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(54) **ULTRASONIC SURGICAL INSTRUMENTS WITH CONTROL MECHANISMS**

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(58) **Field of Classification Search**

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See application file for complete search history.

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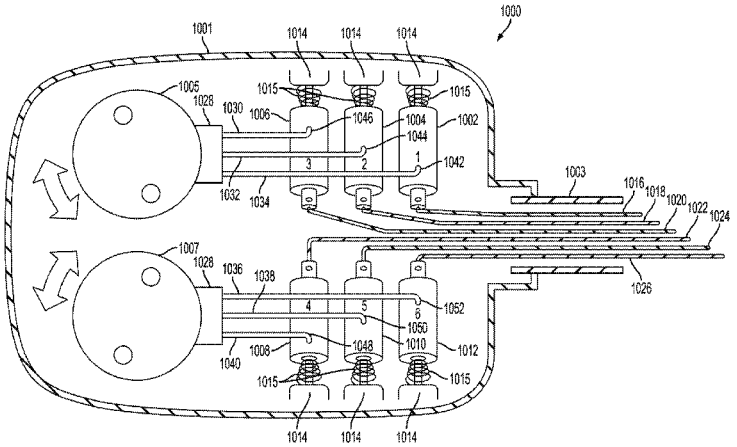
(57) **ABSTRACT**

Various embodiments are directed to surgical instruments for use in handheld applications or with robotic surgical systems. The surgical instruments may comprise an end effector to treat tissue and a shaft extending proximally from the end effector along a longitudinal axis. Some embodiments may be usable with an instrument mounting portion of a robotic surgical instrument. For example, the shaft may extend proximally to the instrument mounting portion.

