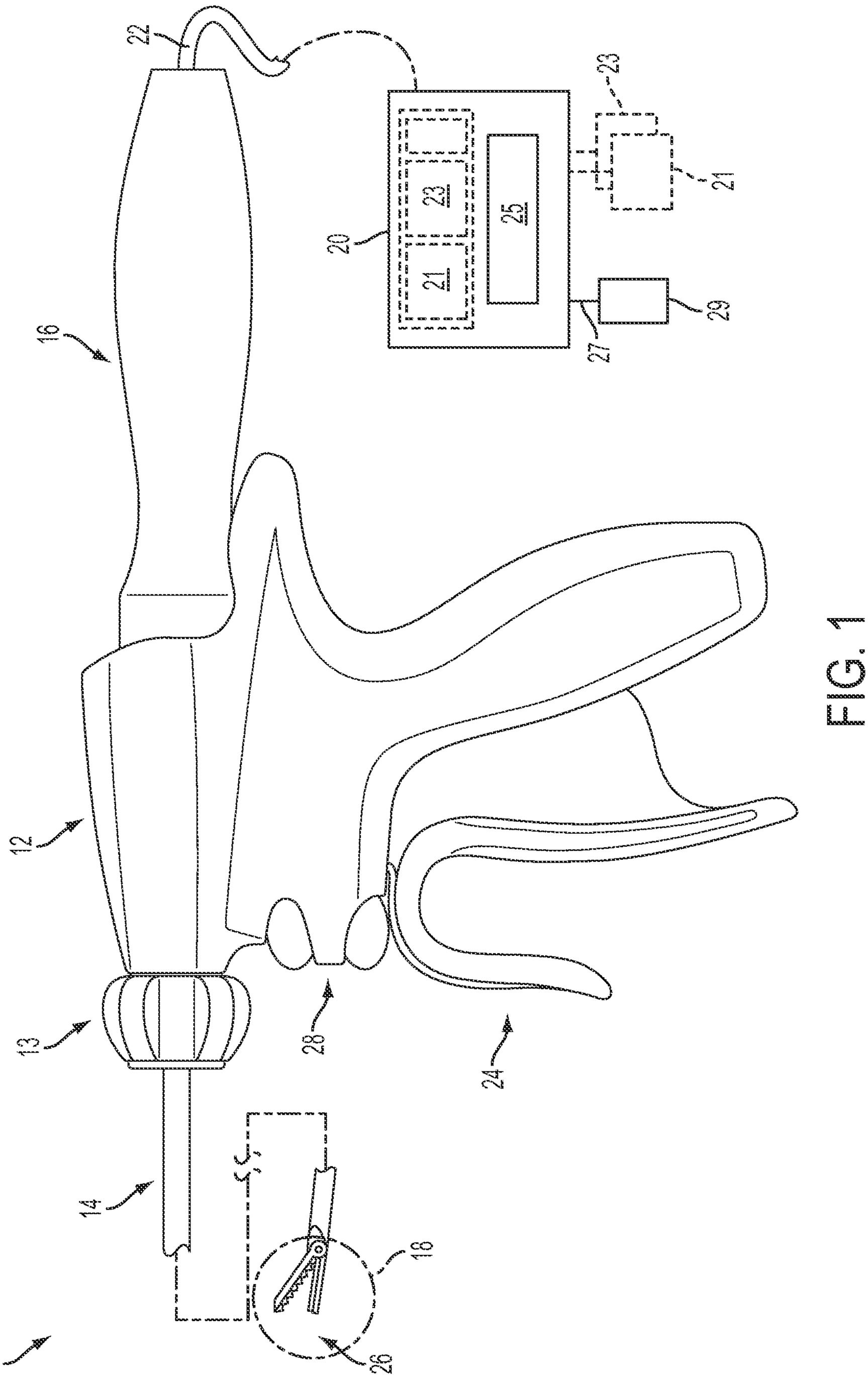

FIG. 1

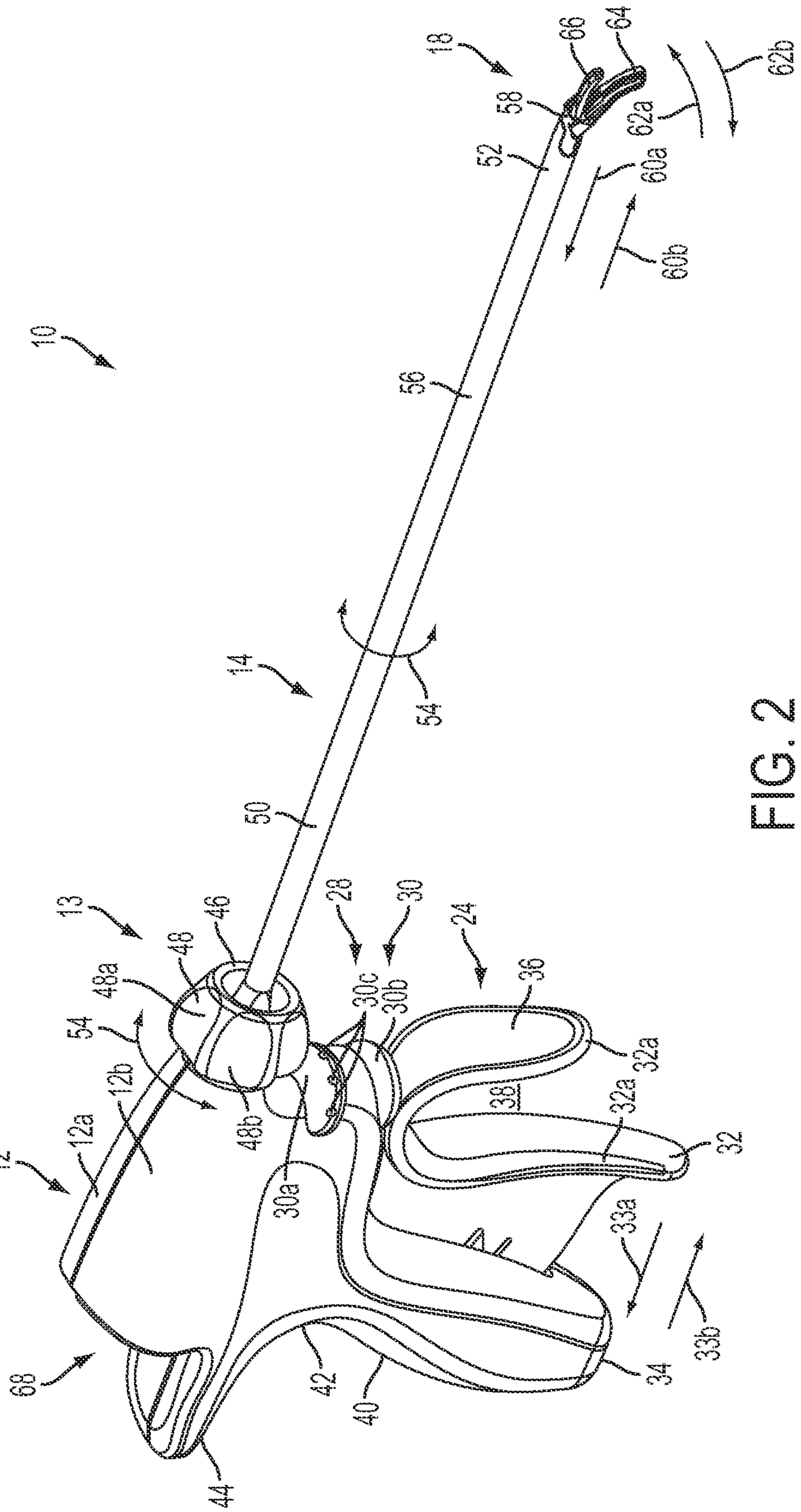
18
66
64
62b
58
62a
52
60a
60b
10
56
14
54
50
13
46
48
28
30
24
48a
30c
30b
36
54
12b
32a
12a
48b
38
32a
12
30a
32
33a
68
42
40
34
33b
44

FIG. 2

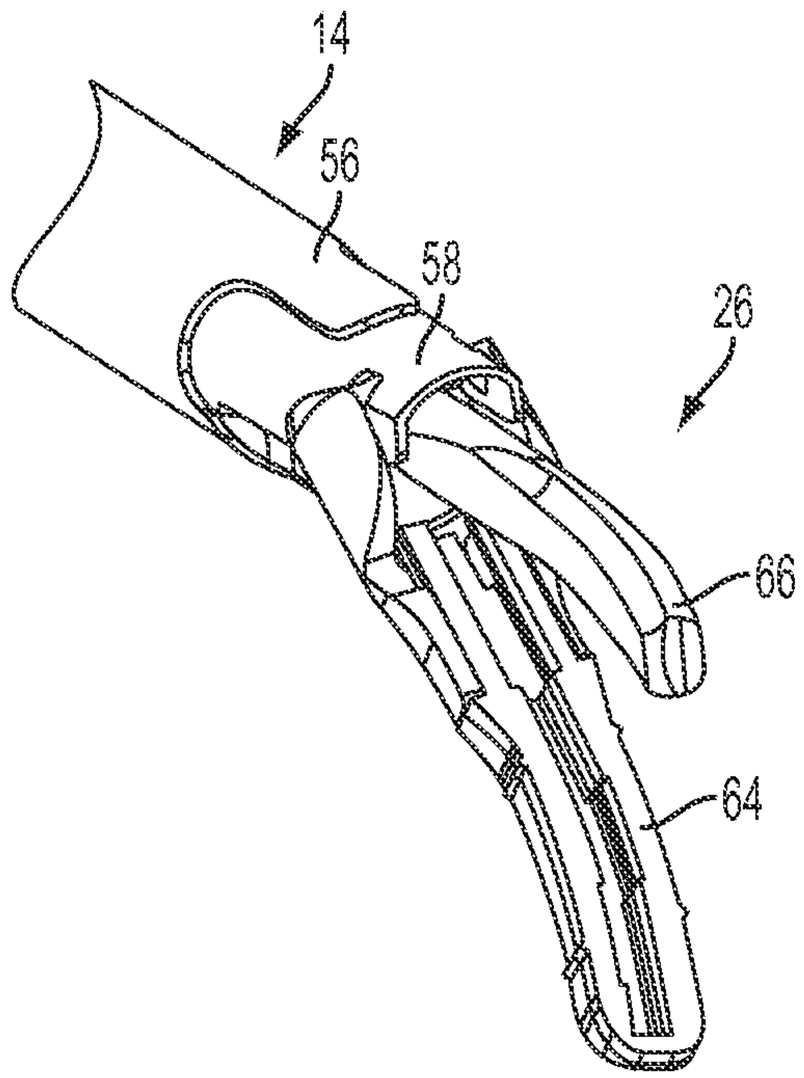

FIG. 3

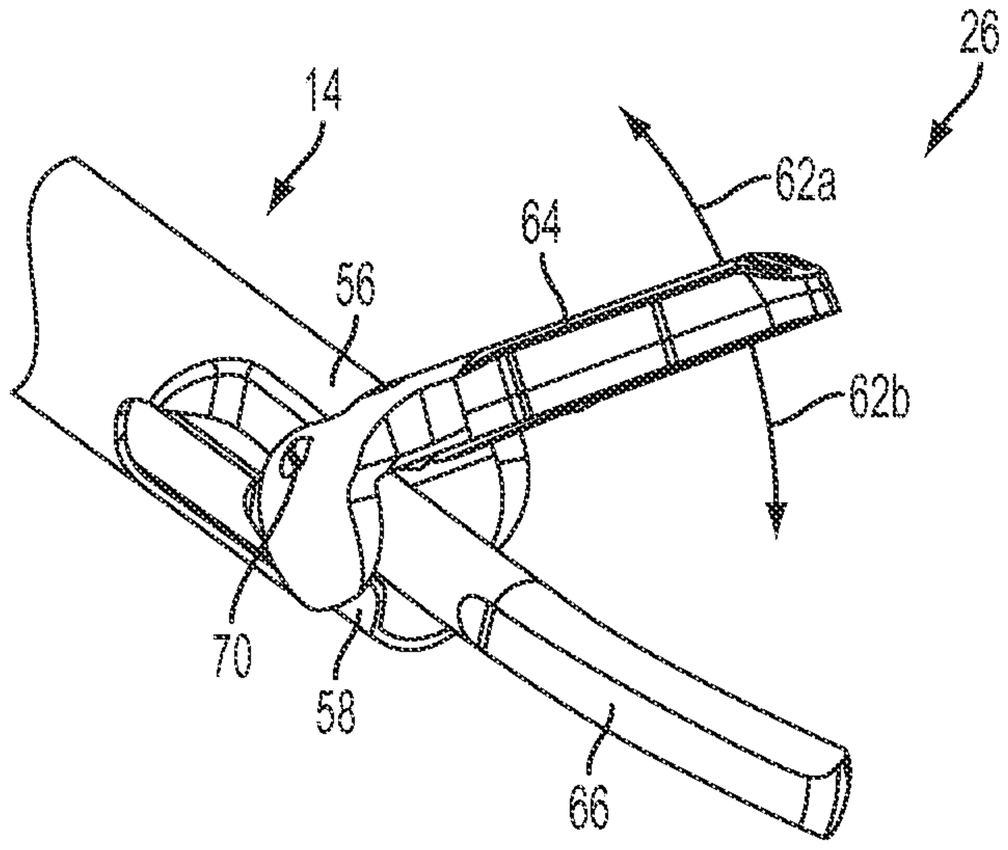

FIG. 4

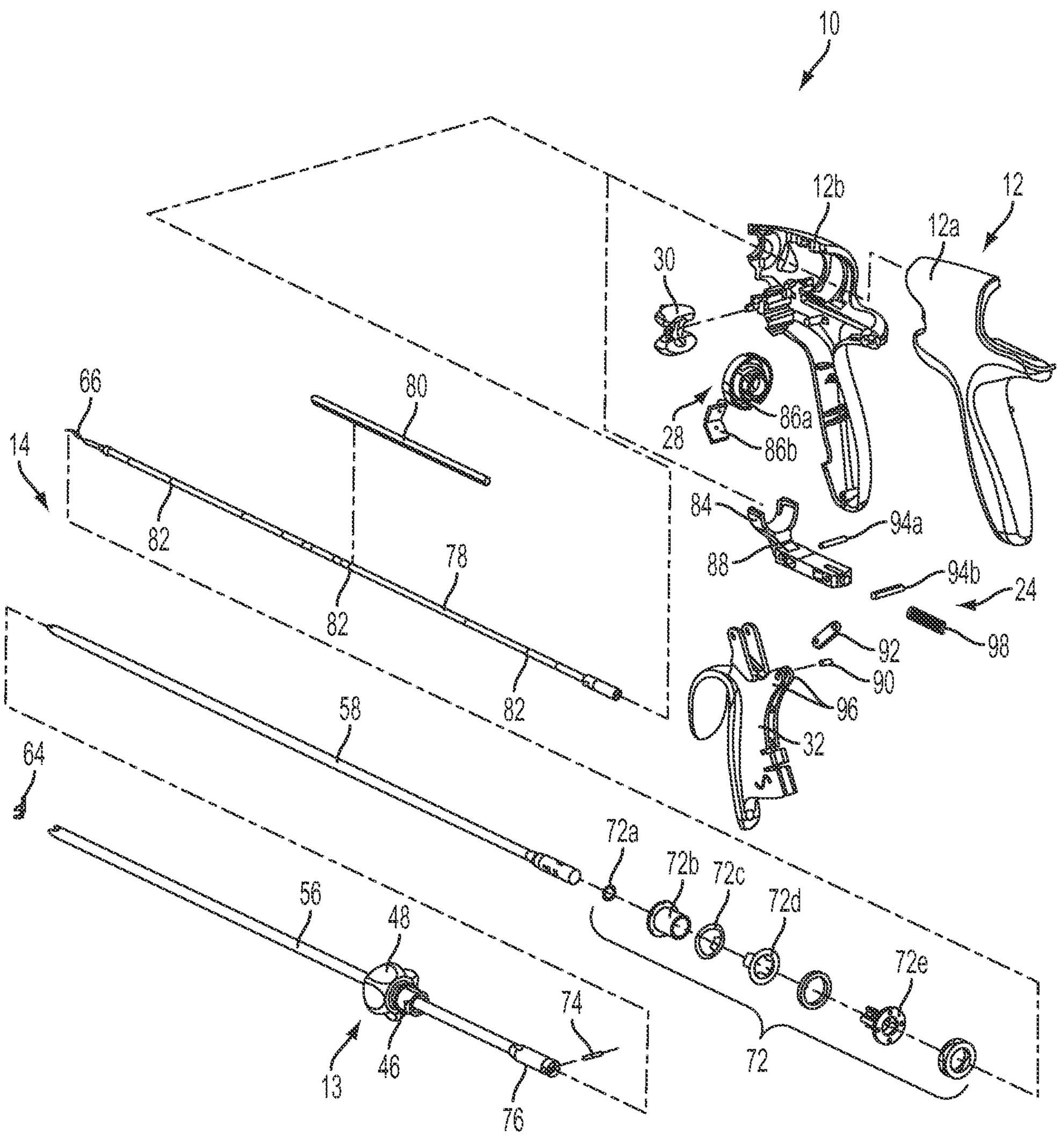
10
12b
12
12a
30
66
80
14
86a
28
86b
84
94a
82
78
88
94b
24
92
98
90
96
58
32
64
72a
72b
72c
72d
72e
56
48
74
72
13
46
76
82

FIG. 5

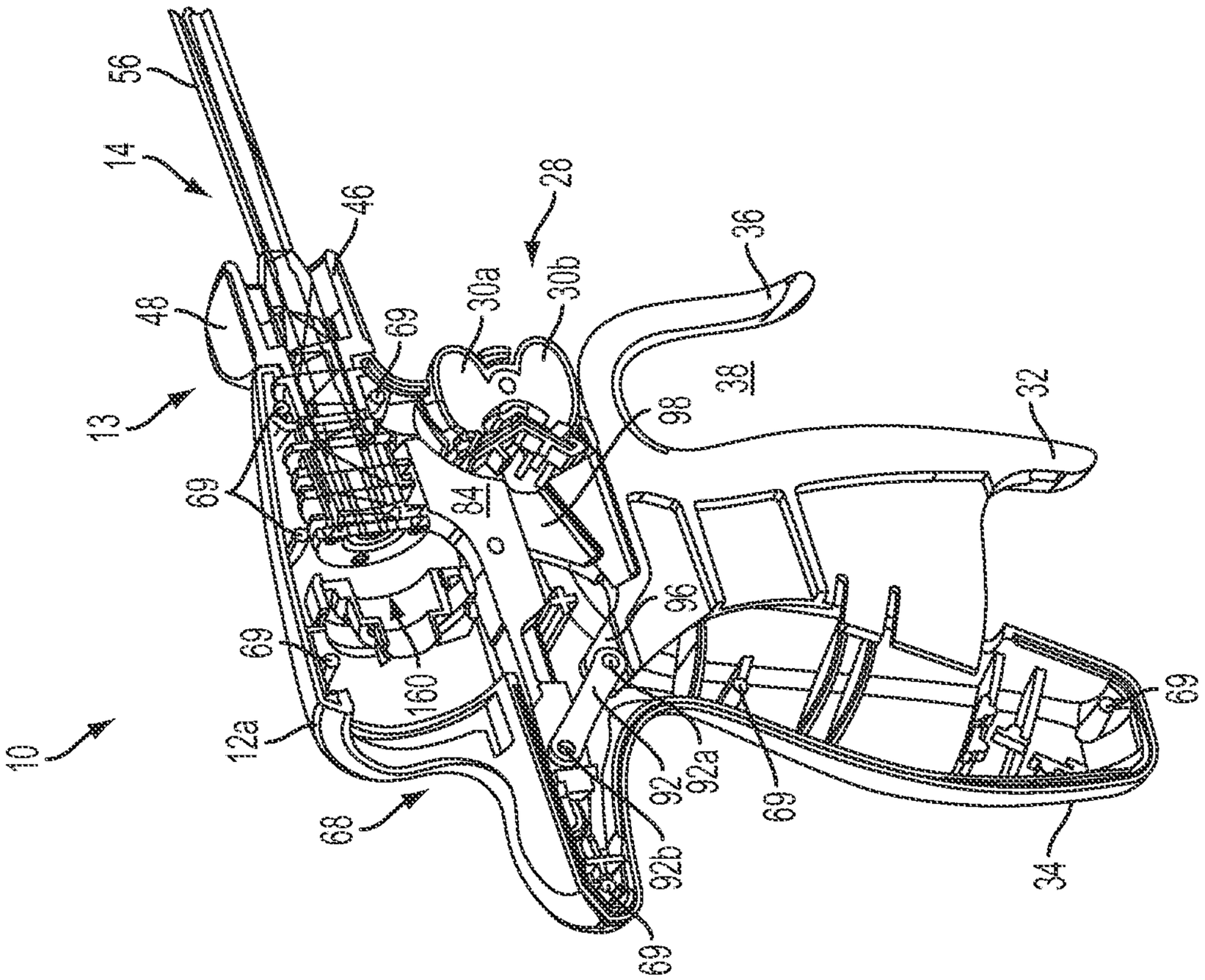
56
14
46
28
48
30a
30b
36
69
13
38
32
84
98
69
96
69
160
12a
10
92
92a
69
68
92b
69
34

FIG. 7

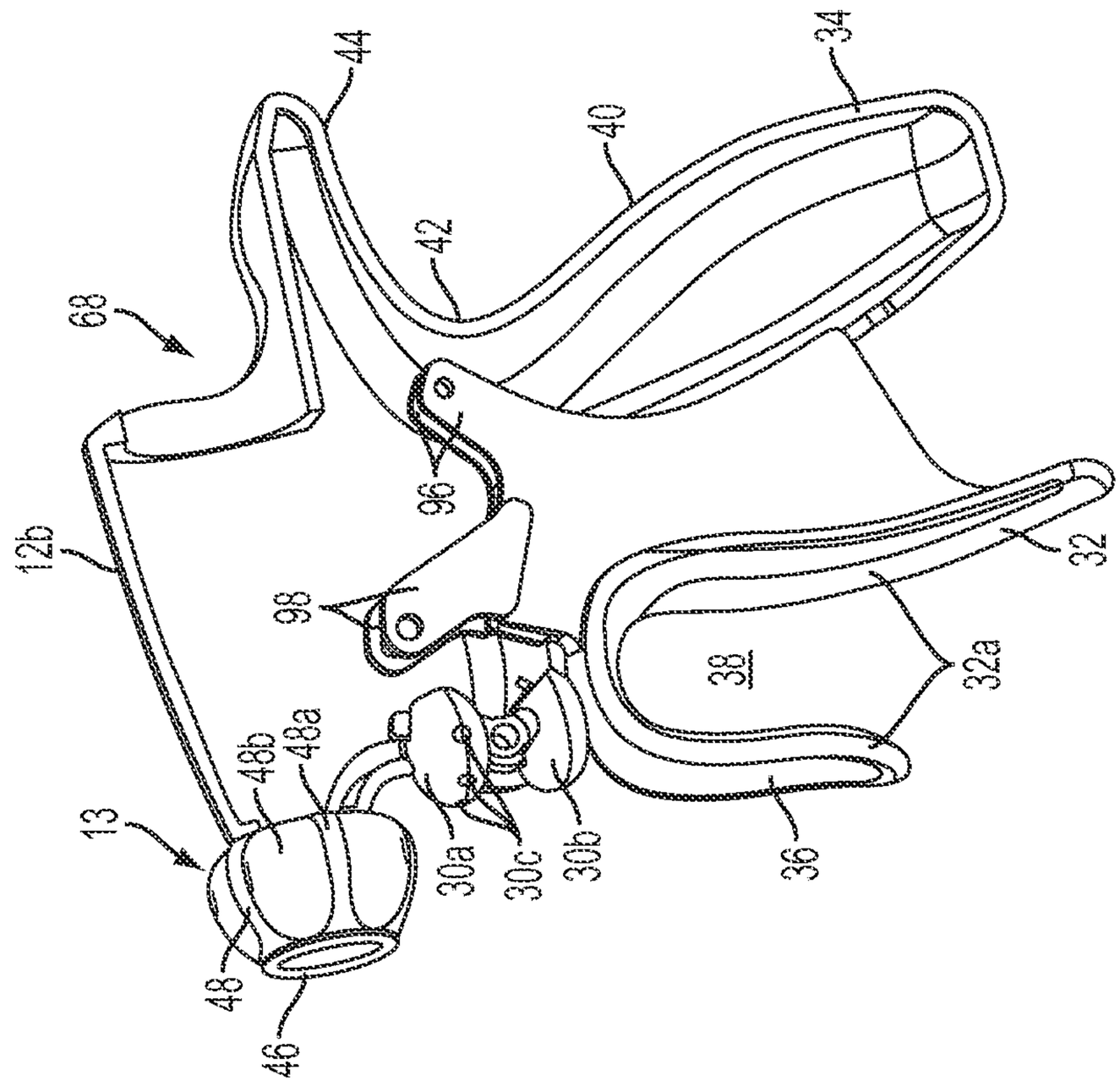
44
34
40
42
68
96
12b
98
32
38
32a
48b
48a
13
30a
30c
30b
36
48
46

FIG. 6

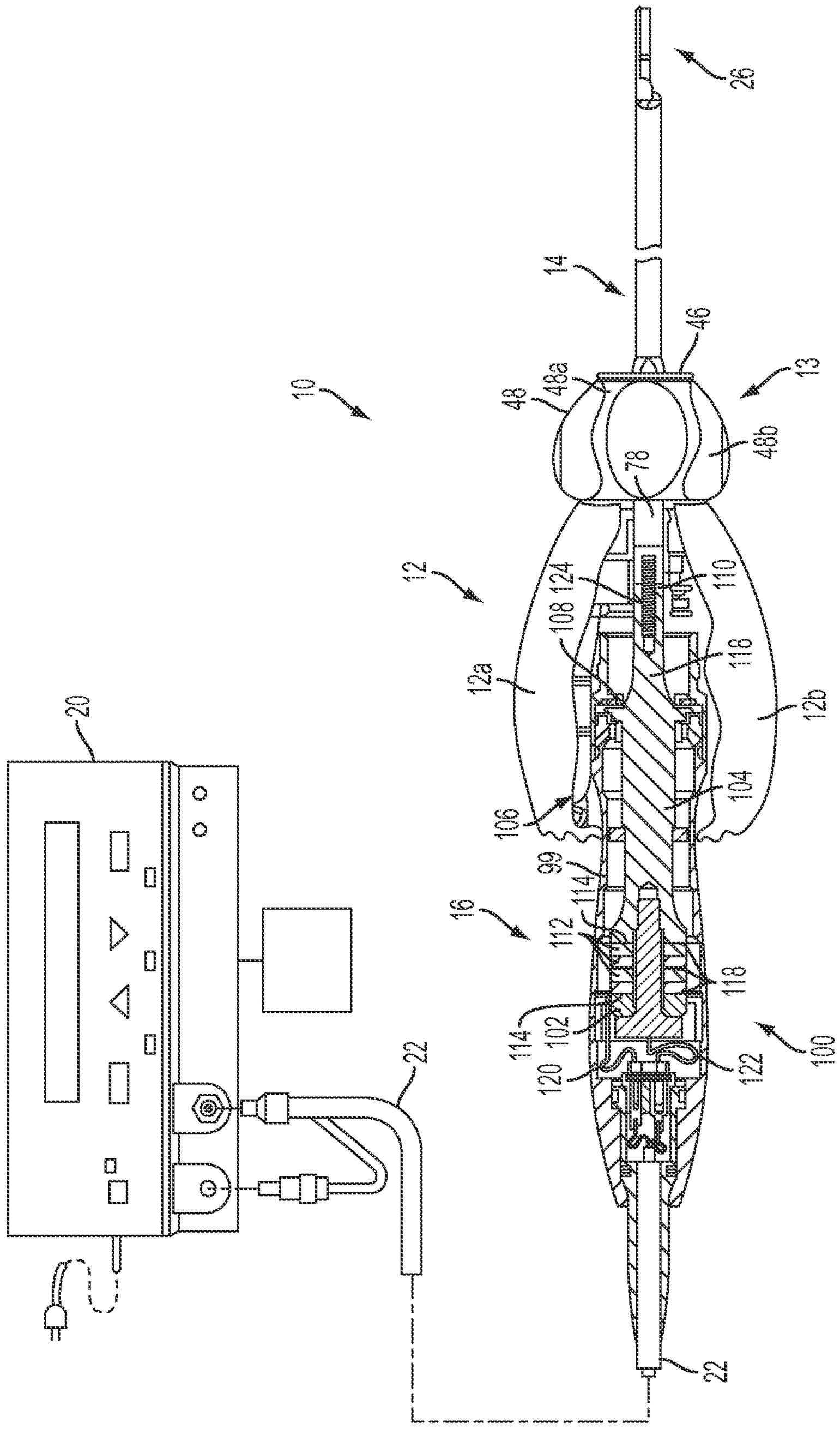
10
12
12a
12b
13
14
16
20
22
26
46
48
48a
48b
78
99
100
102
104
106
108
110
112
114
116
118
120
122
124

FIG. 8

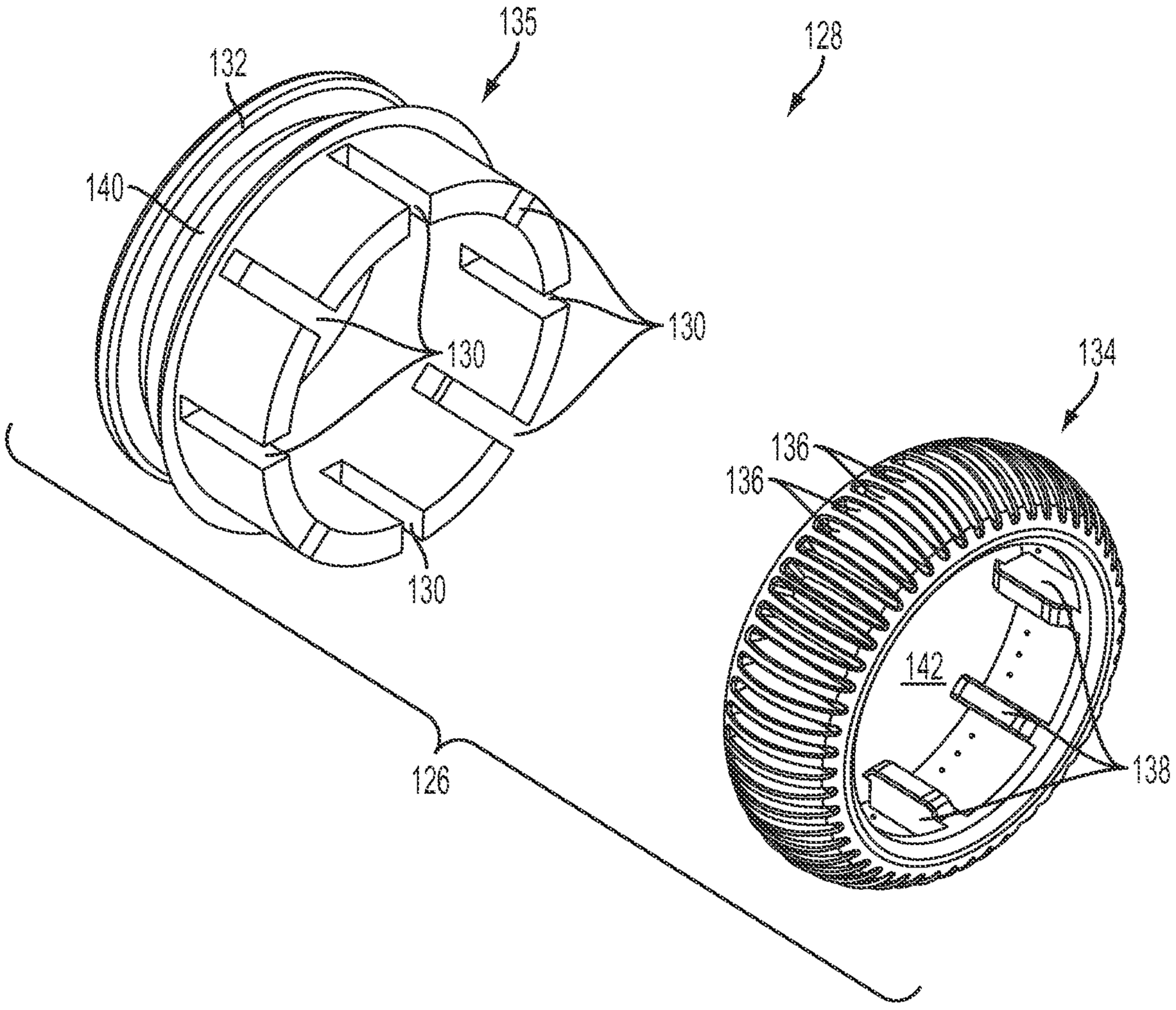

FIG. 9

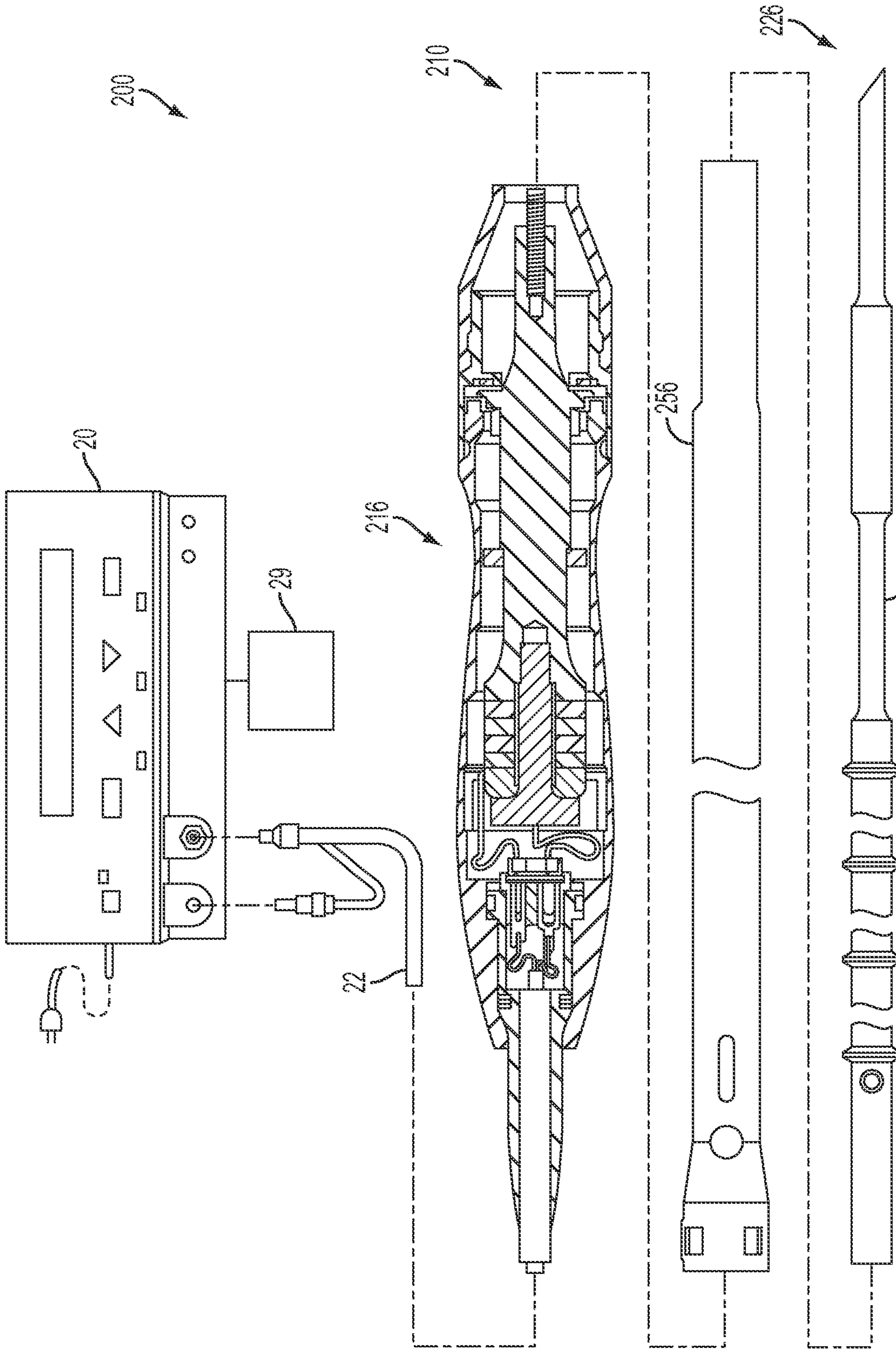

FIG. 10

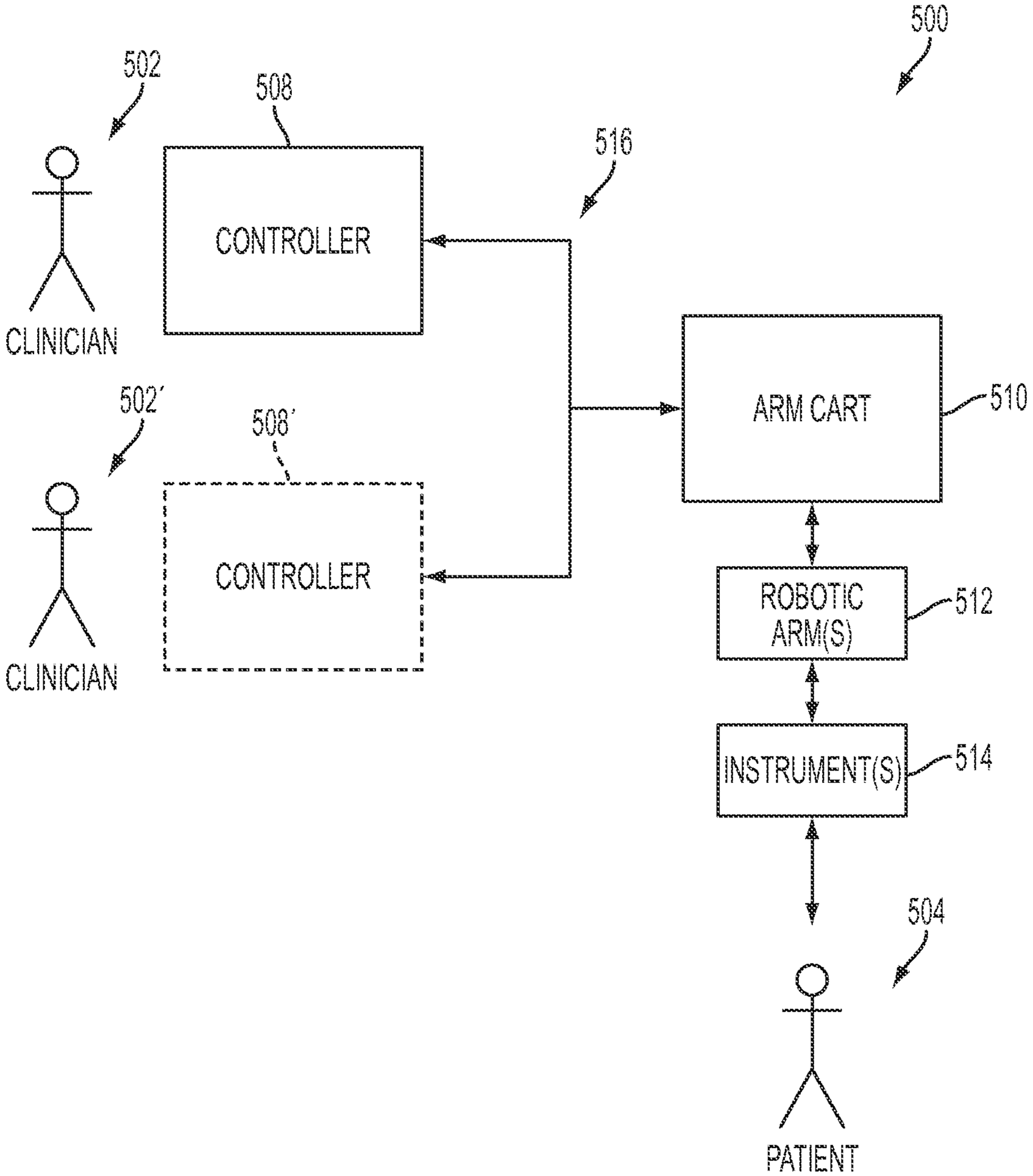
500
502
508
516
CONTROLLER
CLINICIAN
502'
508'
CONTROLLER
CLINICIAN
ARM CART
510
ROBOTIC ARM(S)
512
INSTRUMENT(S)
514
504
PATIENT

FIG. 11

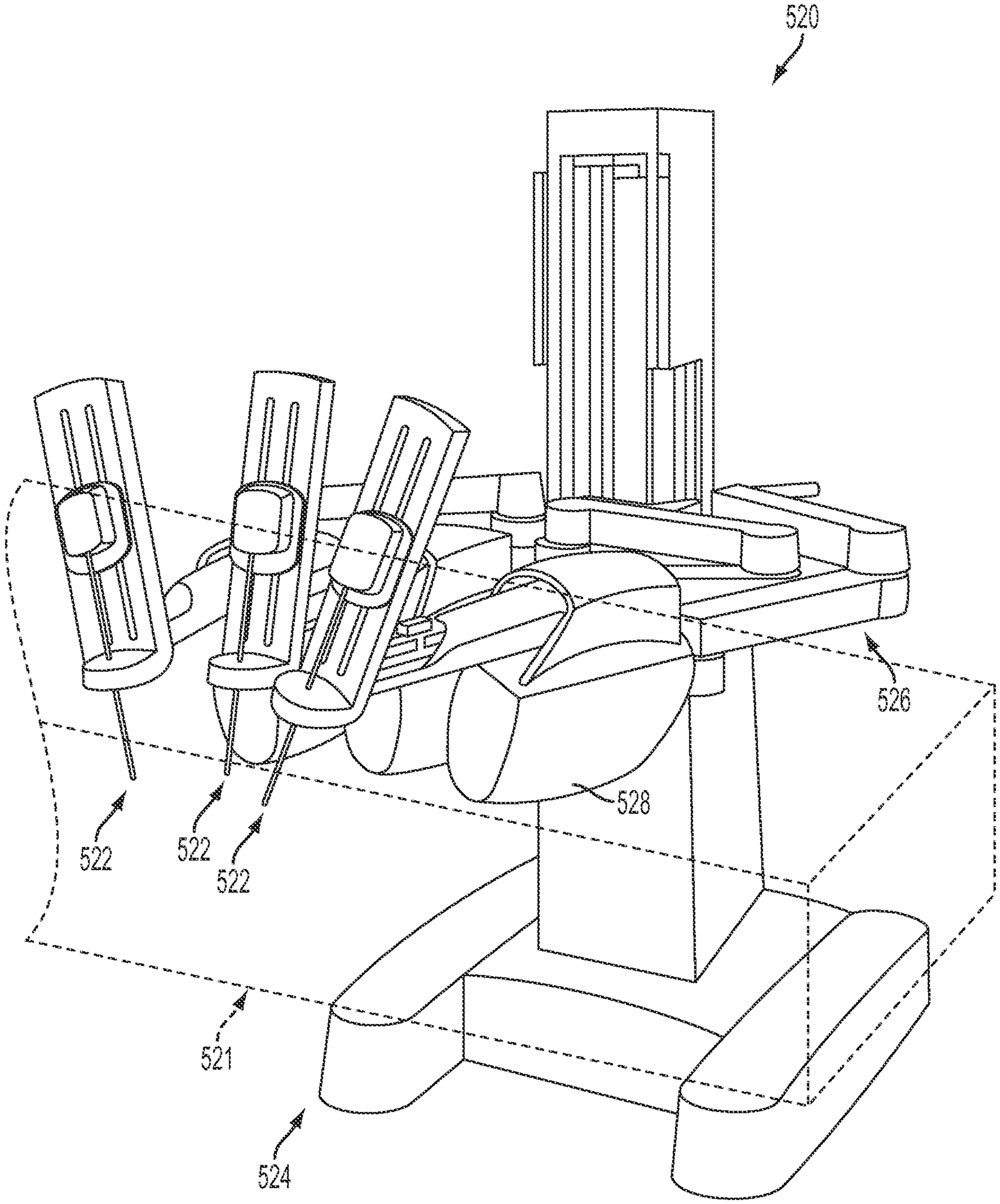

FIG. 12

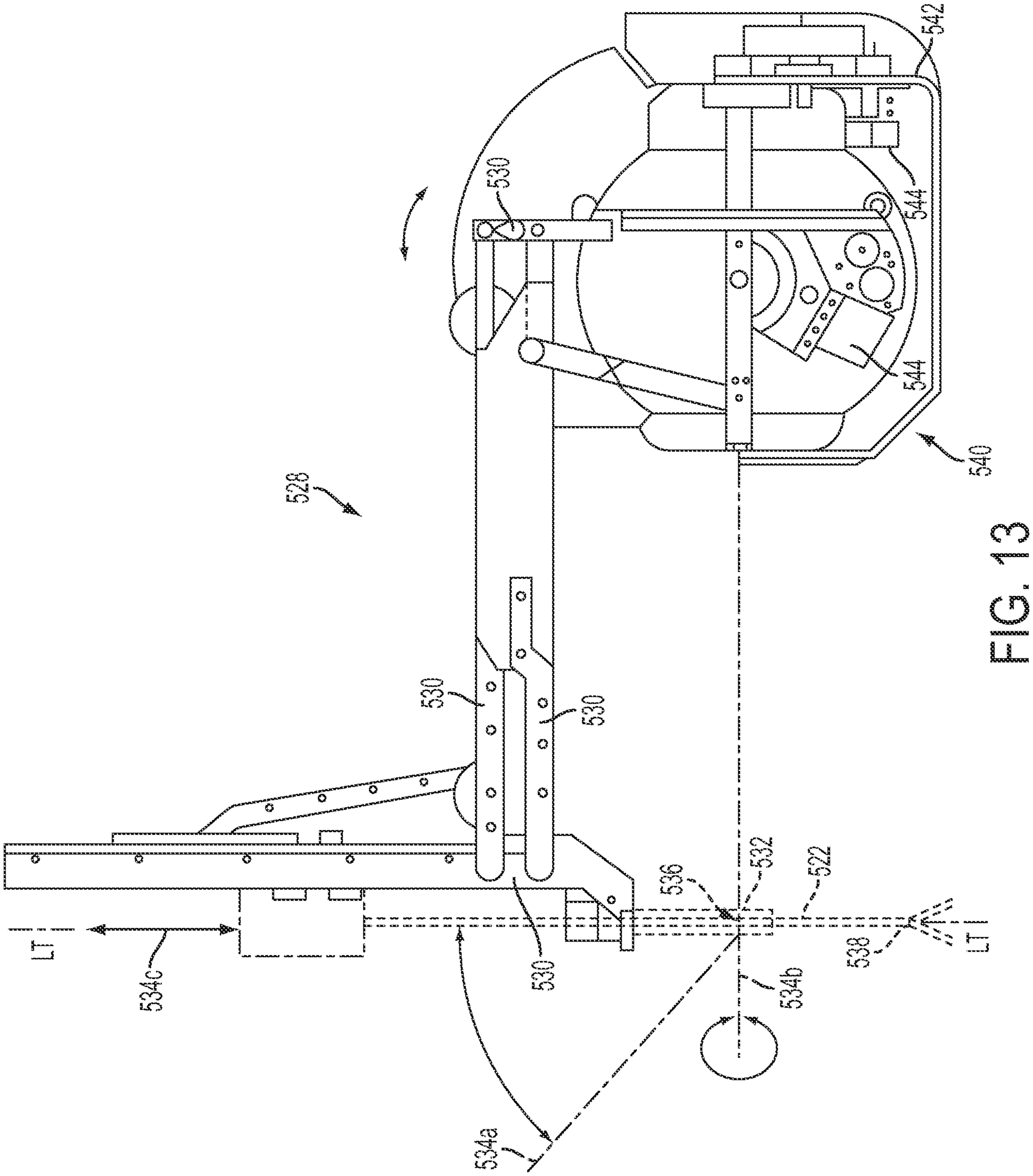
542
530
544
544
540
528
530
530
530
LT
534c
536
532
522
538
LT
534b
534a