12 Claims, 76 Drawing Sheets



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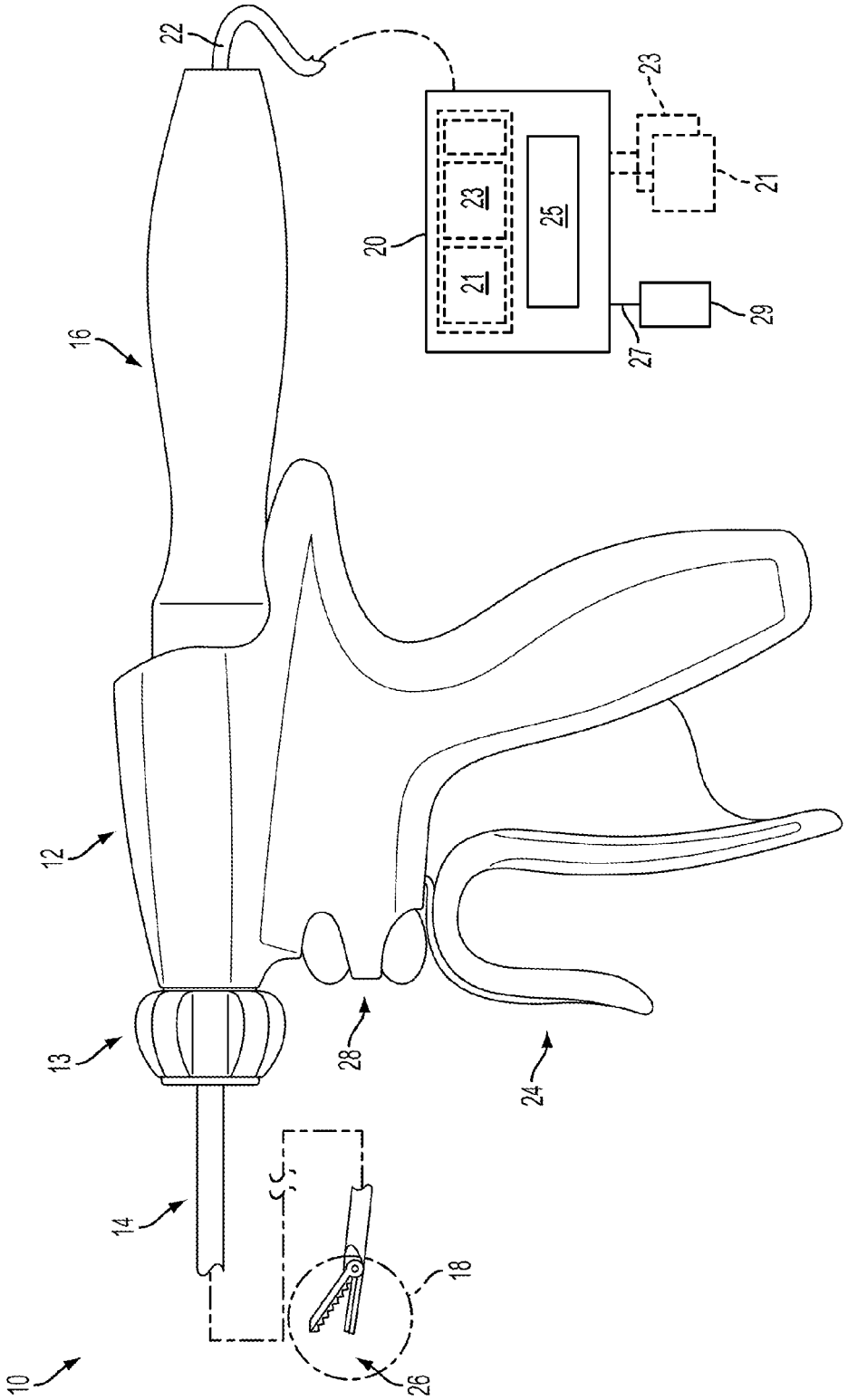
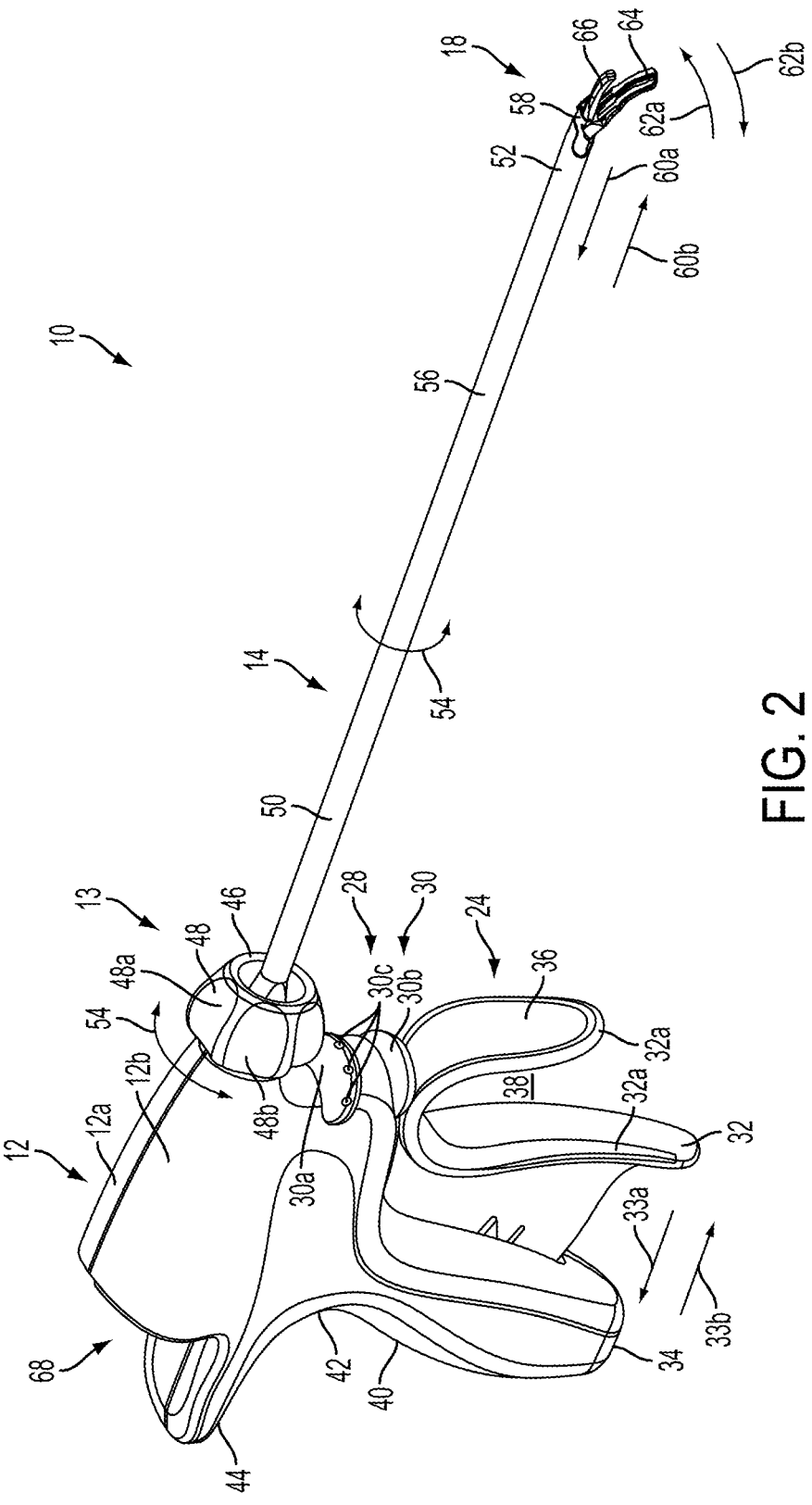