FIG. 13

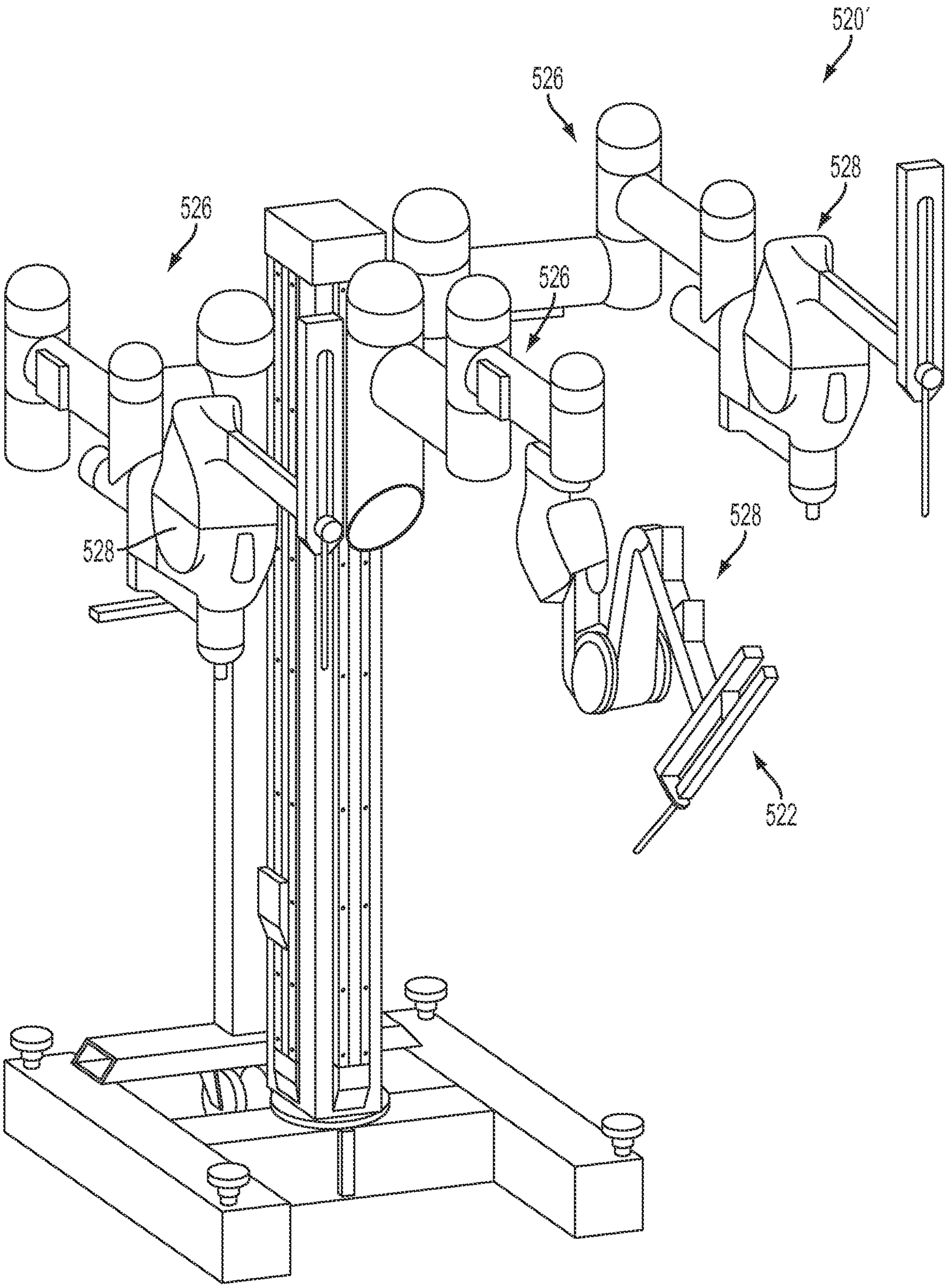

FIG. 14

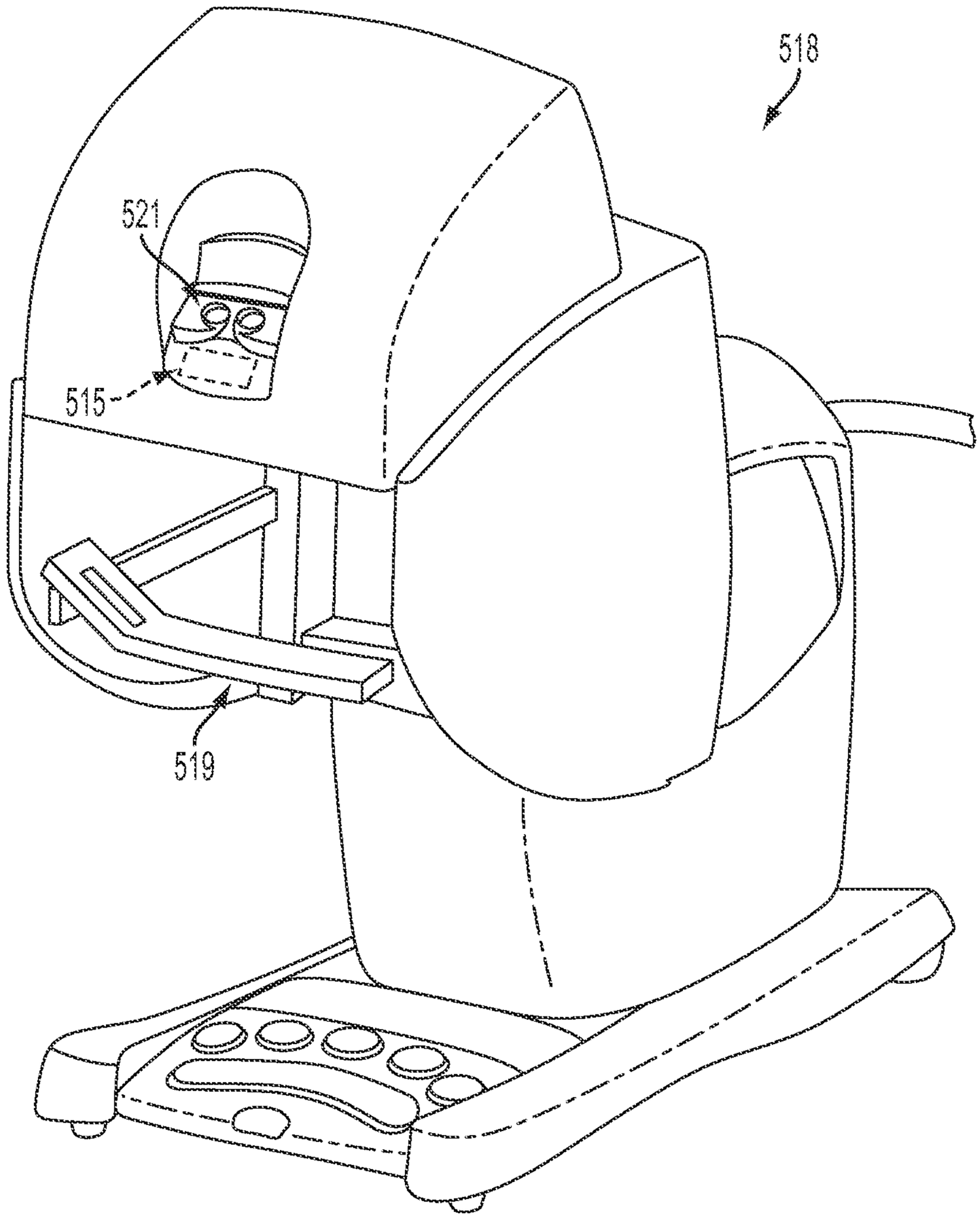

FIG. 15

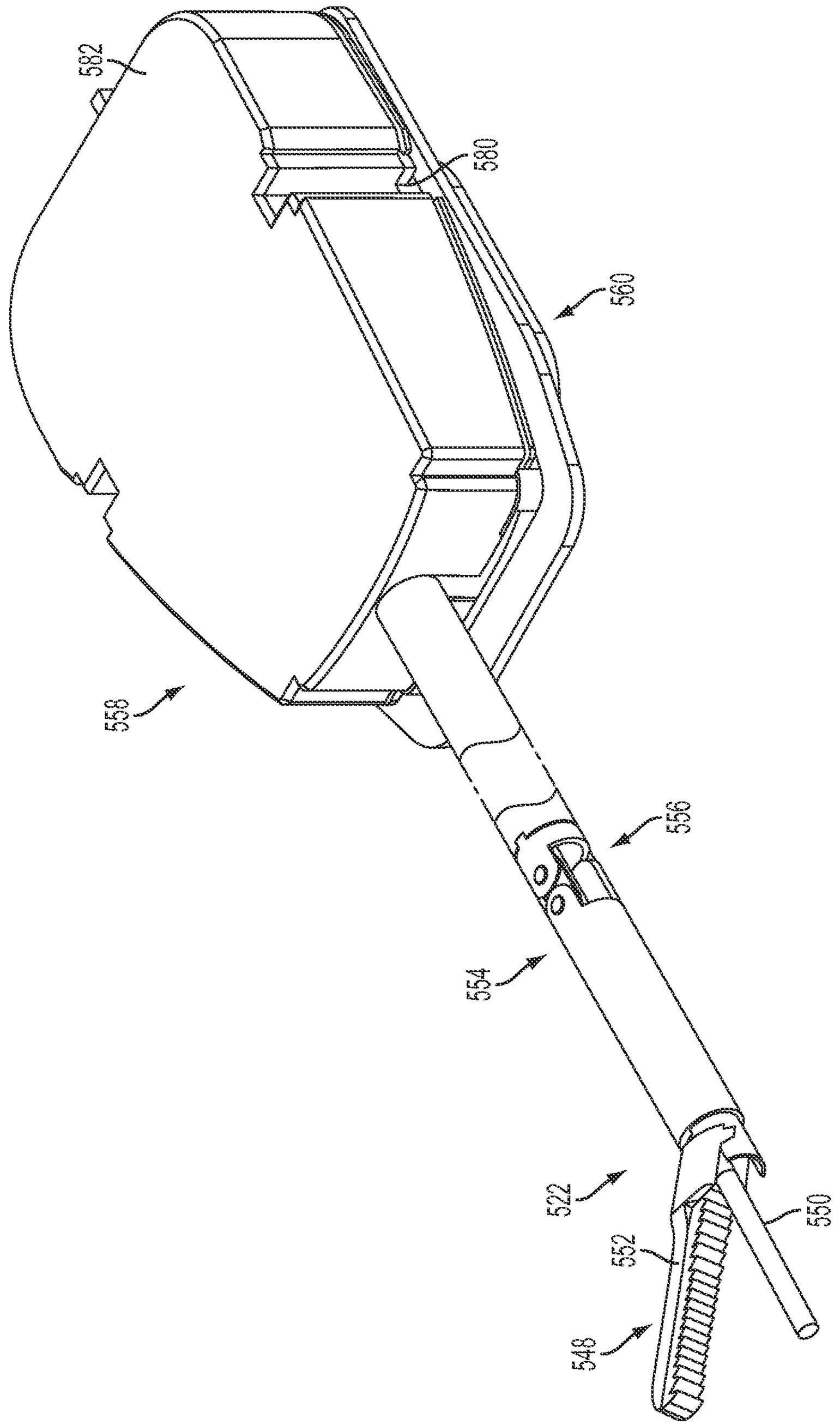

FIG. 16

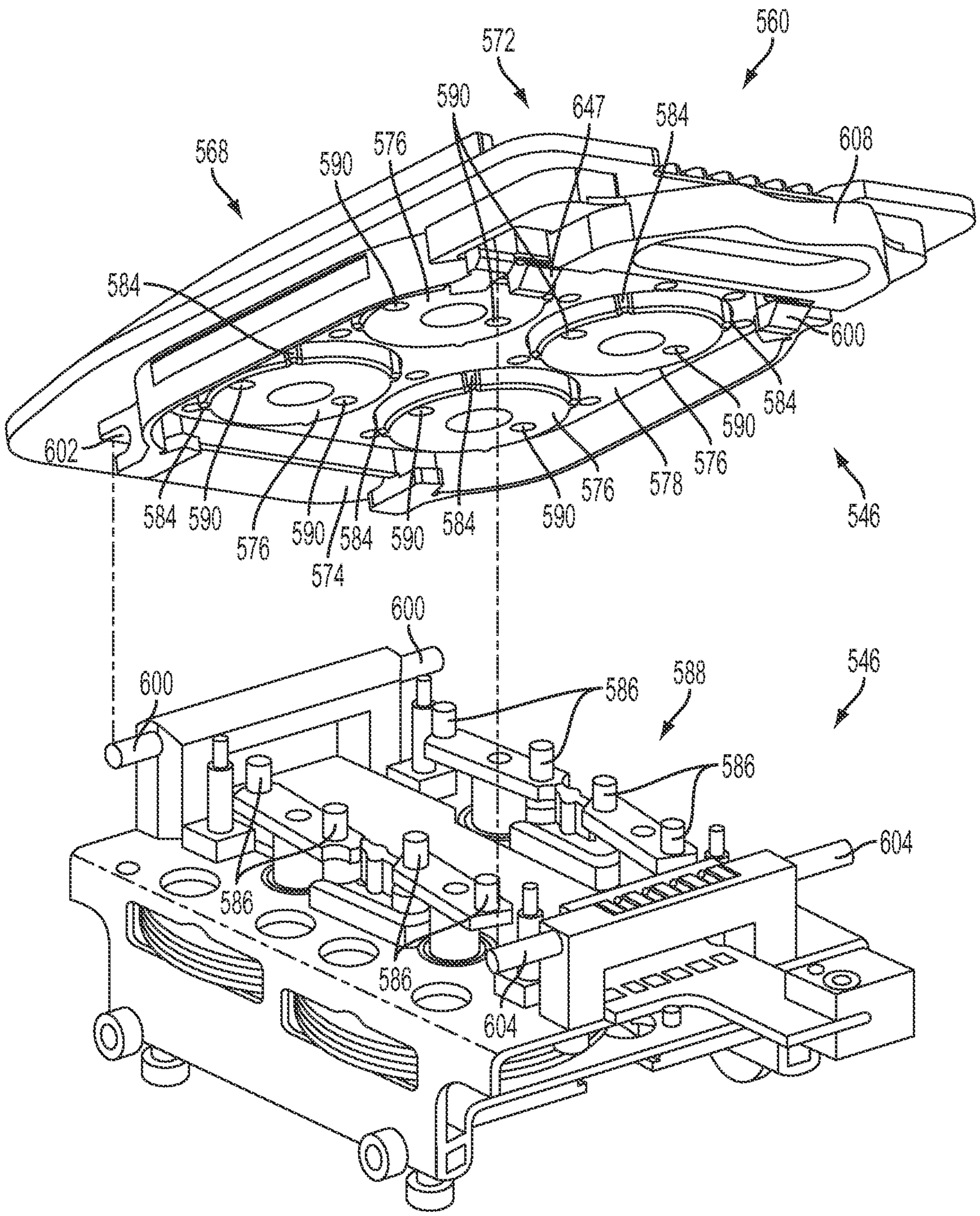
560
572
590
647
584
568
576
590
608
584
600
584
590
602
576
578
576
546
584
590
576
590
584
590
584
590
574
600
600
588
546
586
586
586
604
586
604

FIG. 17

522
505
548
520
554
558
562
564
566
567
568
570
576
578
590
560
636

FIG. 18

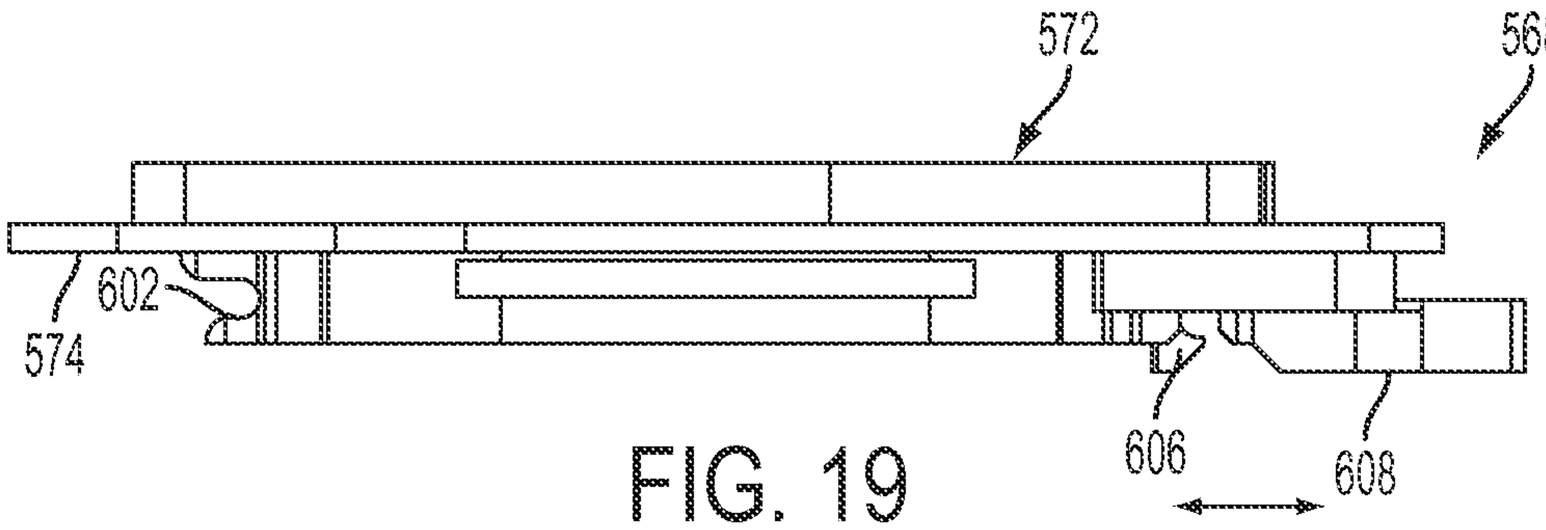
572
568
602
574
606
608

FIG. 19

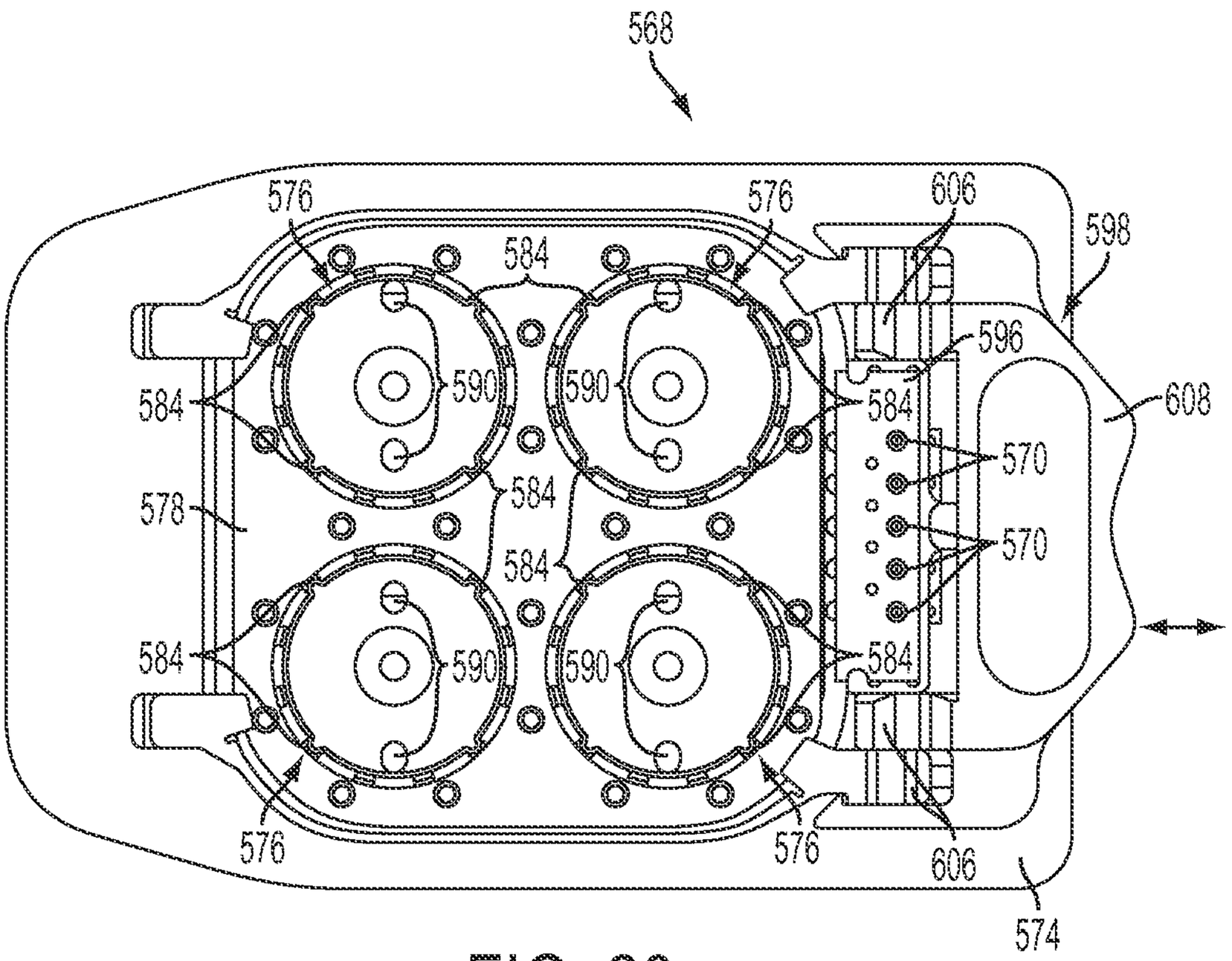
568
576
576
606
598
584
596
590
590
584
608
584
570
578
584
570
584
590
590
584
576
576
606
574

FIG. 20

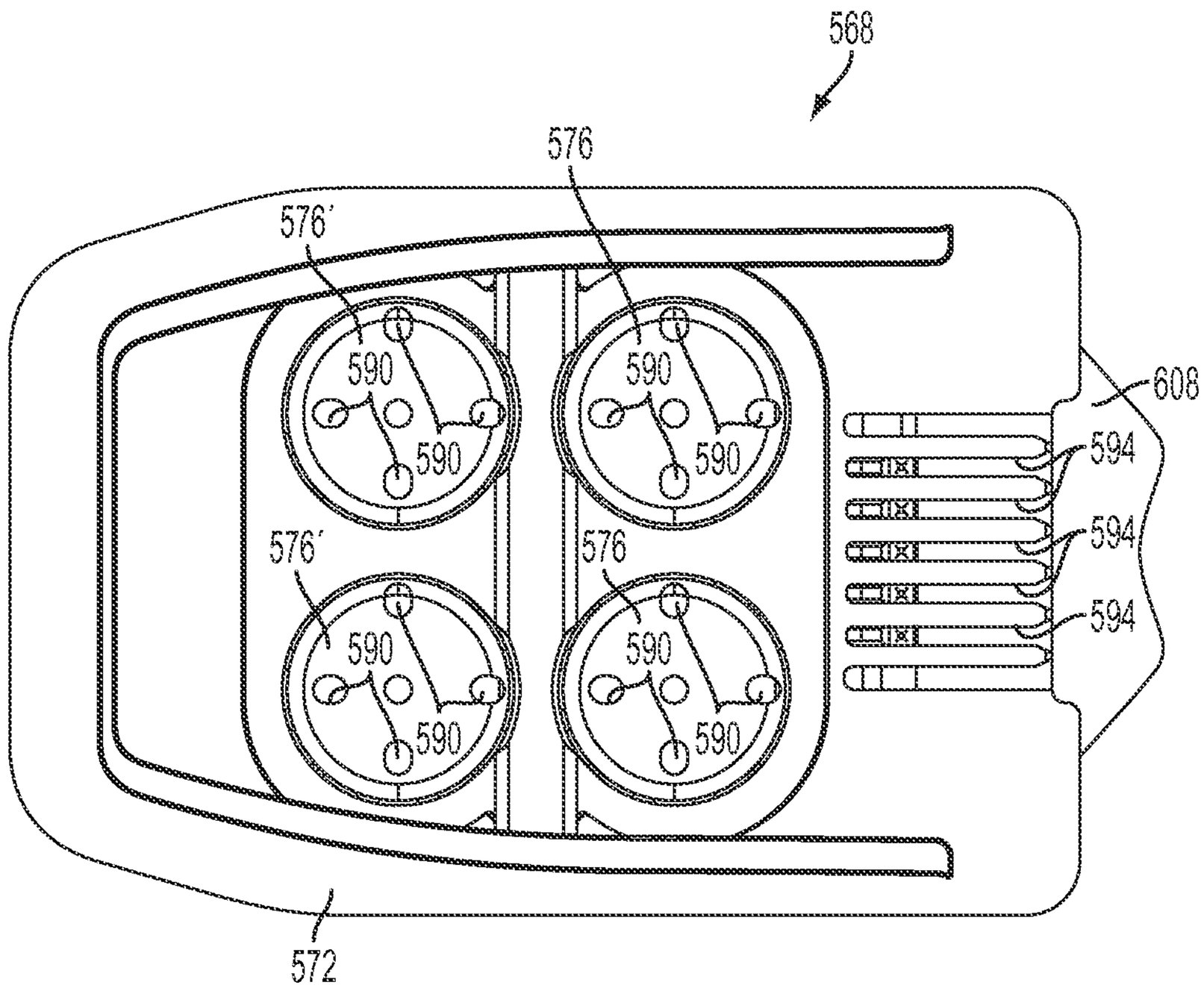
568
576
576'
590
590
590
590
576'
576
590
590
590
590
608
594
594
594
572

FIG. 21

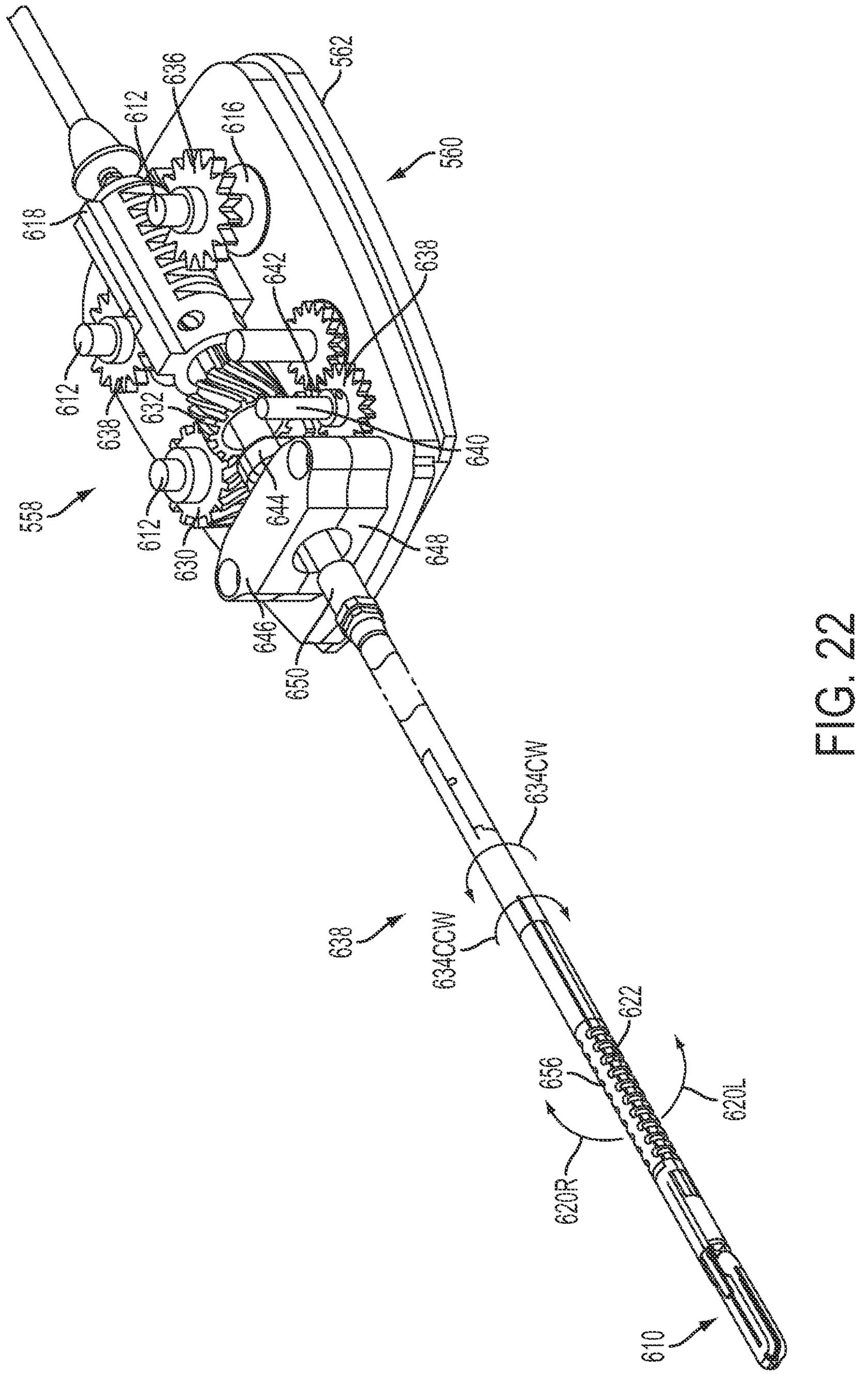
612
636
616
562
560
618
642
638
612
632
638
640
558
612
644
630
648
646
650
638
634CW
634CCW
622
656
620L
620R
610

FIG. 22

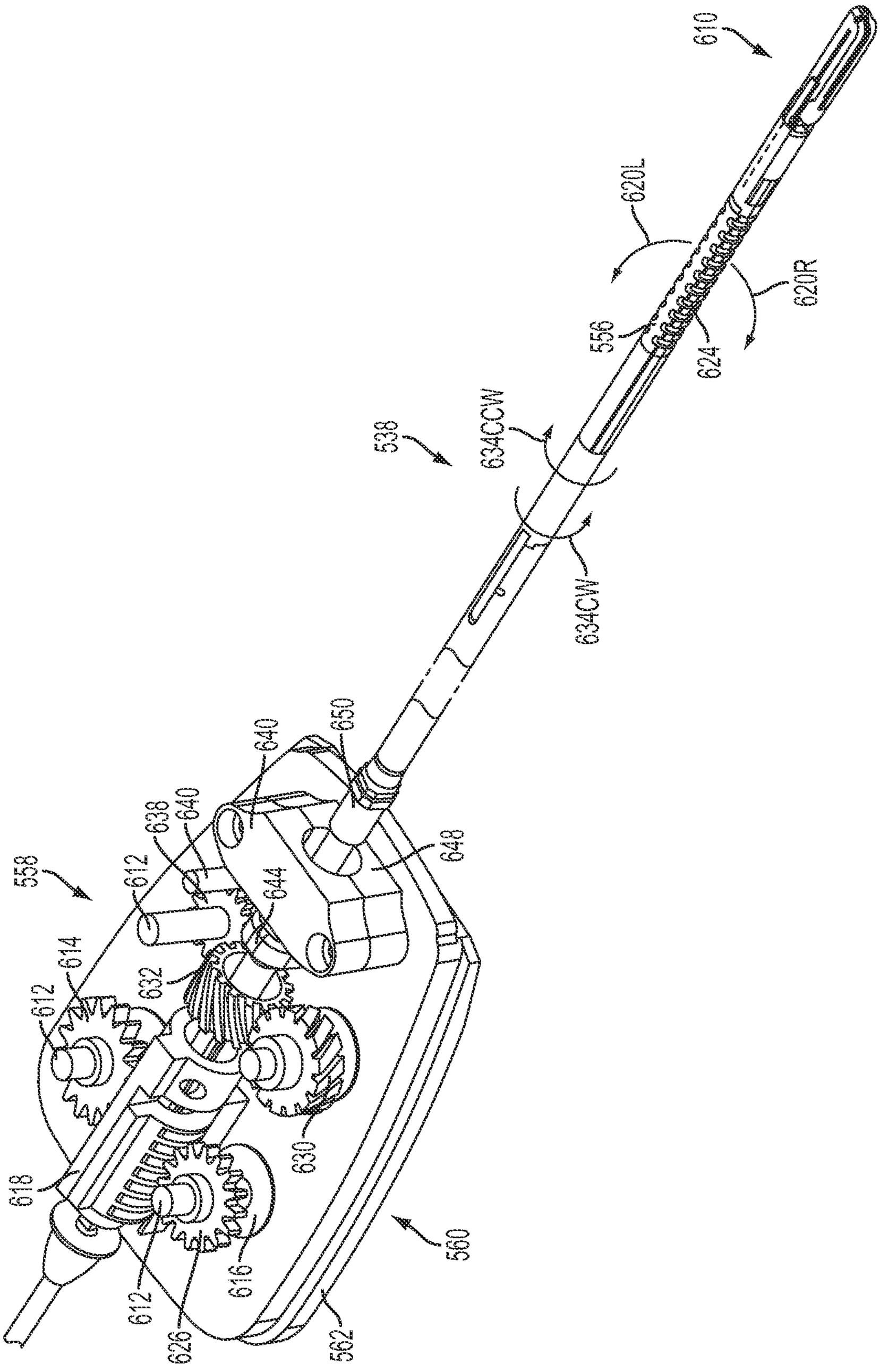
610
620L
620R
556
624
538
634CCW
634CW
558
612
614
632
638
640
644
650
648
618
630
616
626
562
560

FIG. 23

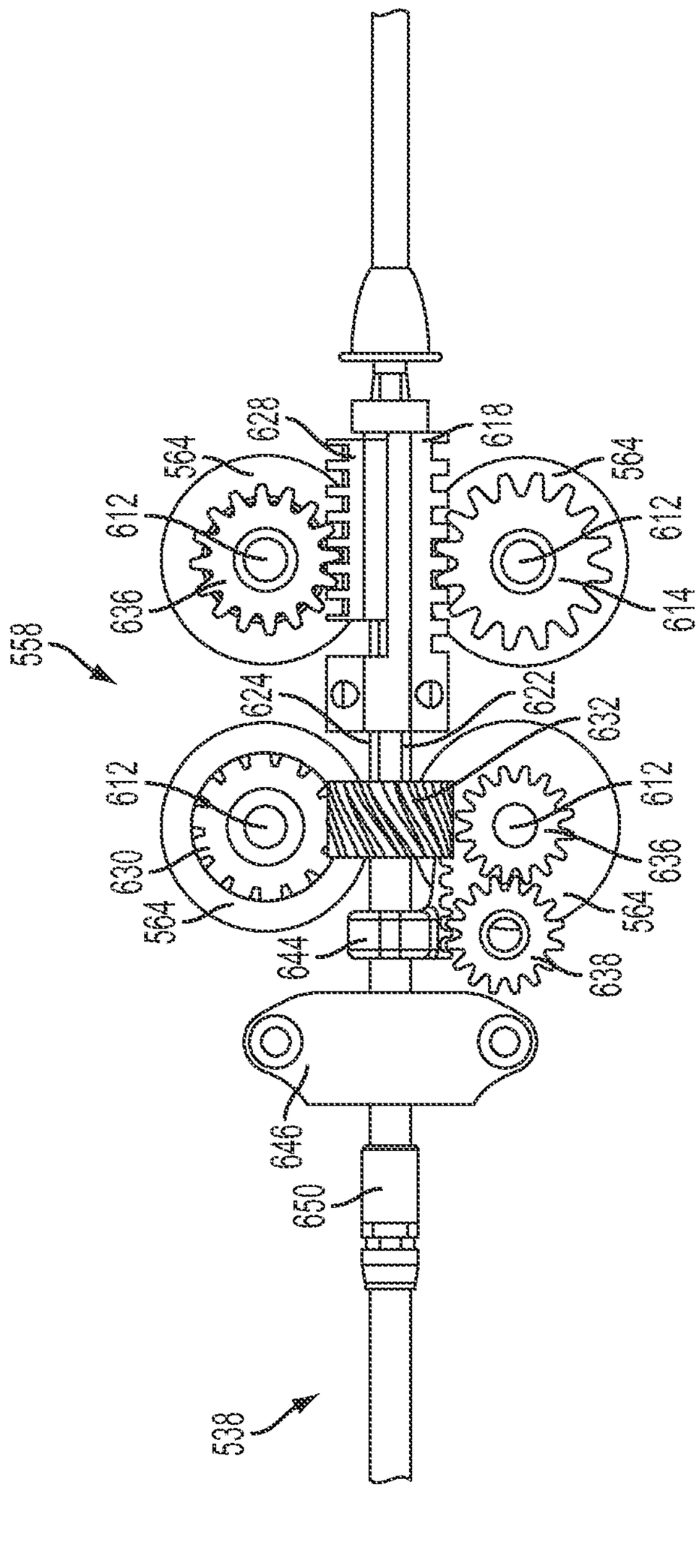

FIG. 24

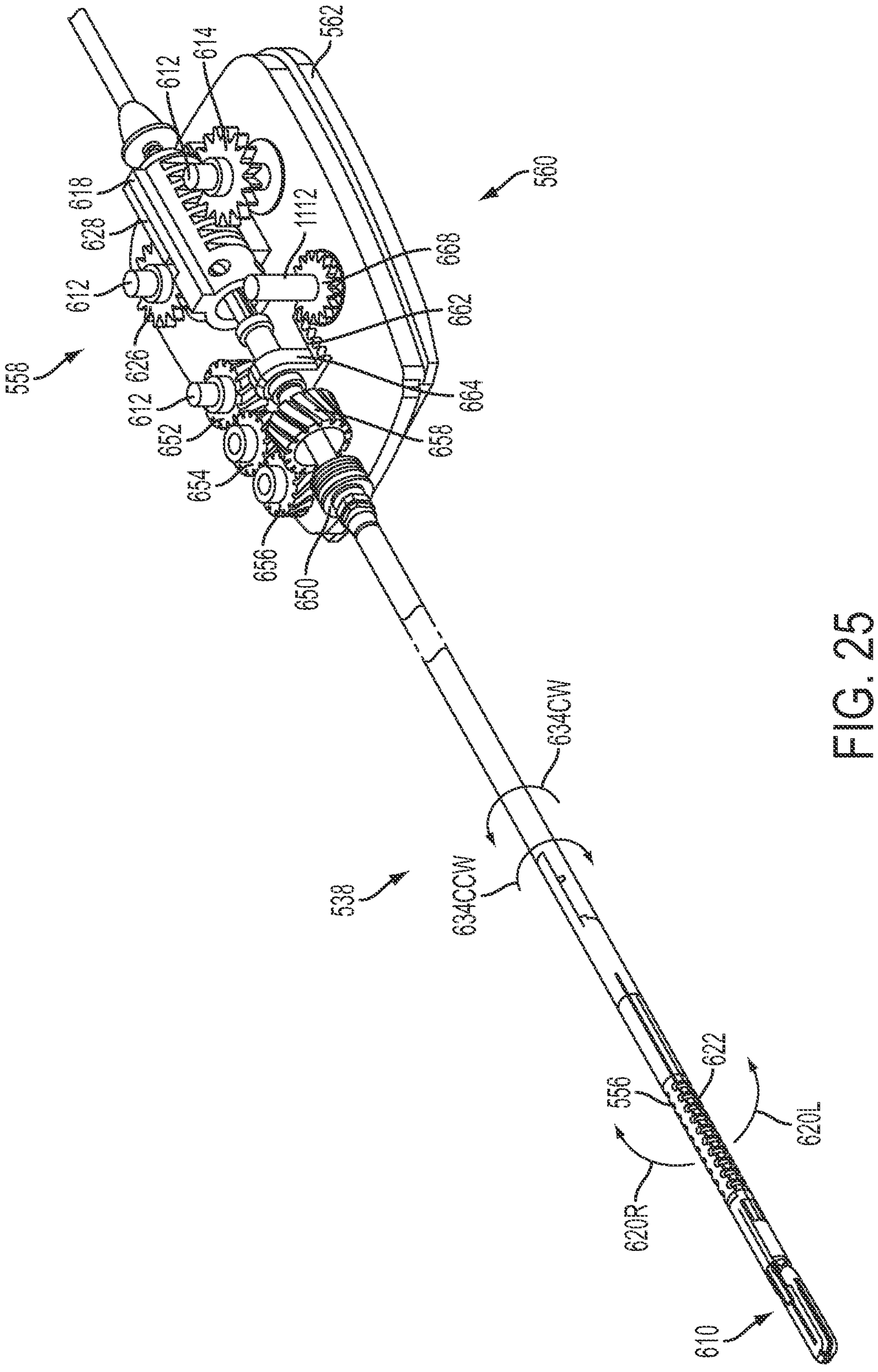
562
614
612
618
628
612
626
612
652
654
656
650
558
560
1112
668
662
664
658
538
634CCW
634CW
622
556
620R
620L
610

FIG. 25

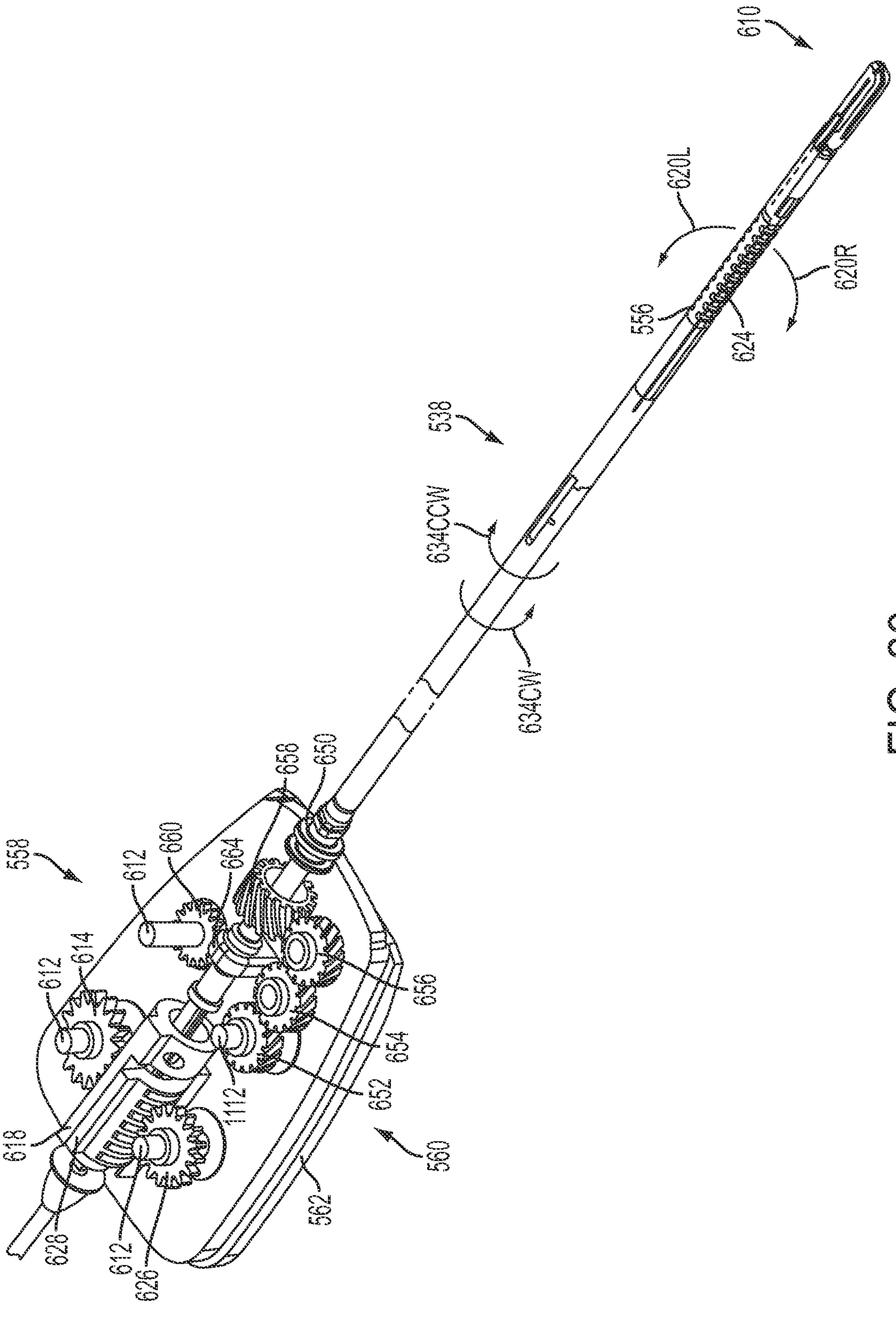
610
620L
620R
556
624
538
634CCW
634CW
558
612
660
664
658
650
614
656
654
652
1112
618
628
626
562
560

FIG. 26

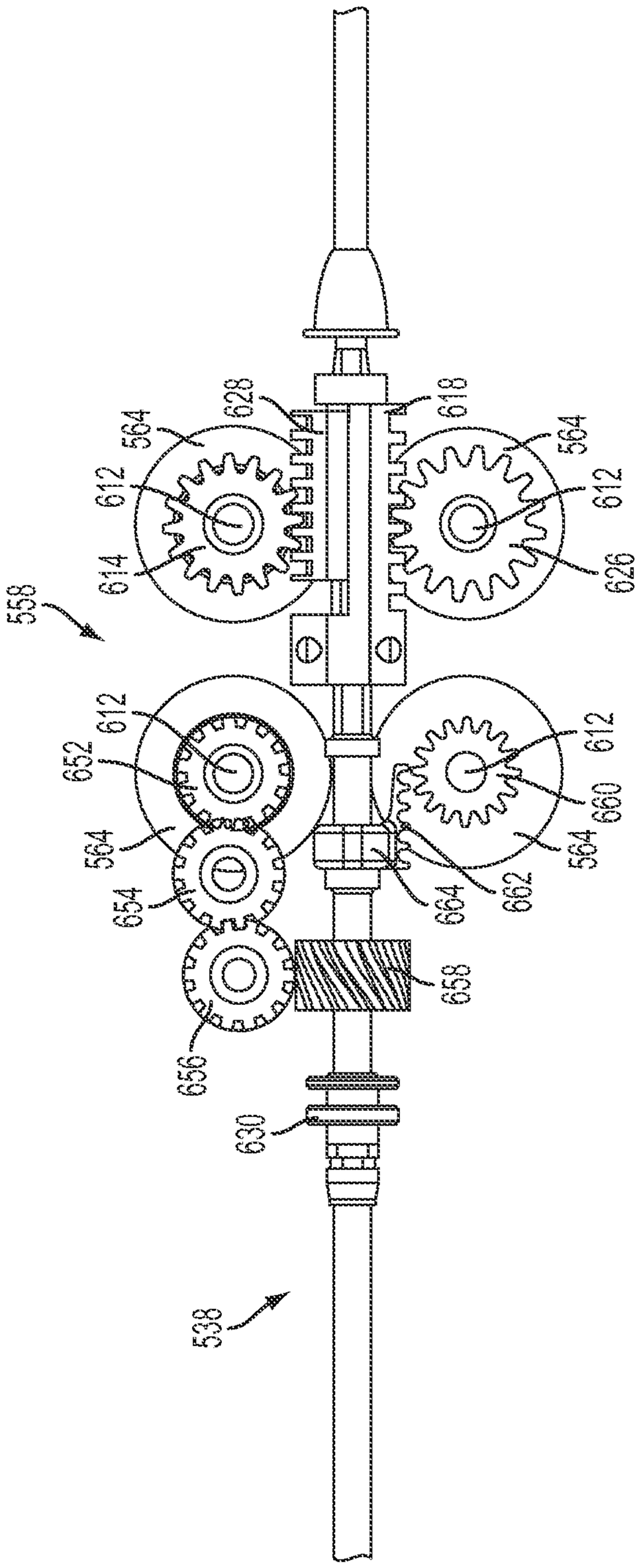

FIG. 27

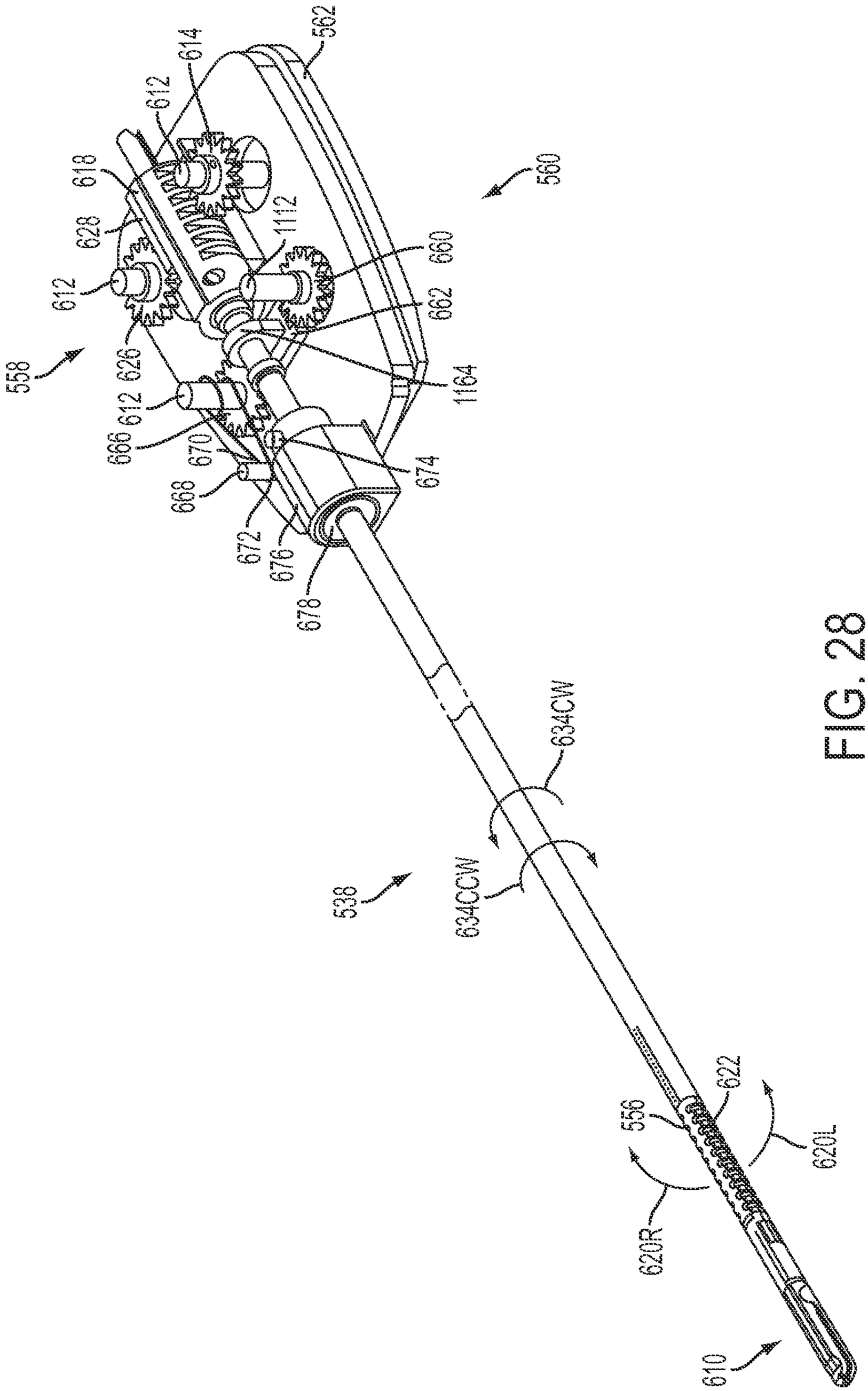
562
614
612
618
628
612
626
612
666
670
668
672
676
678
558
1112
660
662
1164
674
560
634CW
634CCW
538
622
556
620R
620L
610