FIG. 1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12b
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28
30
30a
30b
30c
32
32a
33a
33b
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36
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40
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48a
48b
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56
58
60a
60b
62a
62b
64
66
68

FIG. 2

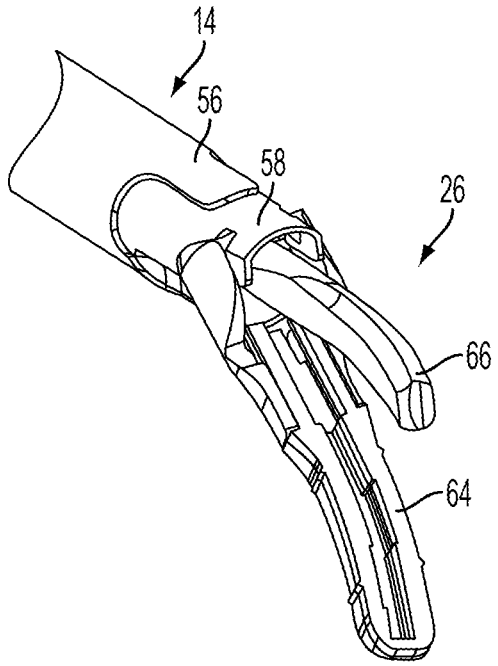


FIG. 3

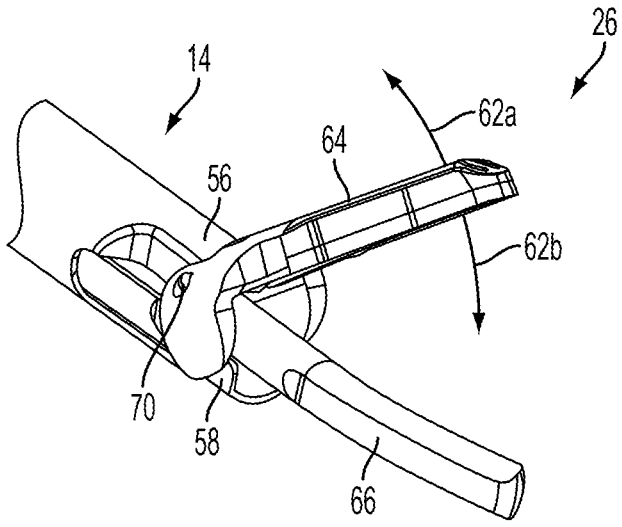
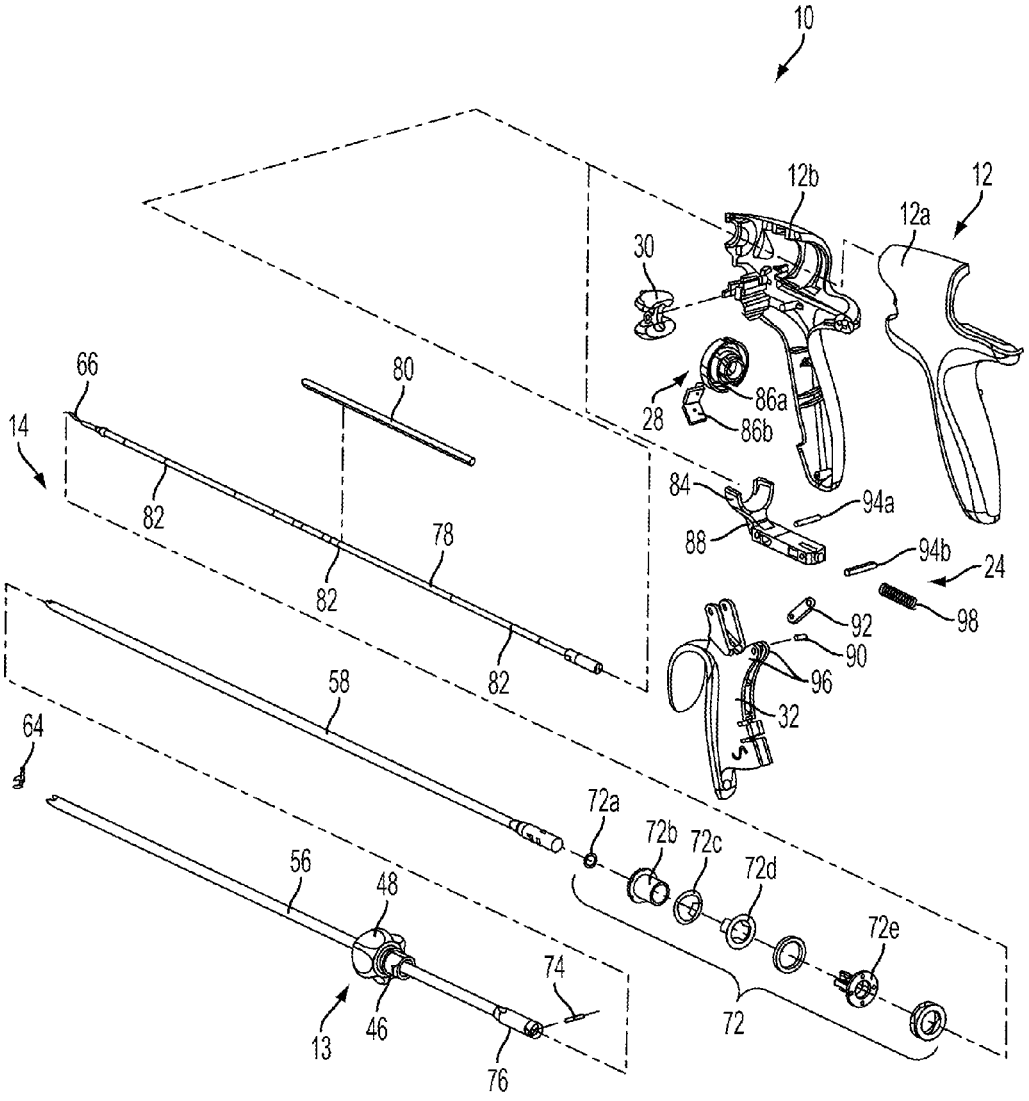