FIG. 28

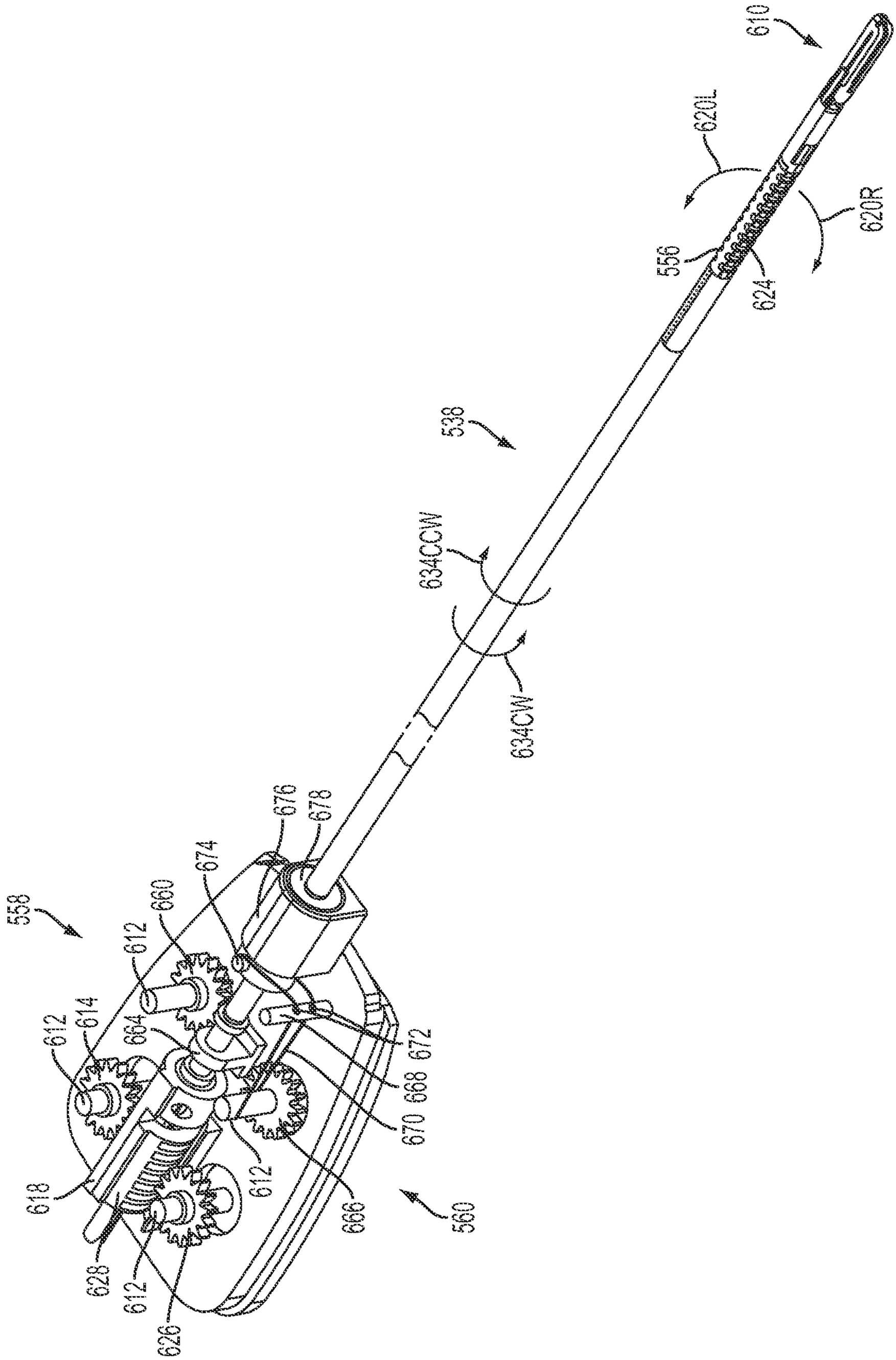
610
620L
620R
556
624
538
634CCW
634CW
558
612
614
660
674
676
678
664
672
670
668
618
628
626
666
560

FIG. 29

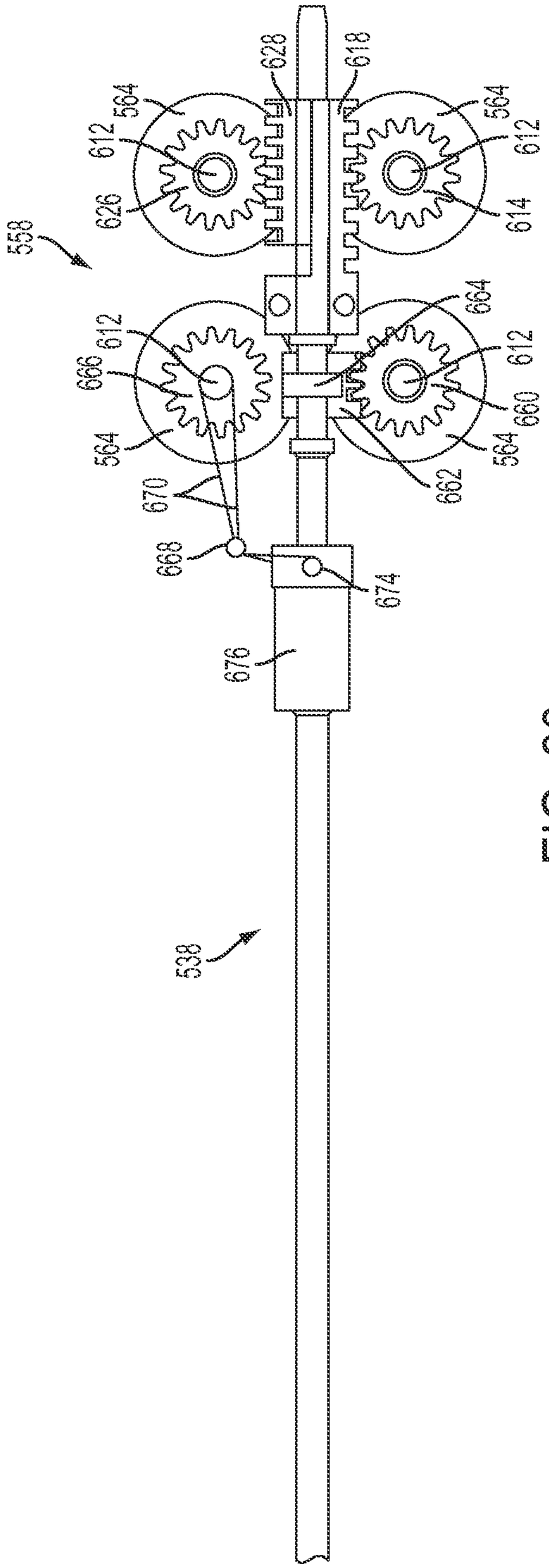

FIG. 30

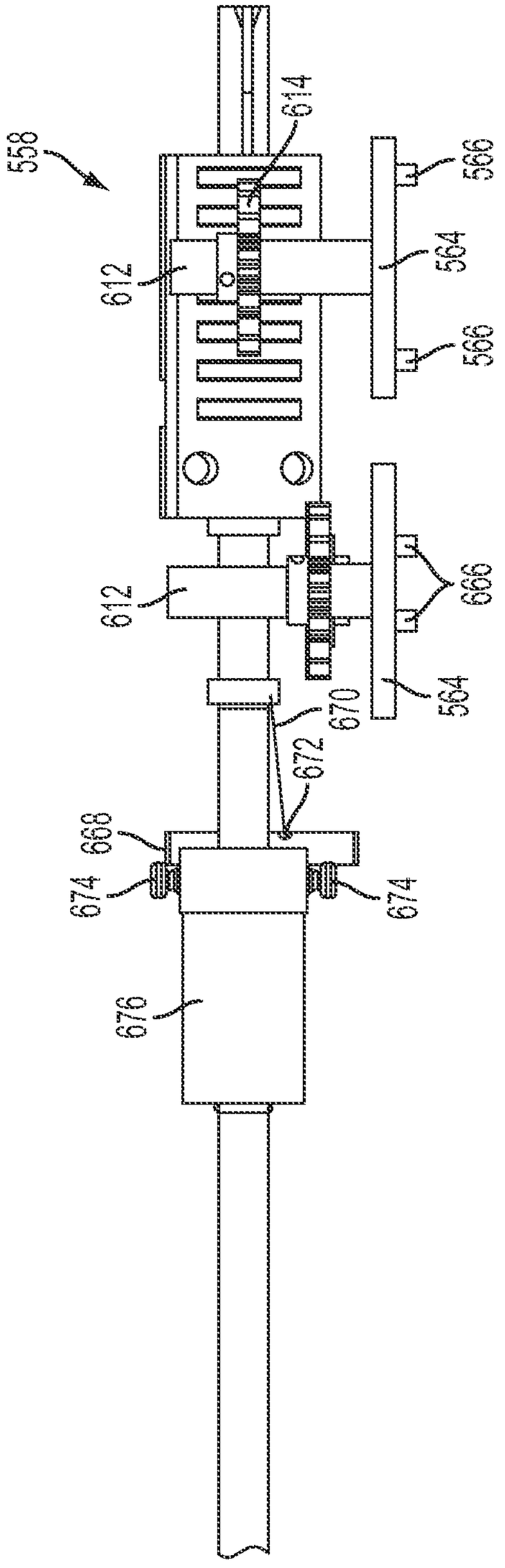
558
614
612
566
564
566
612
666
564
670
672
668
674
674
676

FIG. 31

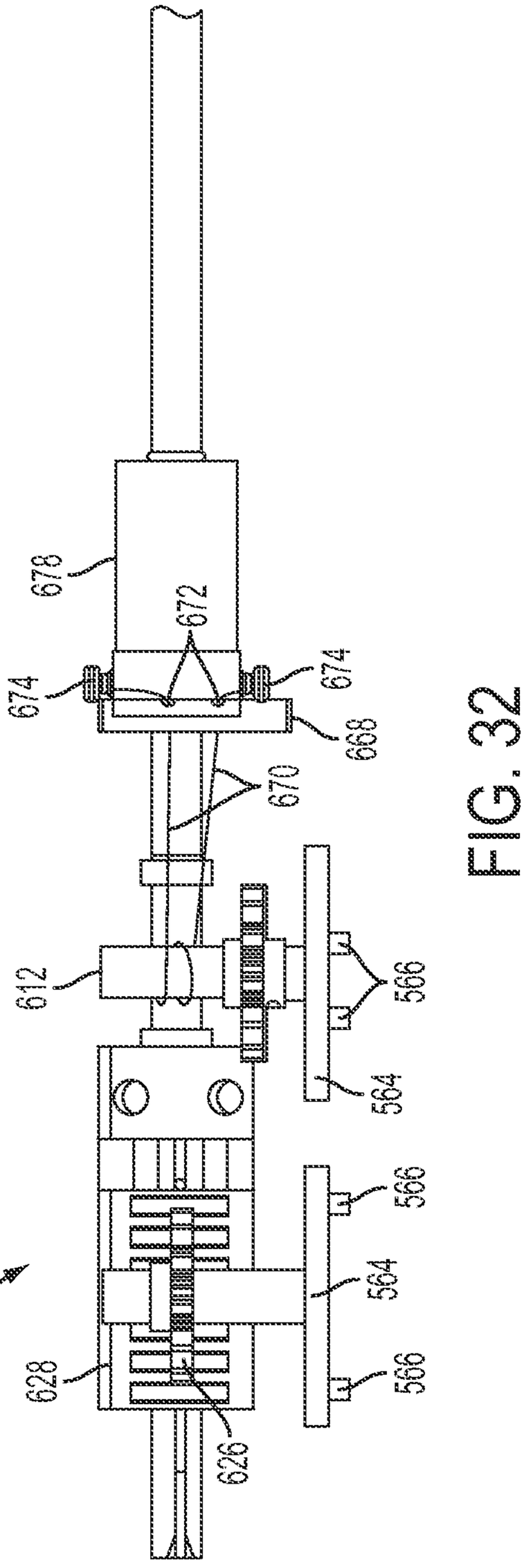
678
672
674
674
668
670
612
566
564
558
628
566
564
566
626

FIG. 32

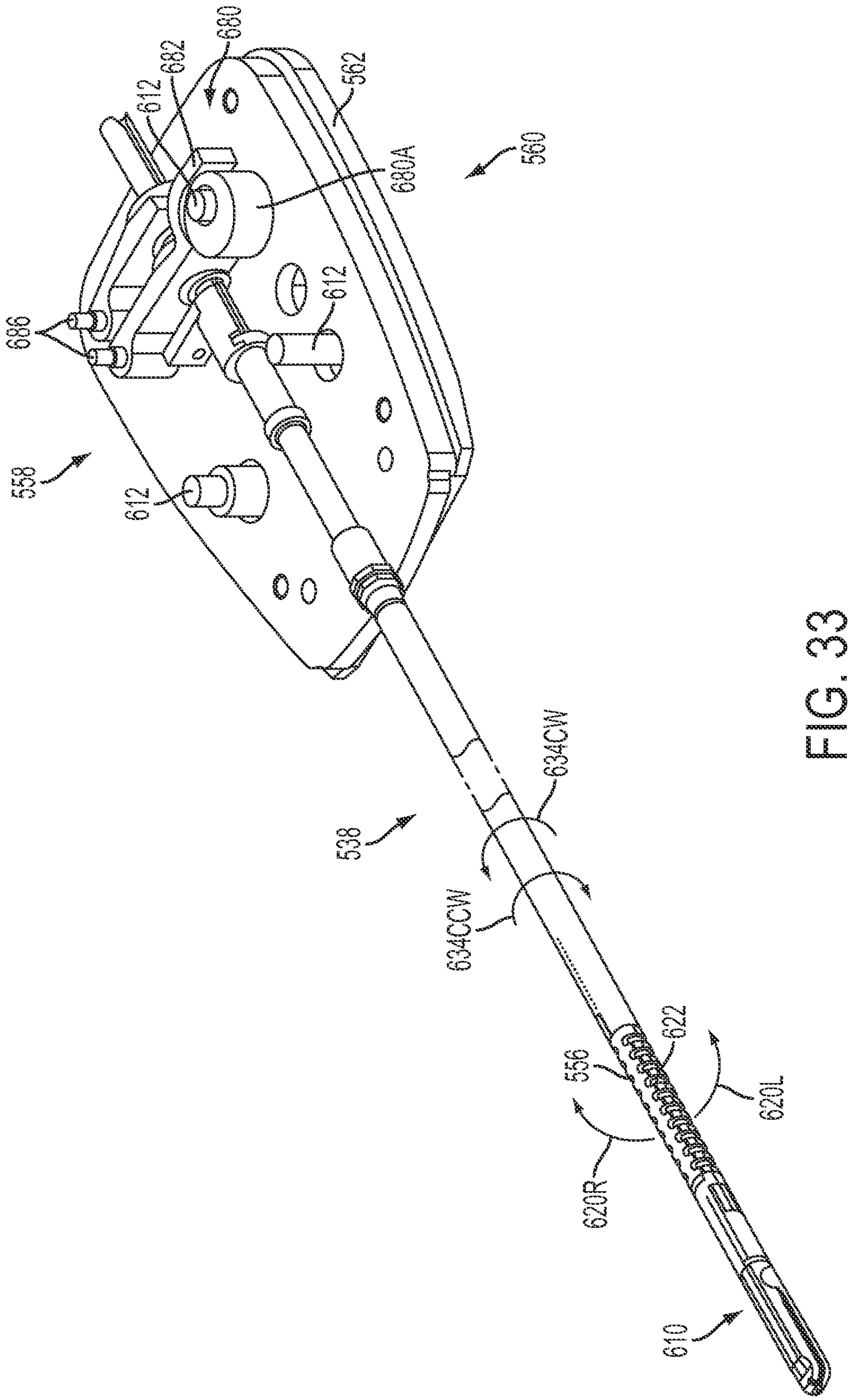
680
682
612
562
560
680A
686
612
558
612
538
634CW
634CCW
556
622
620L
620R
610

FIG. 33

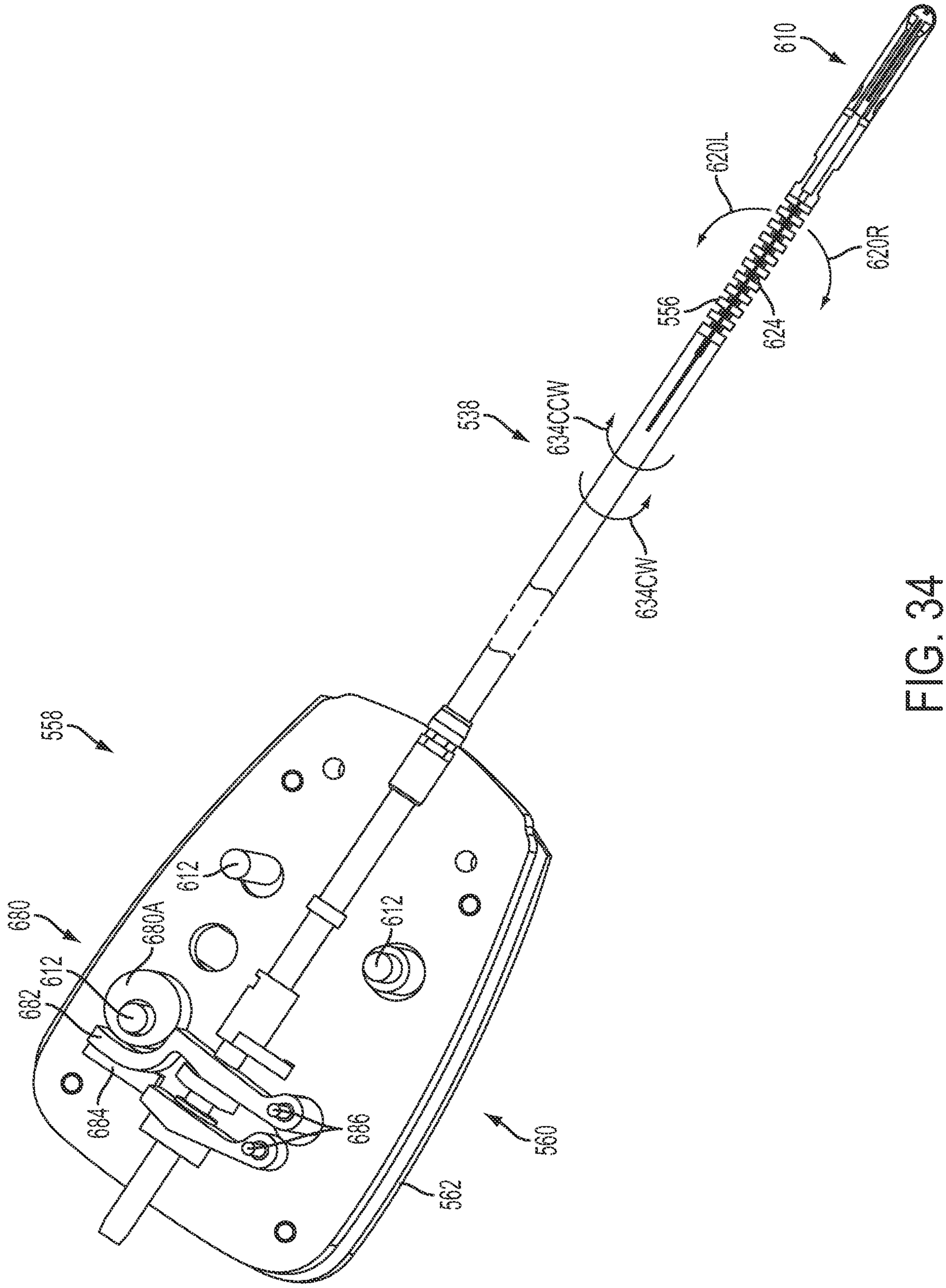
610
620L
620R
556
624
538
634CCW
634CW
558
612
680
680A
682
684
686
560
562

FIG. 34

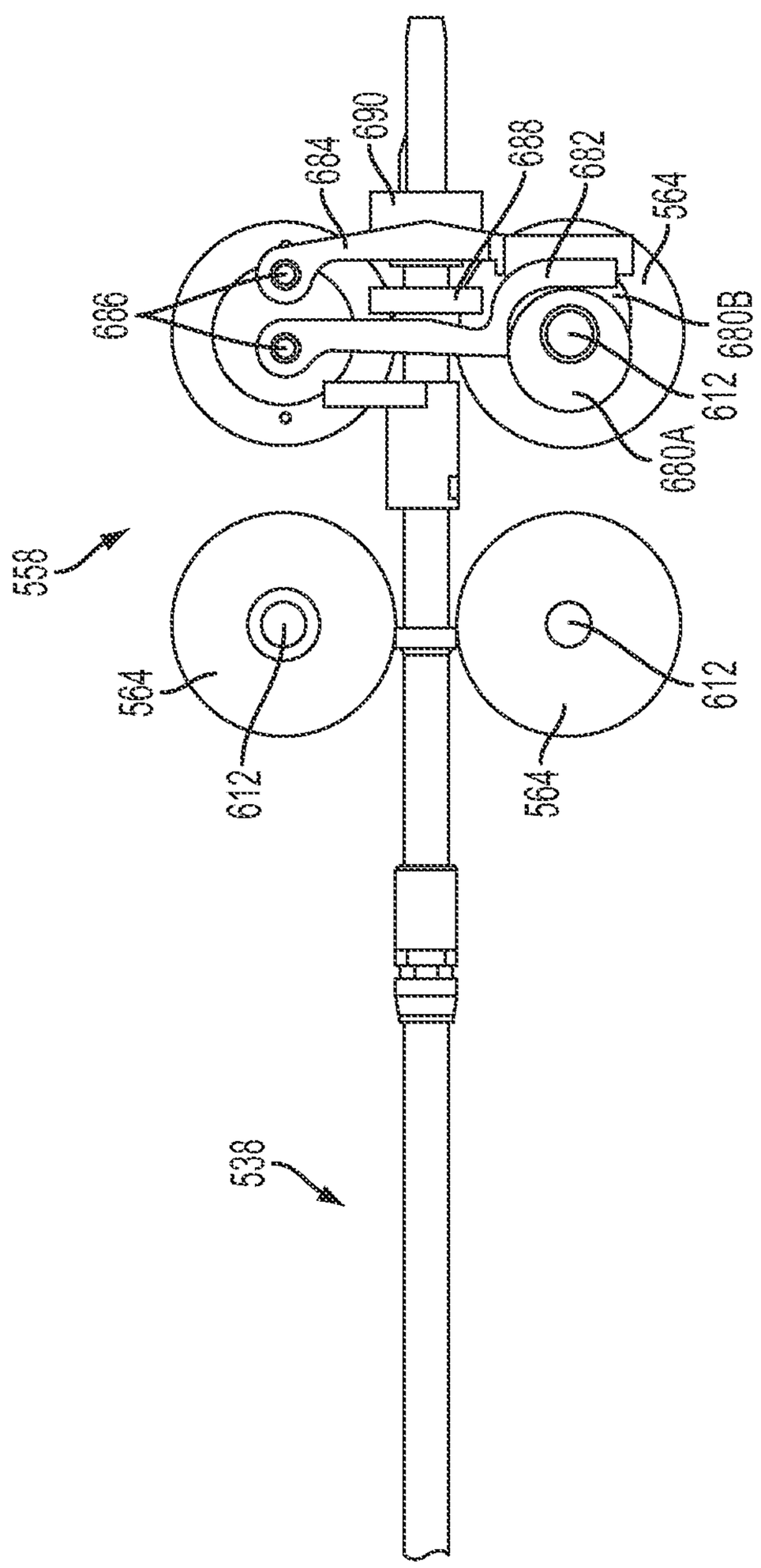

FIG. 35

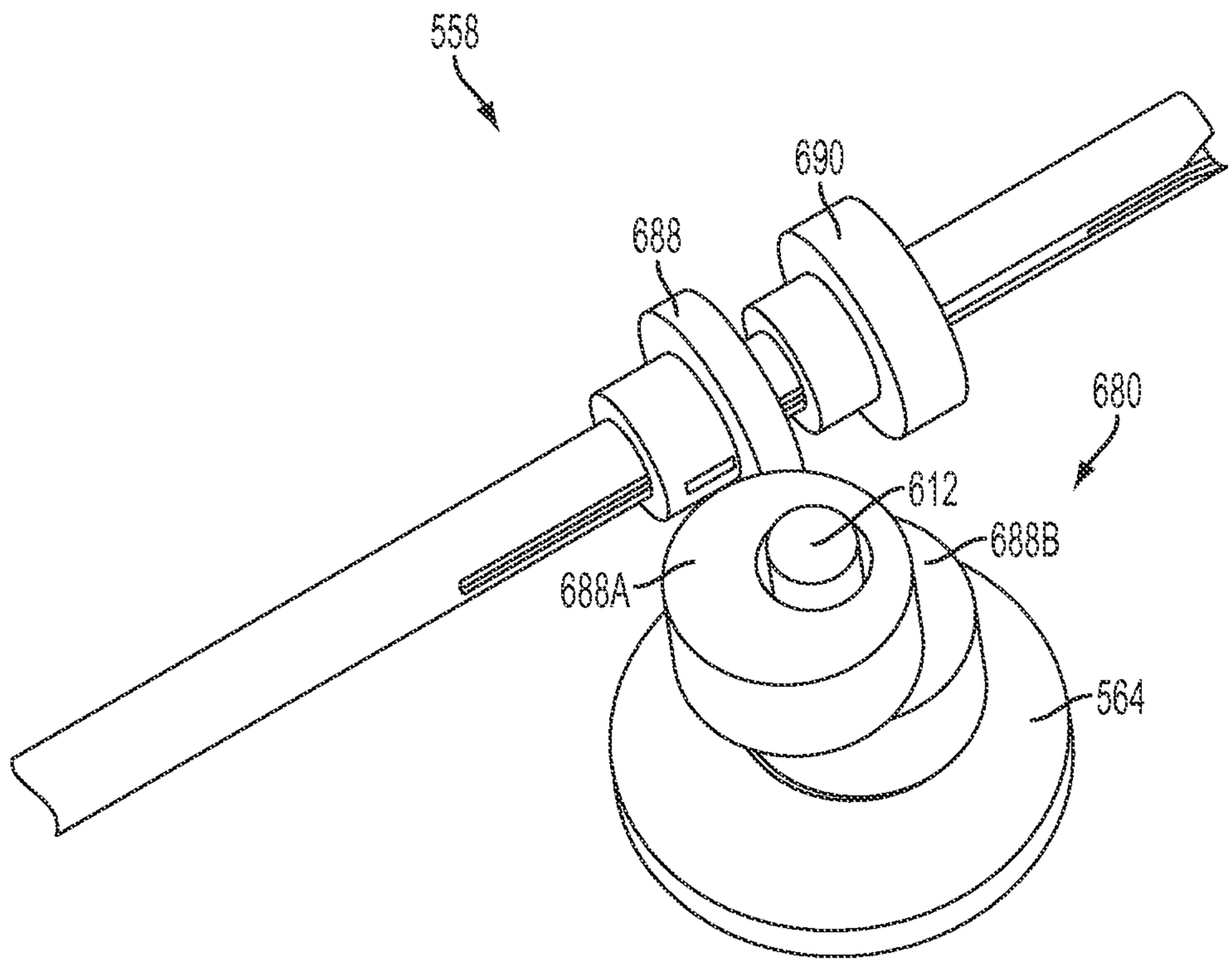

FIG. 36A

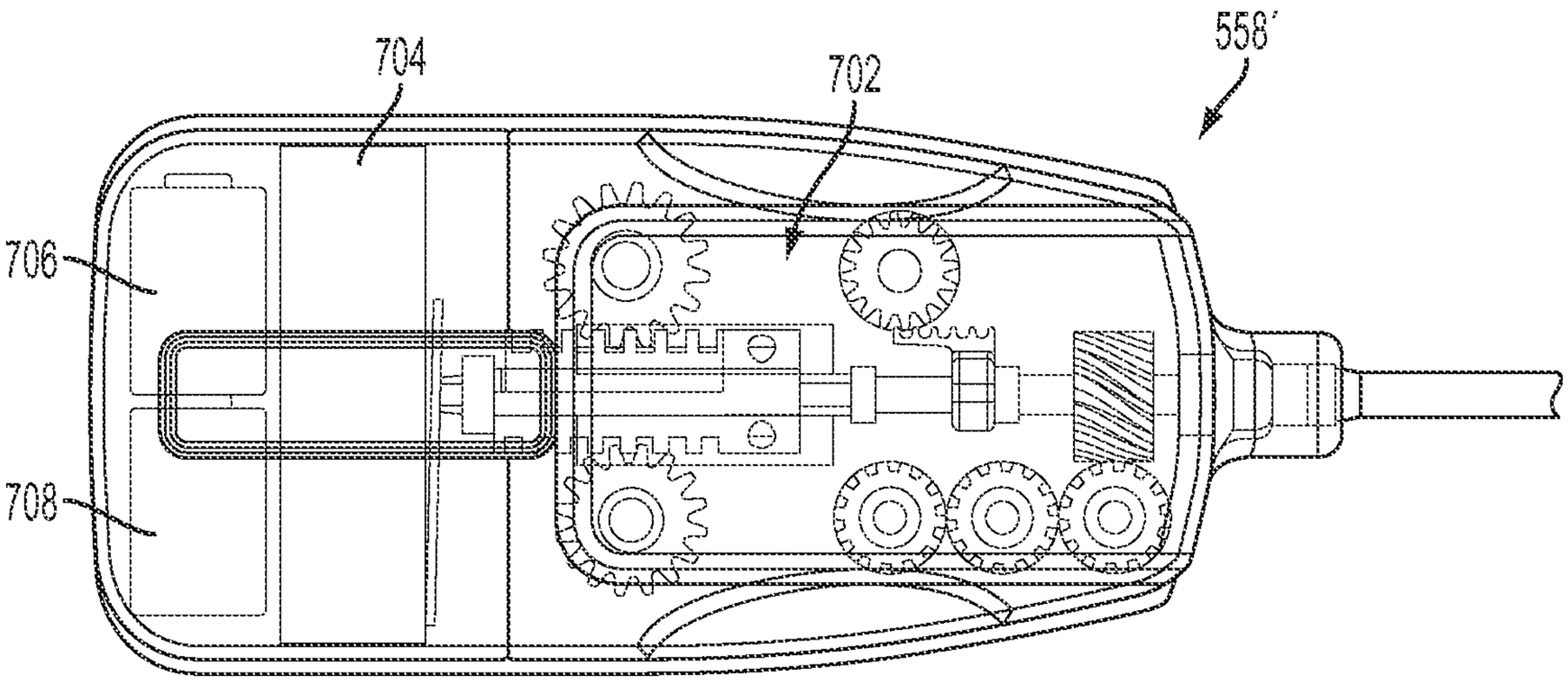

FIG. 36B

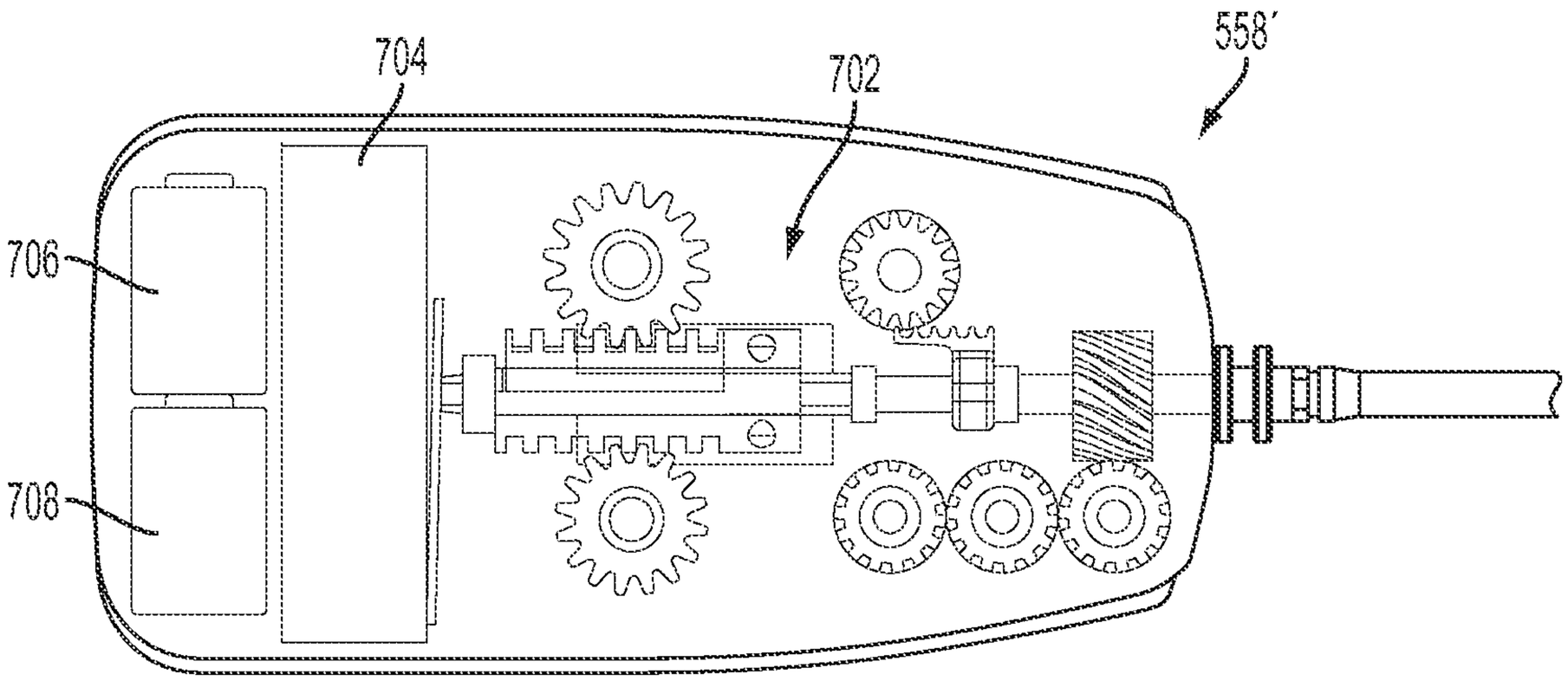

FIG. 36C

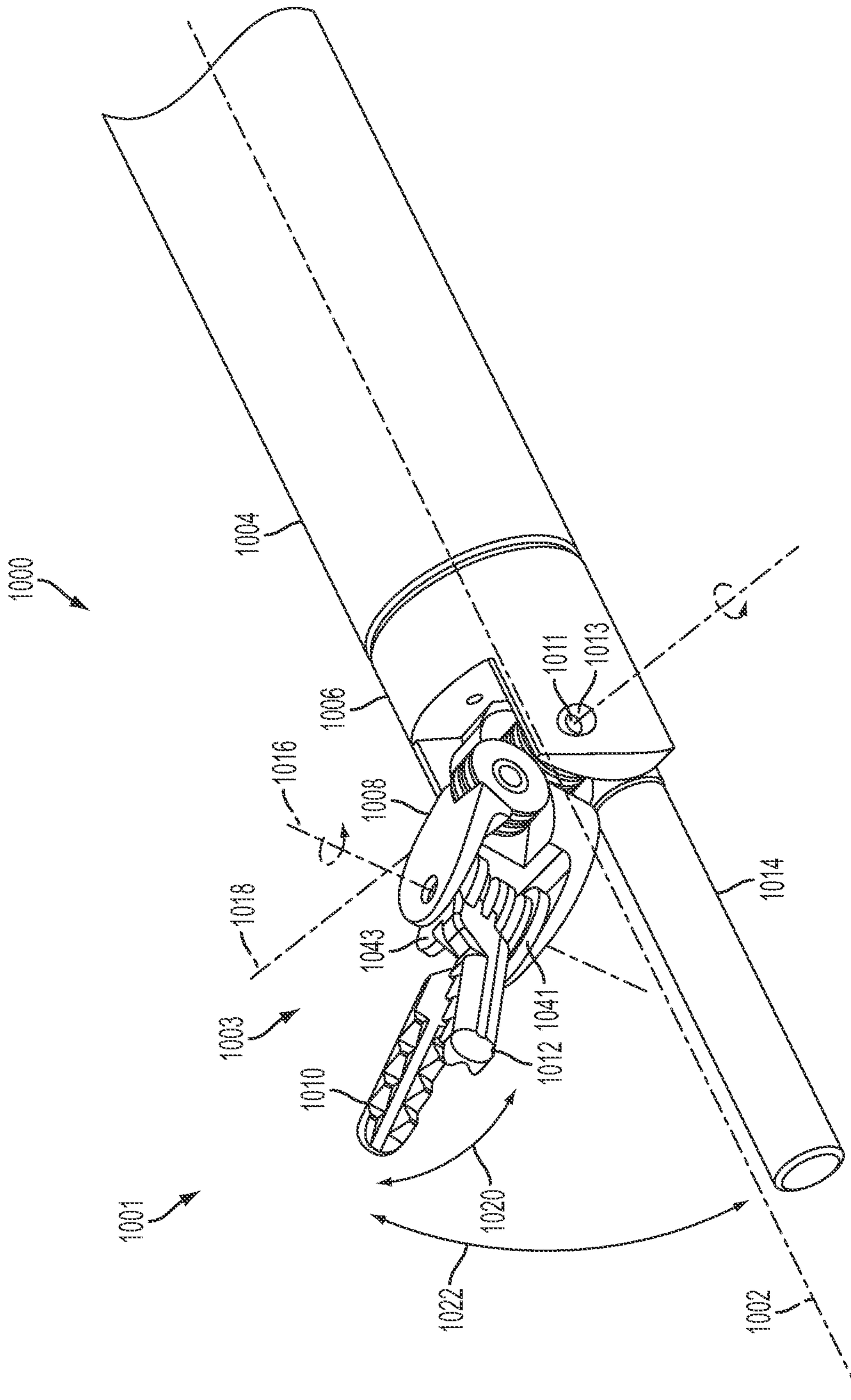
1000
1004
1006
1008
1010
1011
1012
1013
1014
1016
1018
1020
1022
1001
1002
1003
1041
1043

FIG. 37

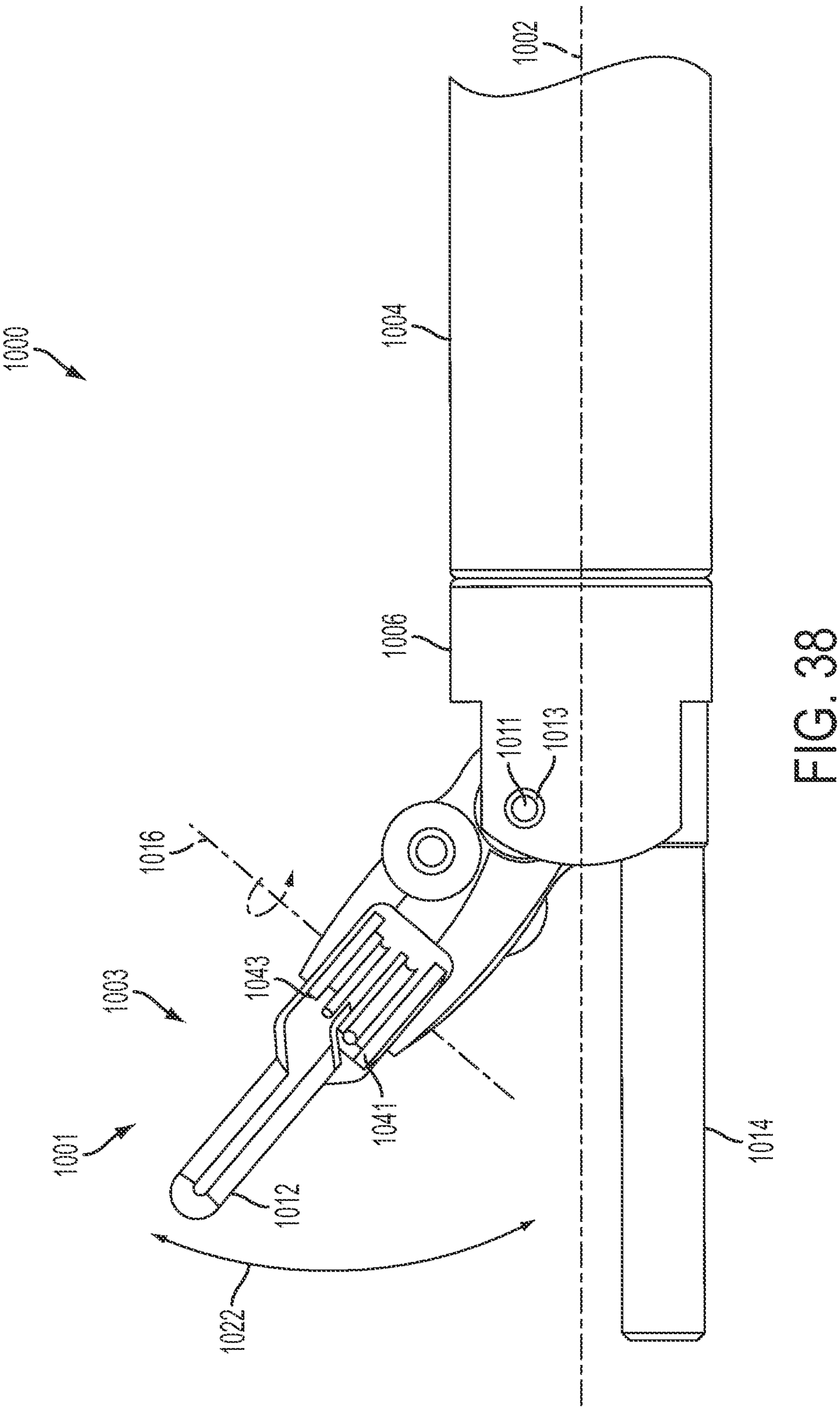
1000
1001
1002
1003
1004
1006
1011
1012
1013
1014
1016
1022
1041
1043

FIG. 38

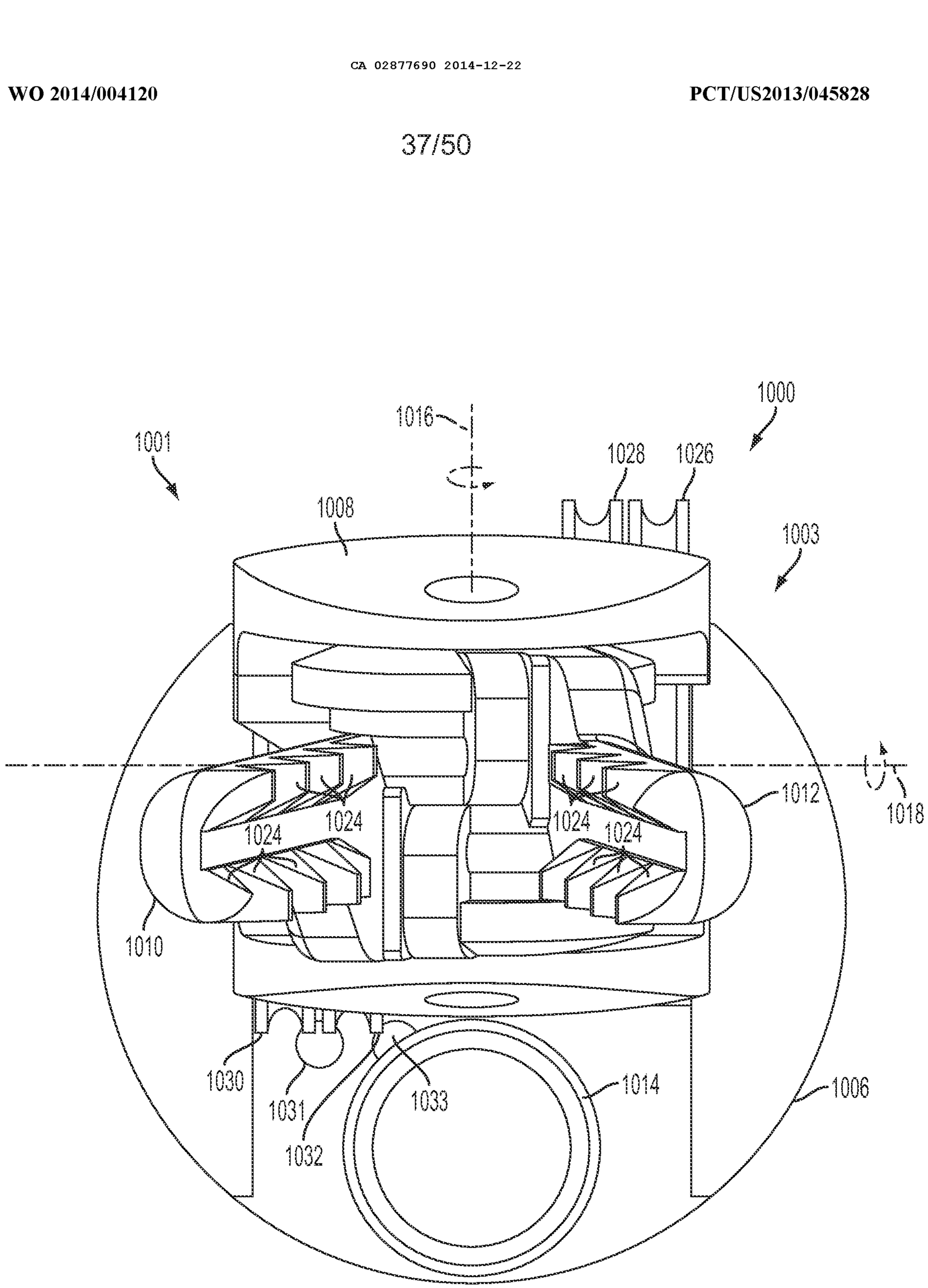
1000
1016
1001
1028
1026
1008
1003
1012
1018
1024
1024
1024
1024
1010
1030
1031
1032
1033
1014
1006