FIG. 4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12b
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12a
30
66
80
14
28
86a
86b
82
84
94a
88
78
94b
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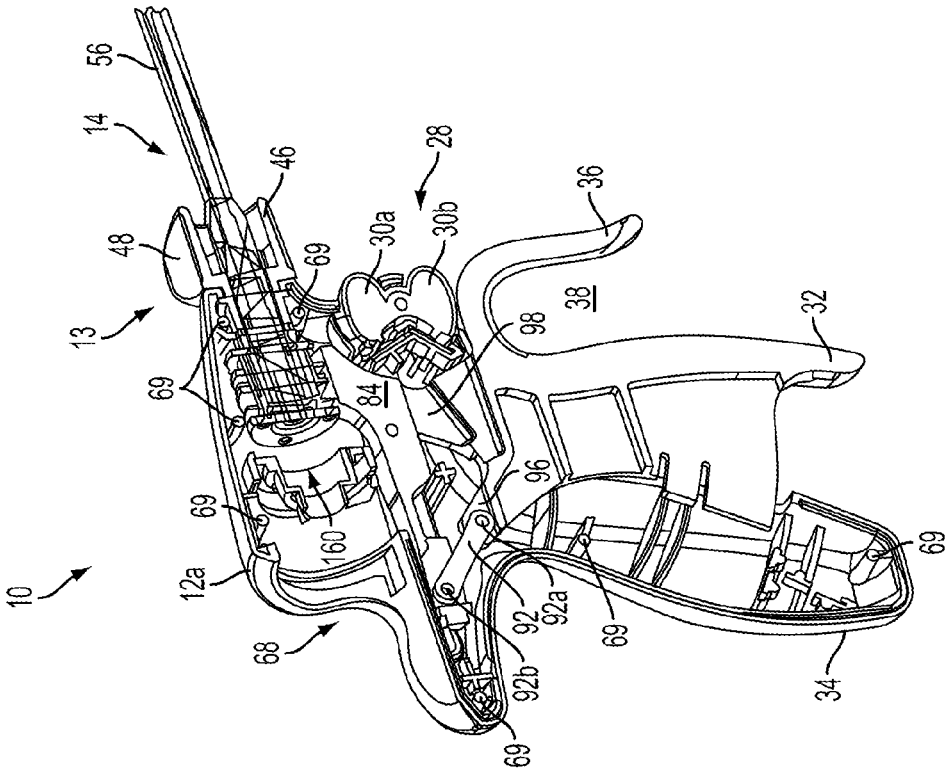
82
92
98
90
58
96
82
64
32
72a
72b
72c
72d
56
48
72e
74
13
46
72
76

FIG. 5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46
28
36
48
69
30a
30b
38
13
98
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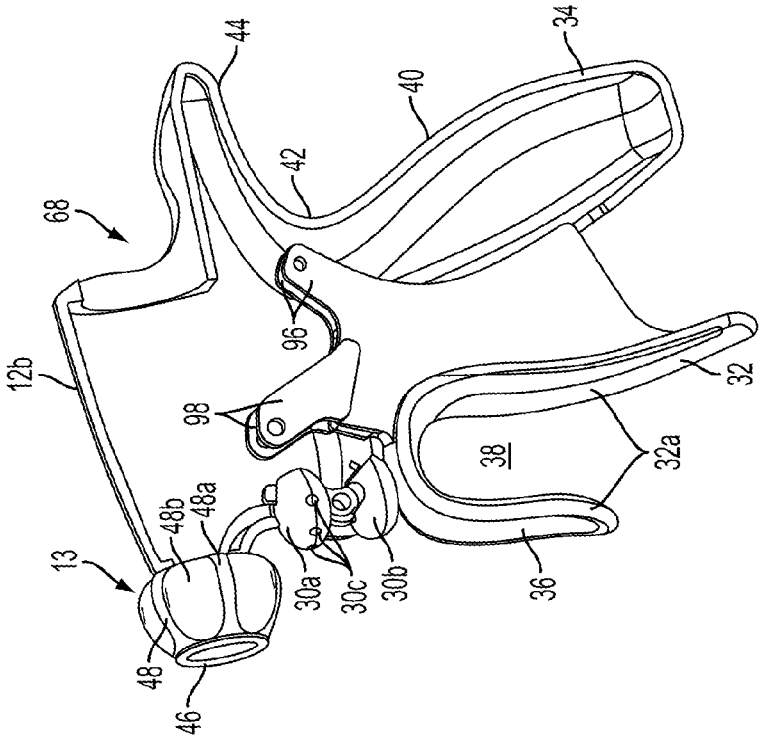
84
96
69
160
69
10
12a
92a
92
69
68
92b
34
69