FIG. 39

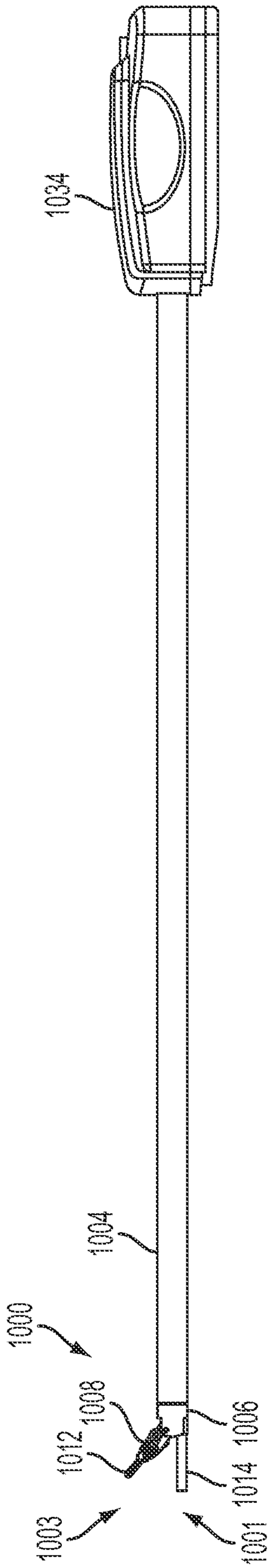

FIG. 40

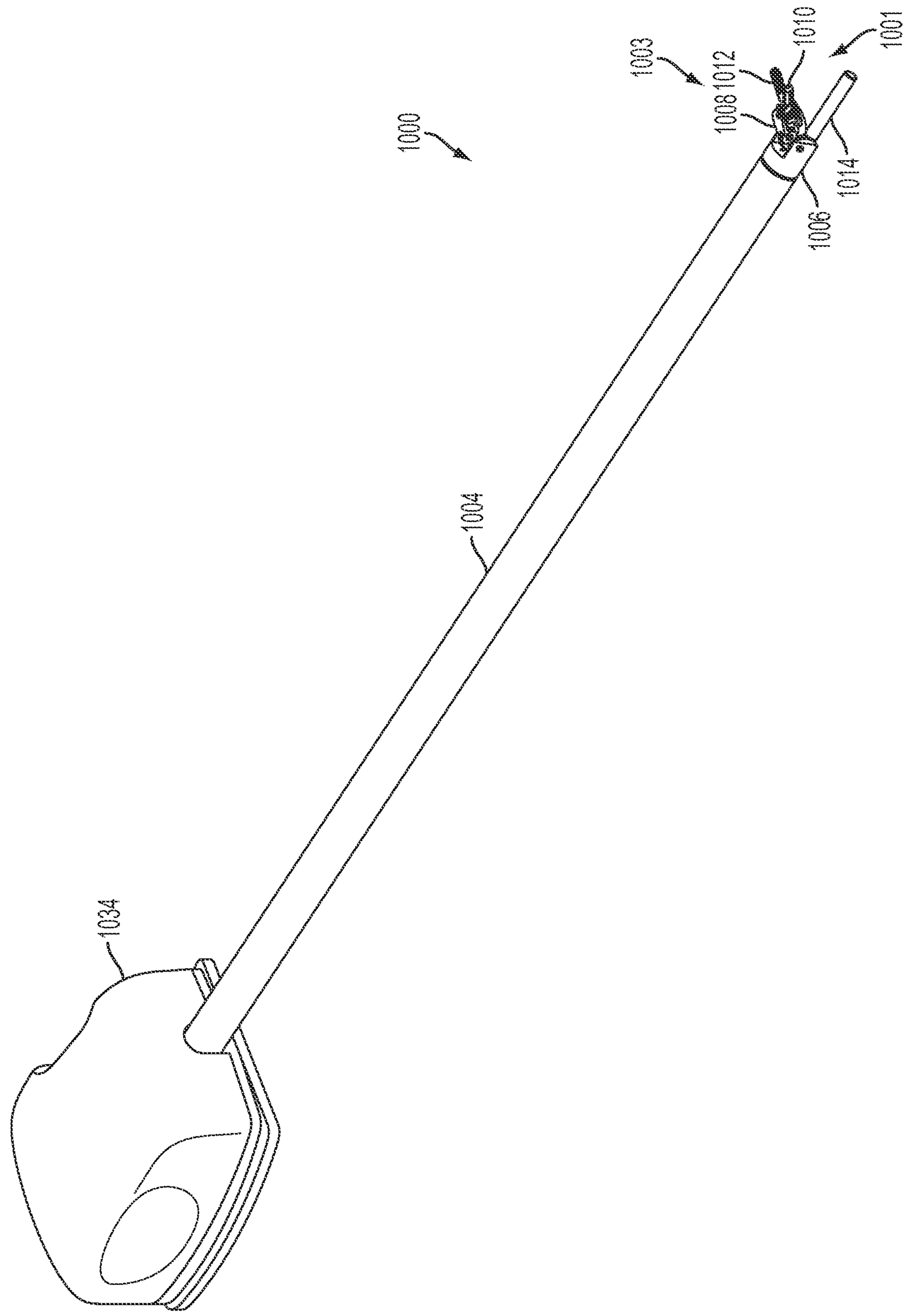

FIG. 41

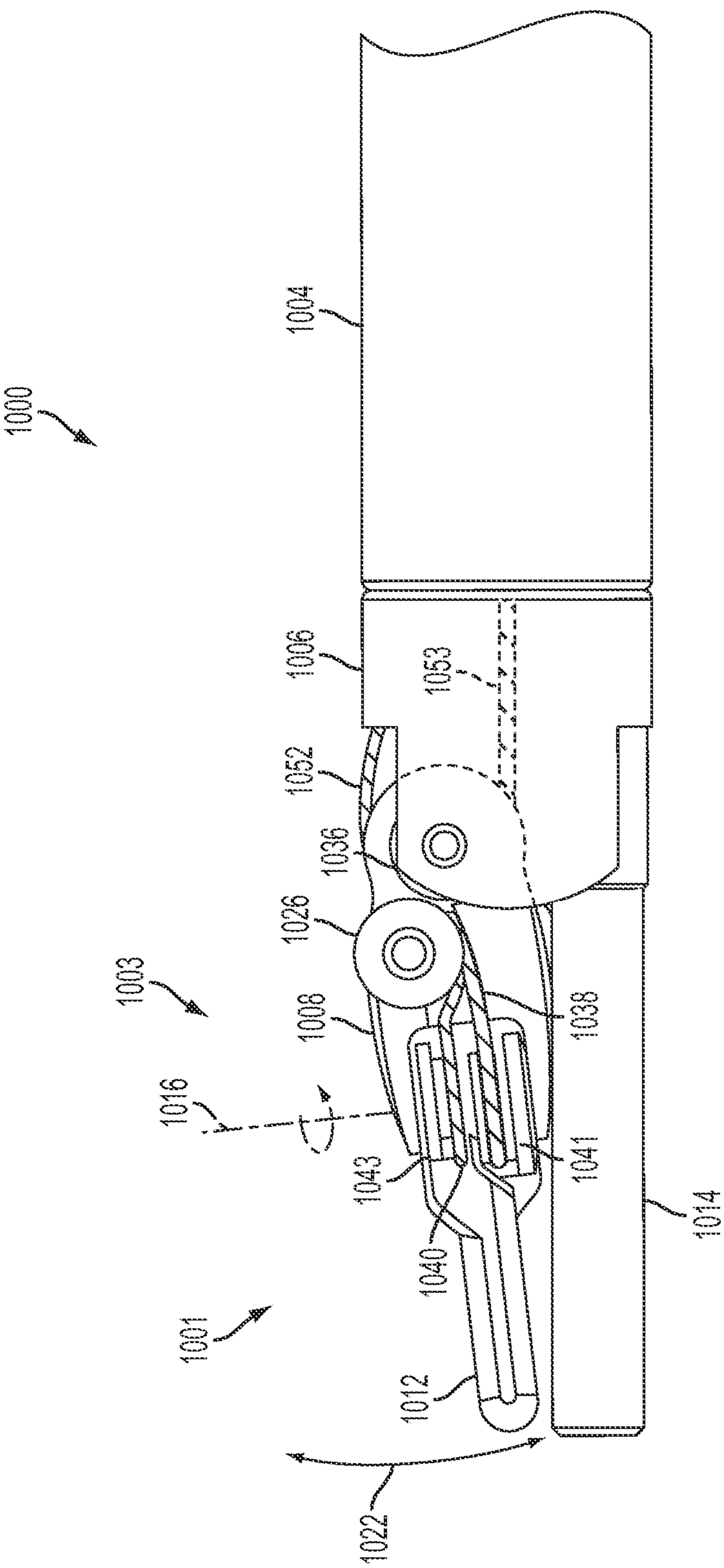
1000
1004
1006
1053
1052
1036
1026
1003
1008
1038
1016
1043
1041
1001
1040
1014
1012
1022

FIG. 42

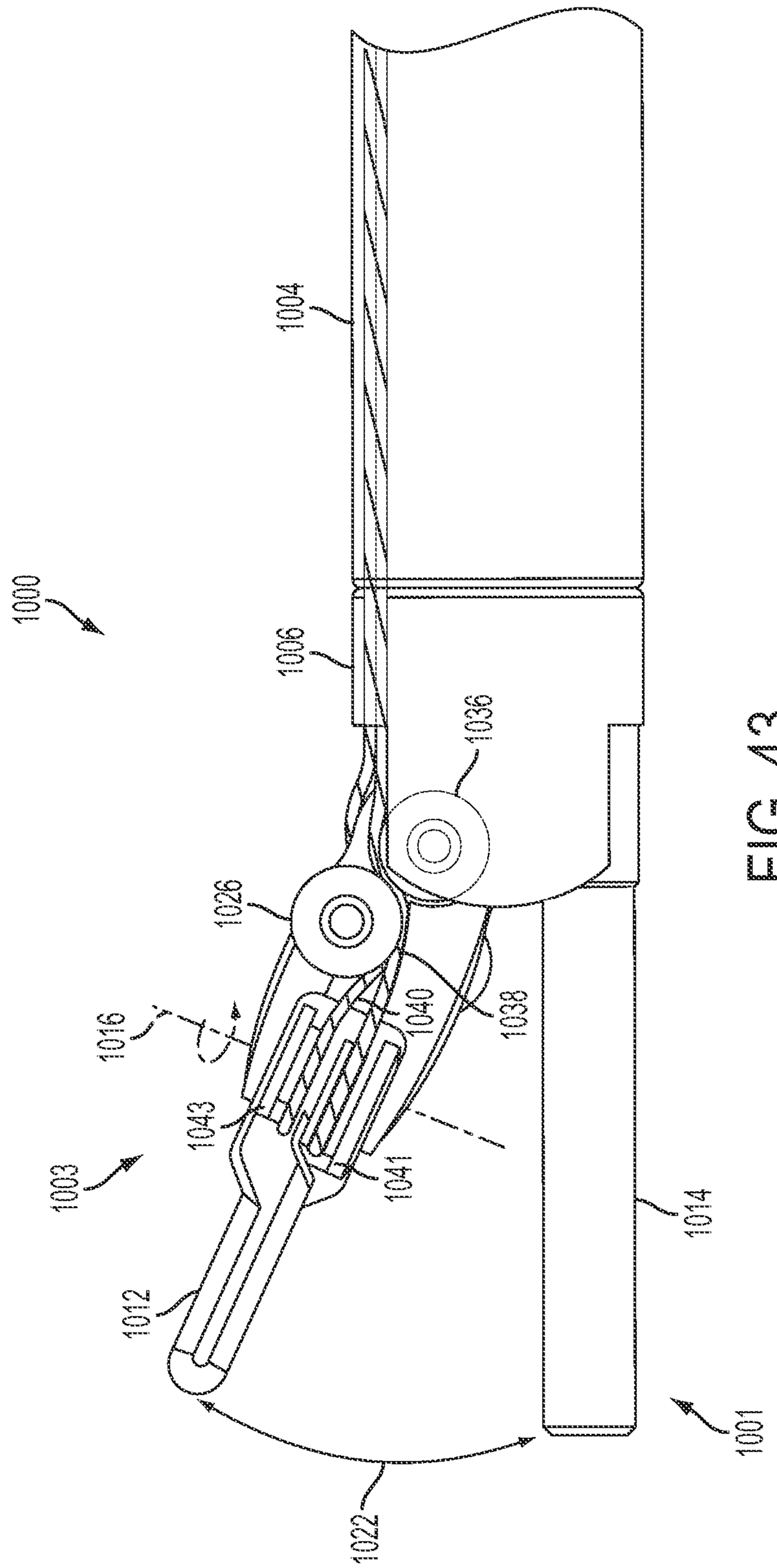
1000
1004
1006
1036
1026
1016
1040
1038
1043
1003
1041
1012
1014
1022
1001

FIG. 43

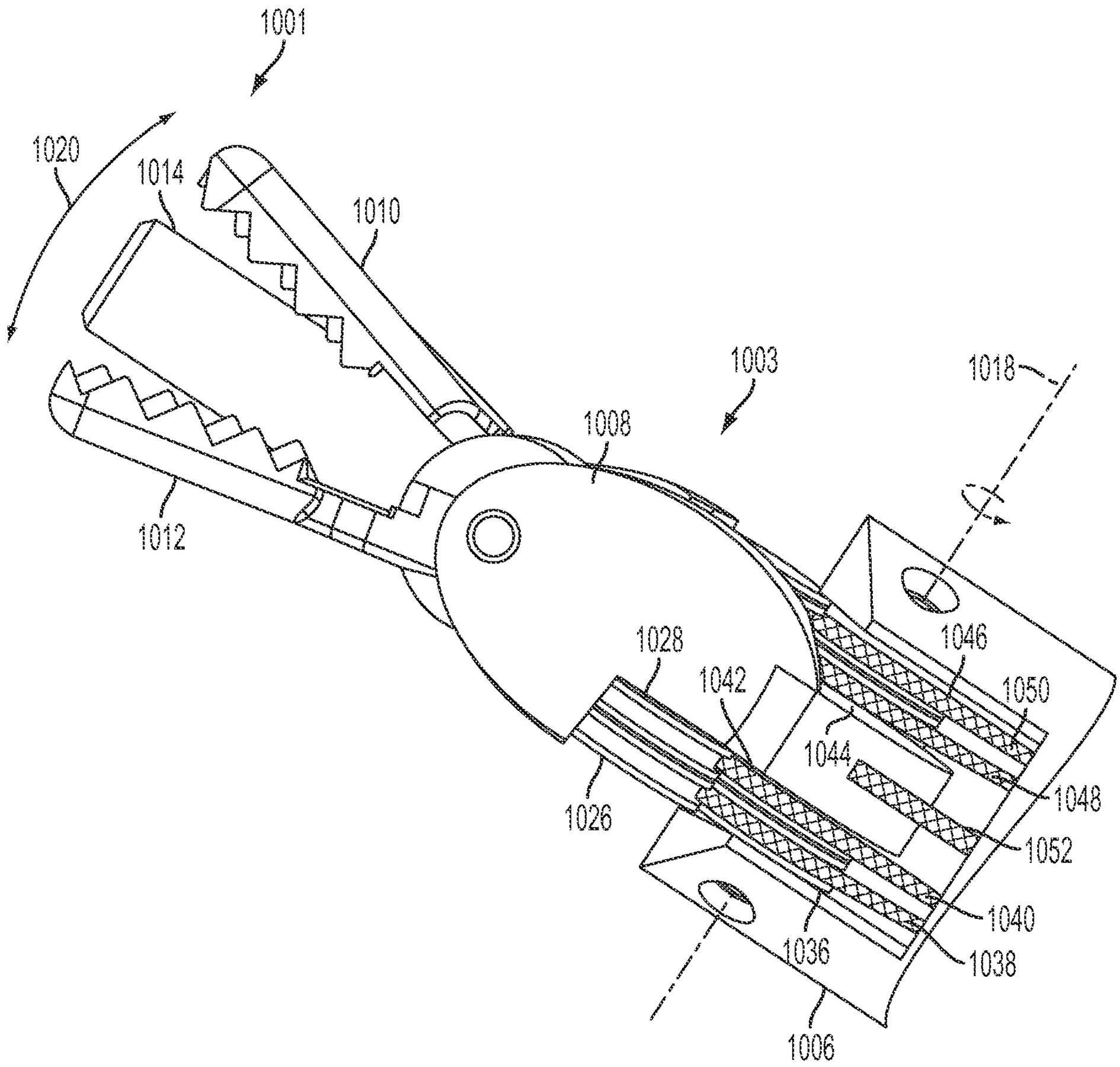
1001
1020
1014
1010
1003
1018
1008
1012
1028
1042
1046
1050
1044
1048
1026
1052
1040
1036
1038
1006

FIG. 44

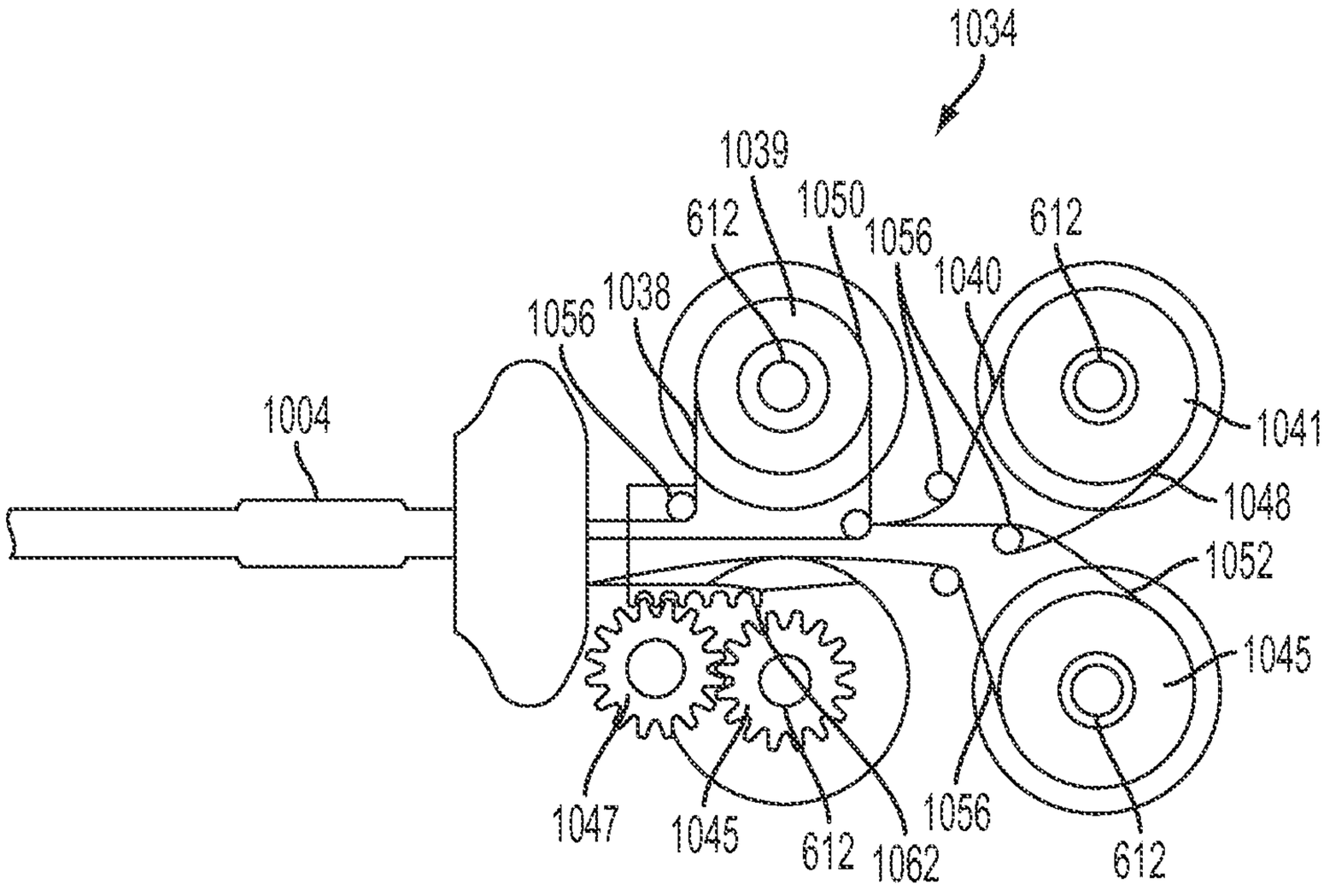

FIG. 45A

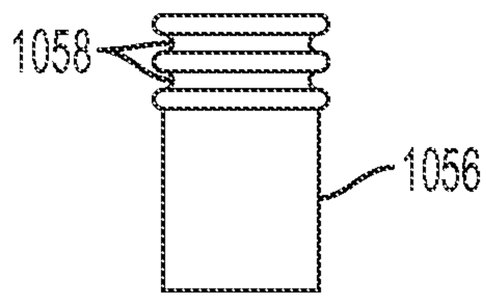

FIG. 45B

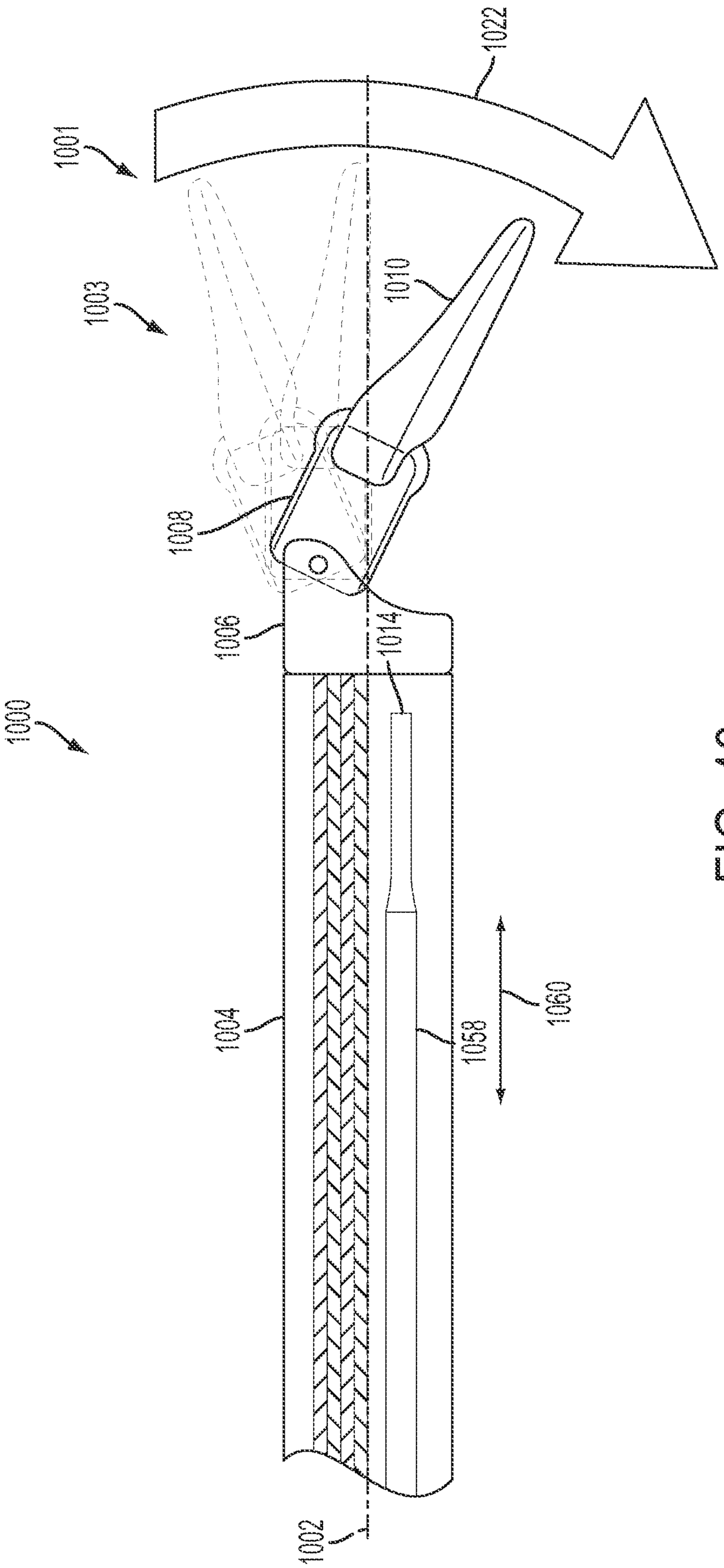

FIG. 46

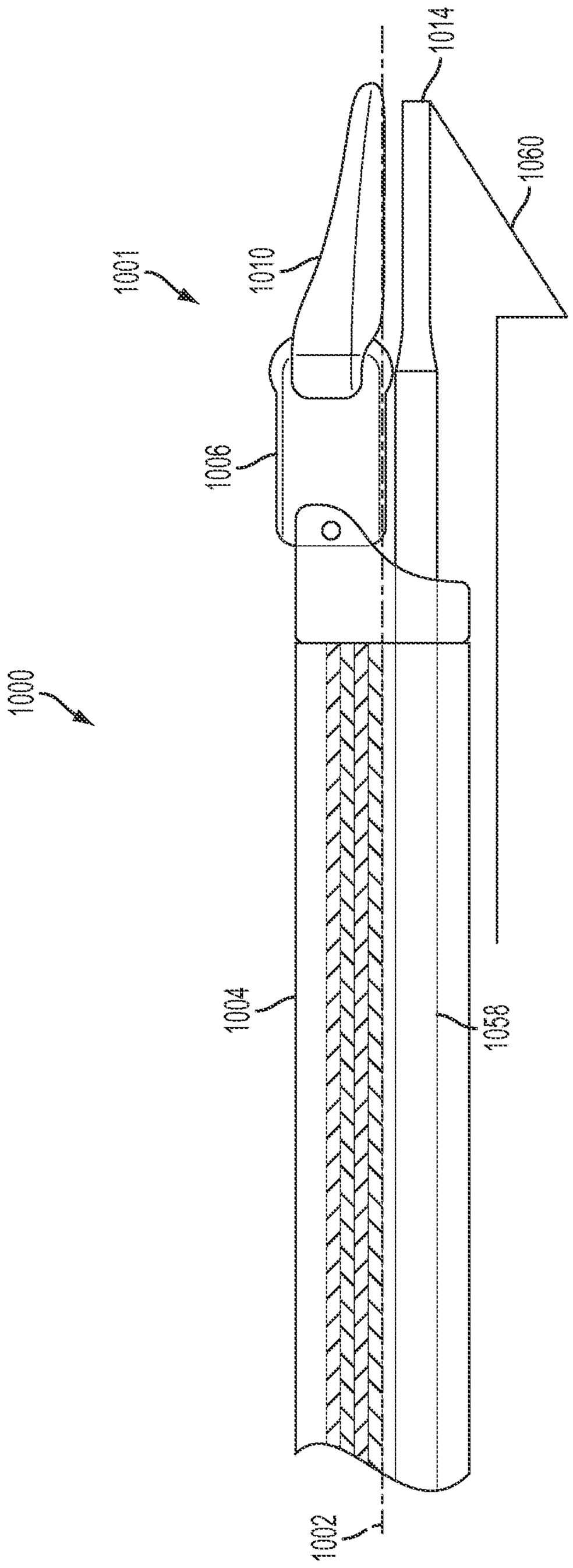

FIG. 47

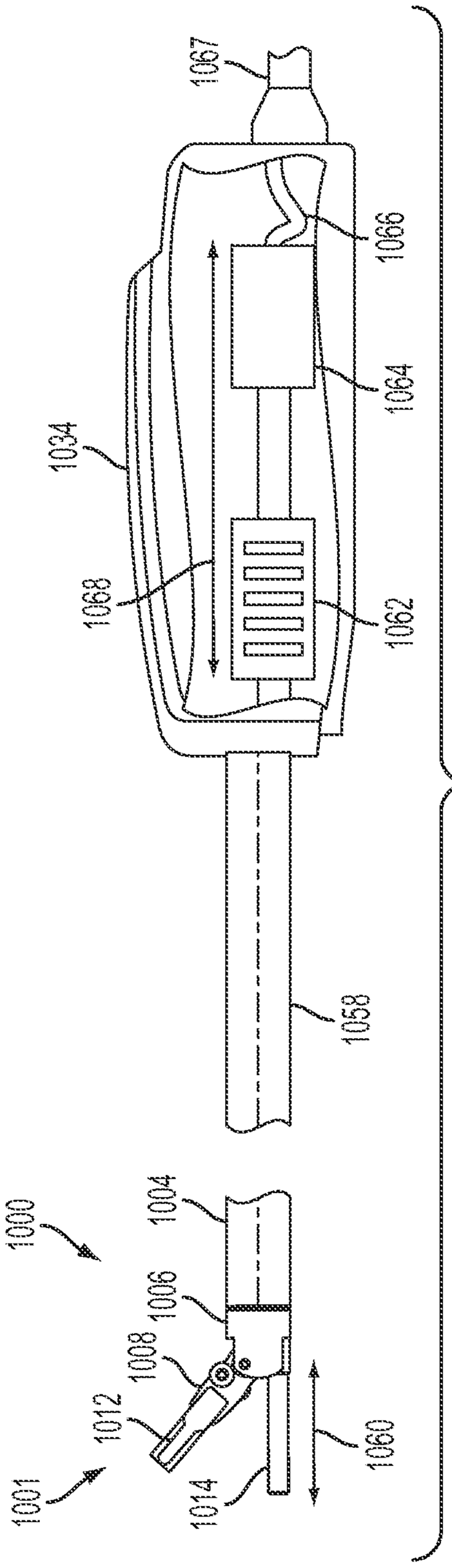
1067
1066
1064
1034
1068
1062
1058
1000
1004
1006
1008
1012
1001
1014
1060

FIG. 48

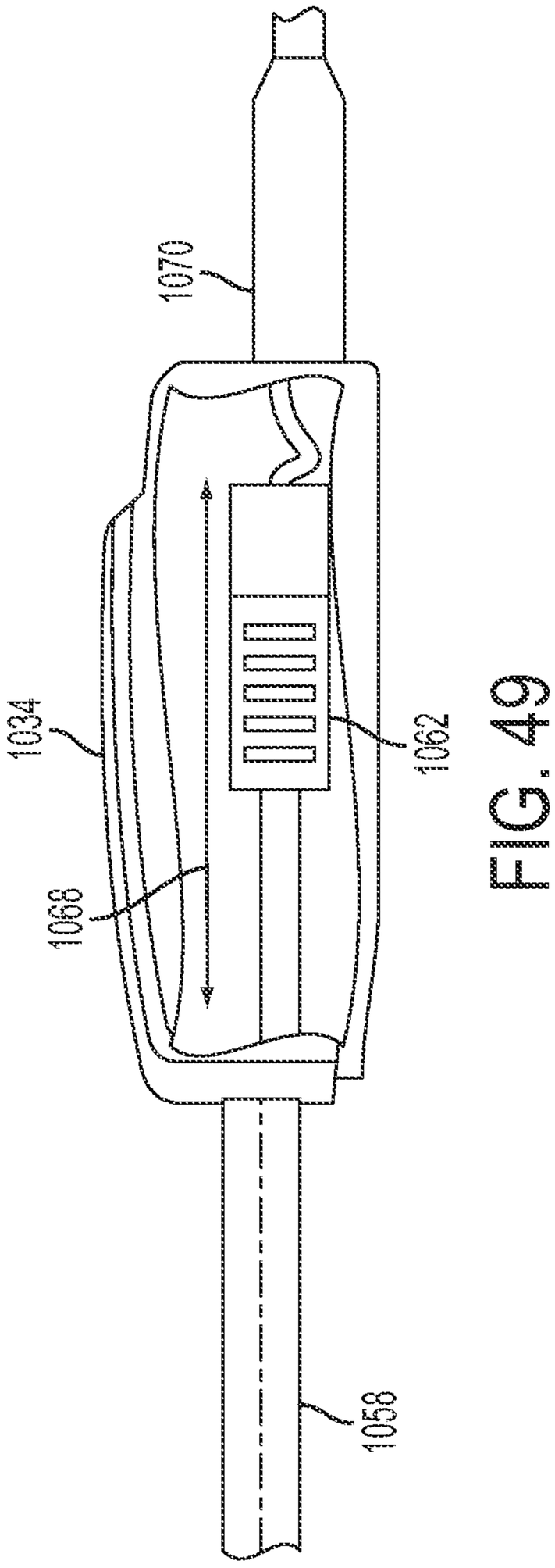

FIG. 49

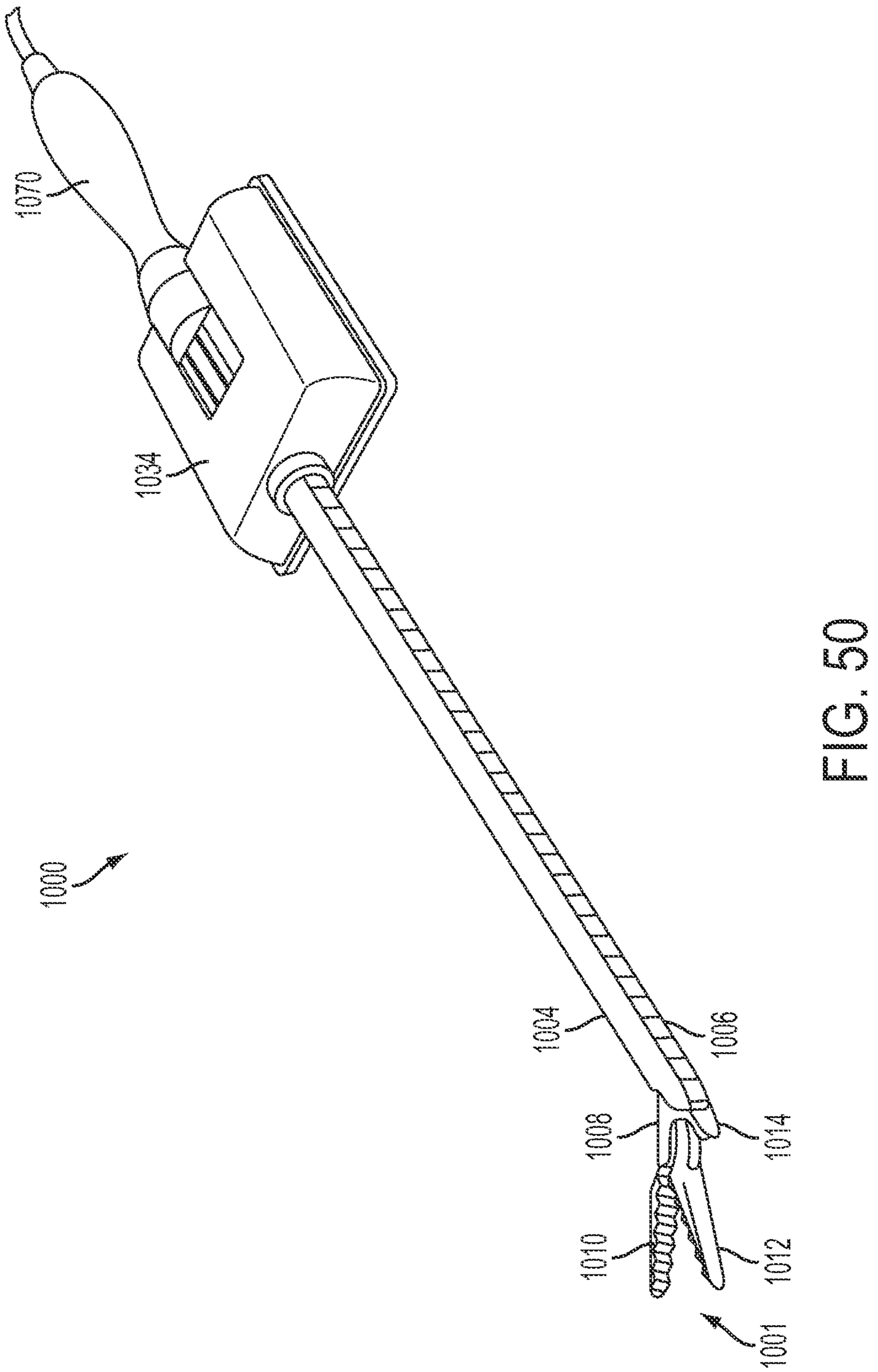

FIG. 50

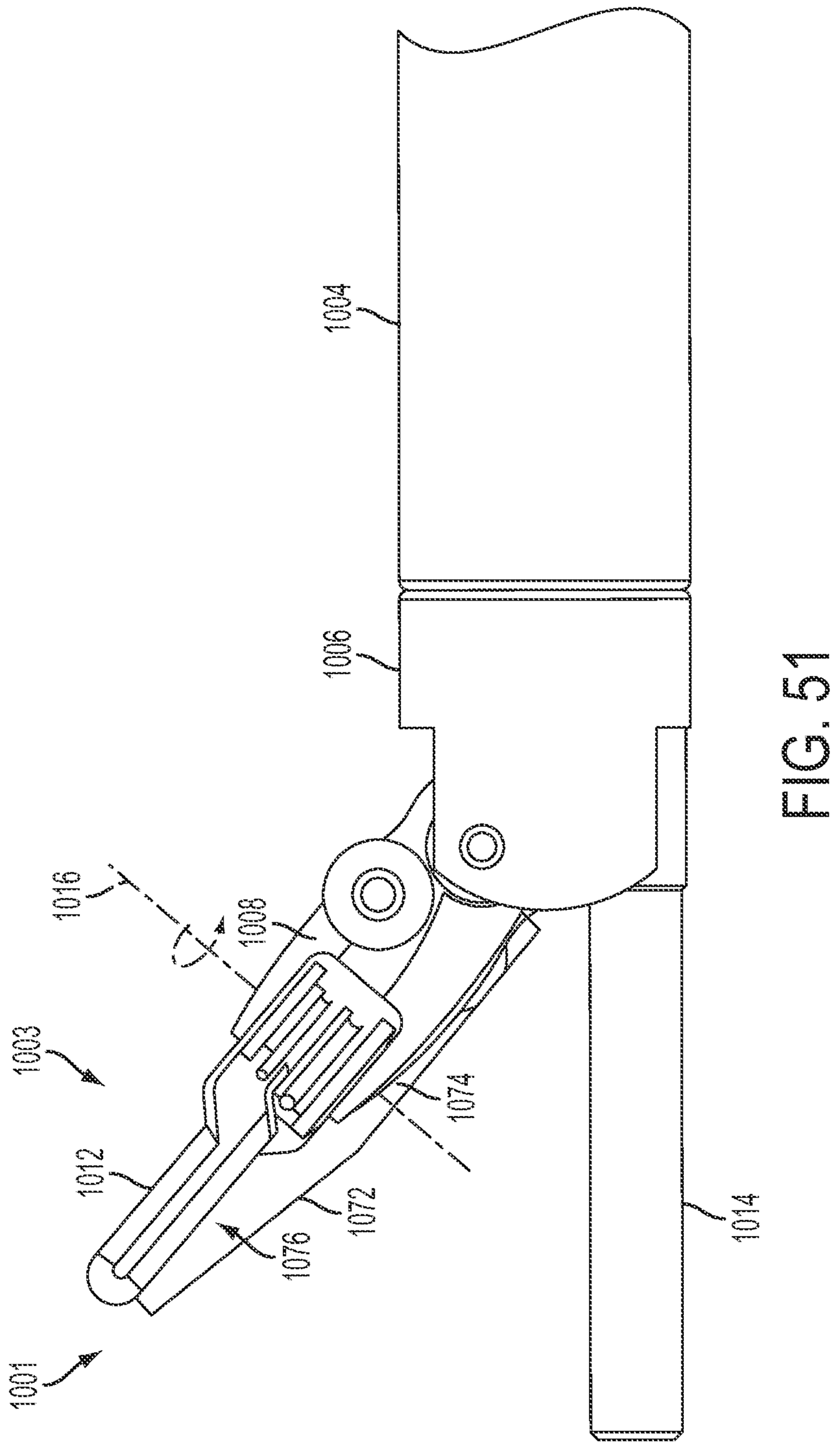

FIG. 51

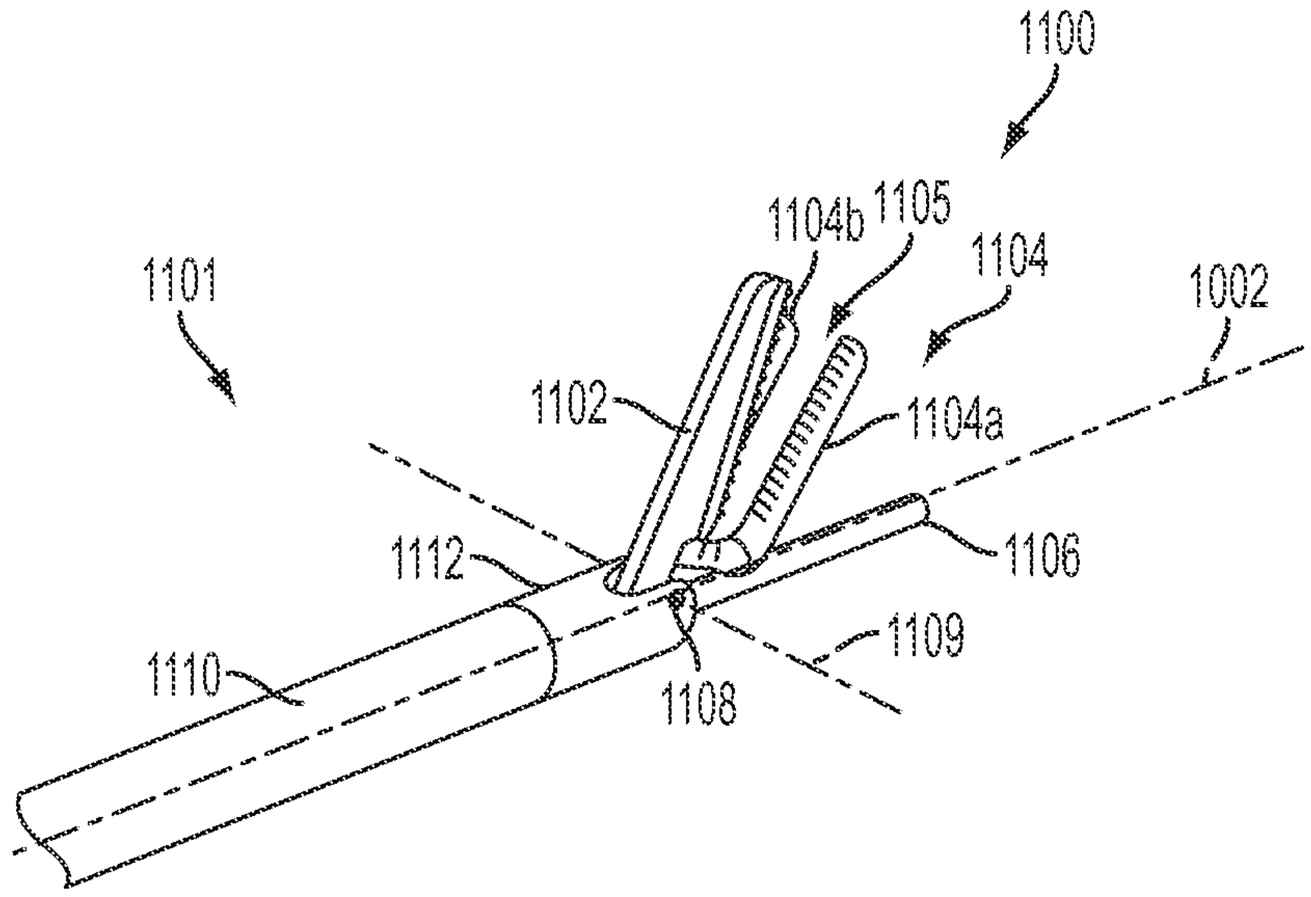

FIG. 52

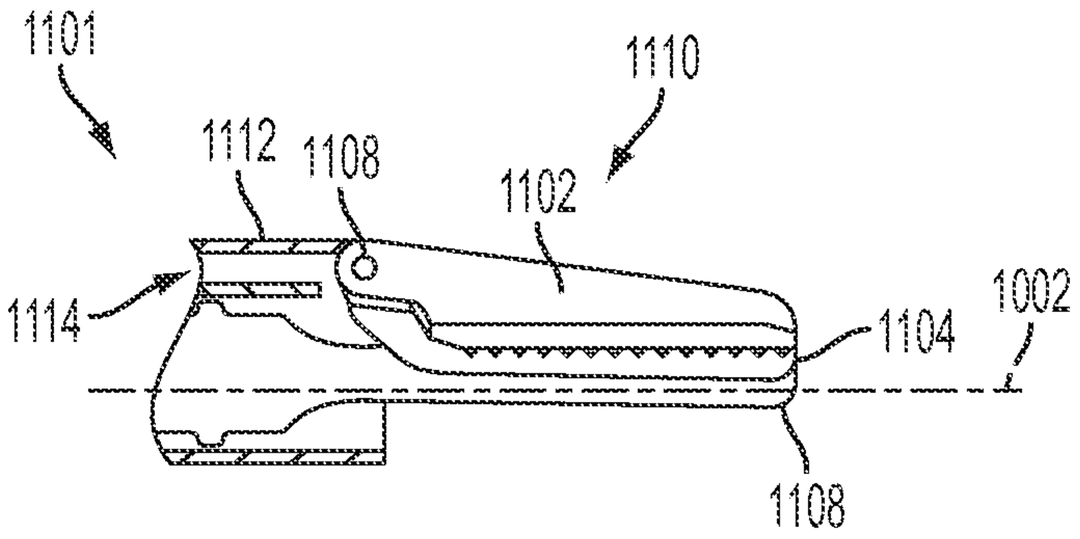

FIG. 53

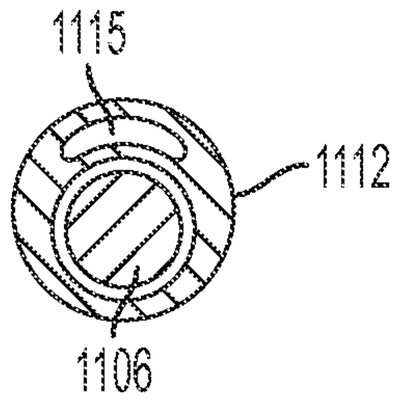

FIG. 54

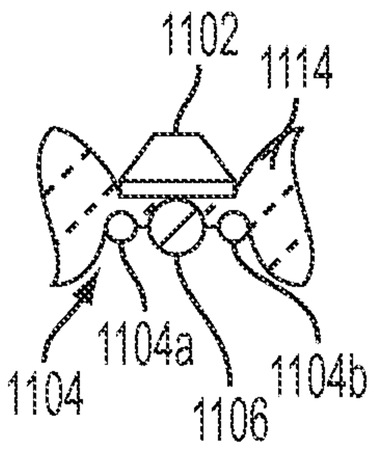

FIG. 55

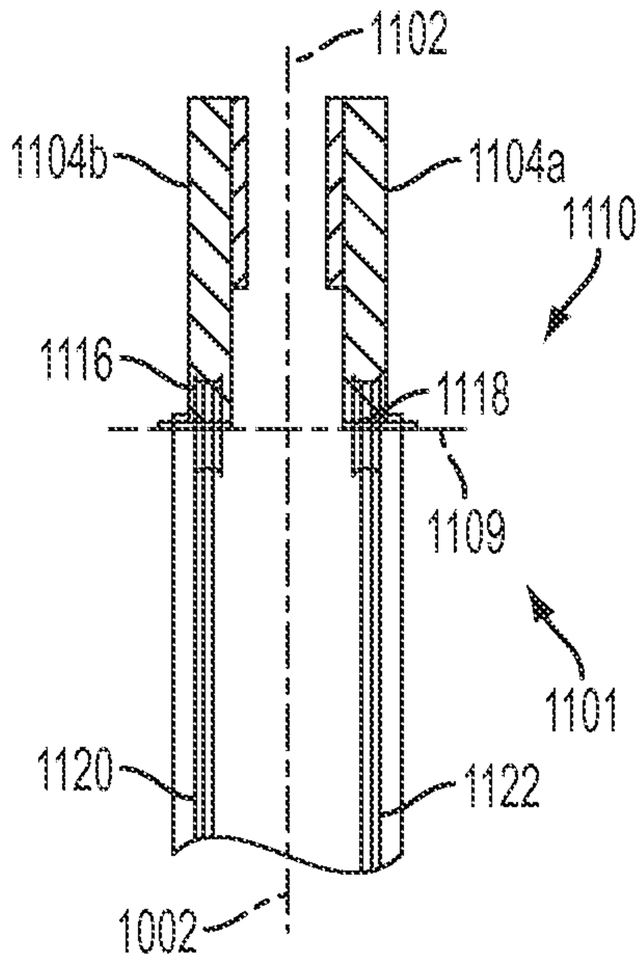

FIG. 56

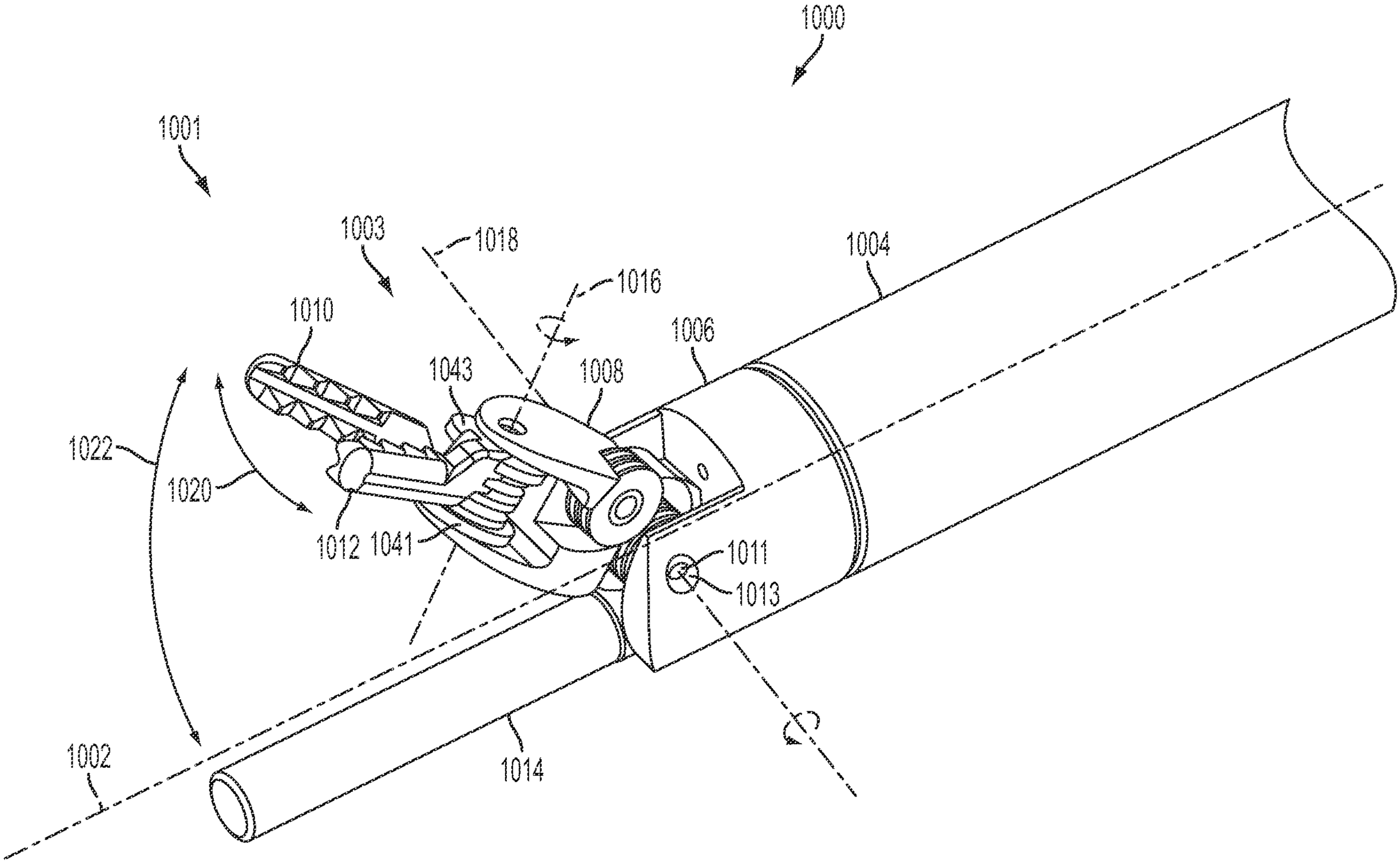
1000
1001
1003
1018
1016
1004
1010
1006
1043
1008
1022
1020
1012
1041
1011
1013
1002
1014

FIG. 37