FIG. 7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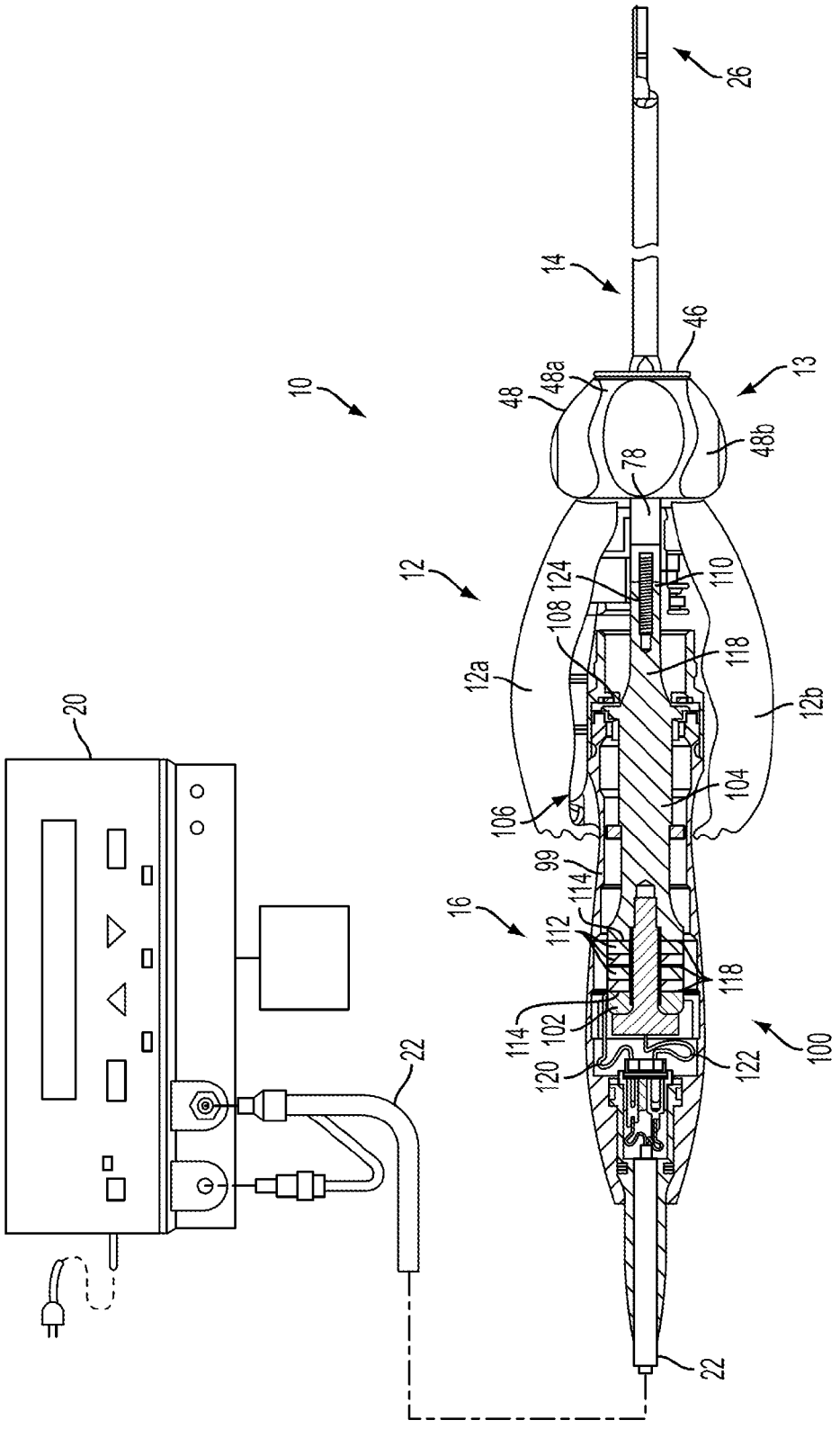
34
40
42
68
96
12b
32
98
38
32a
48b
48a
13
30a
30c
30b
36
48
46

FIG. 6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124

FIG. 8

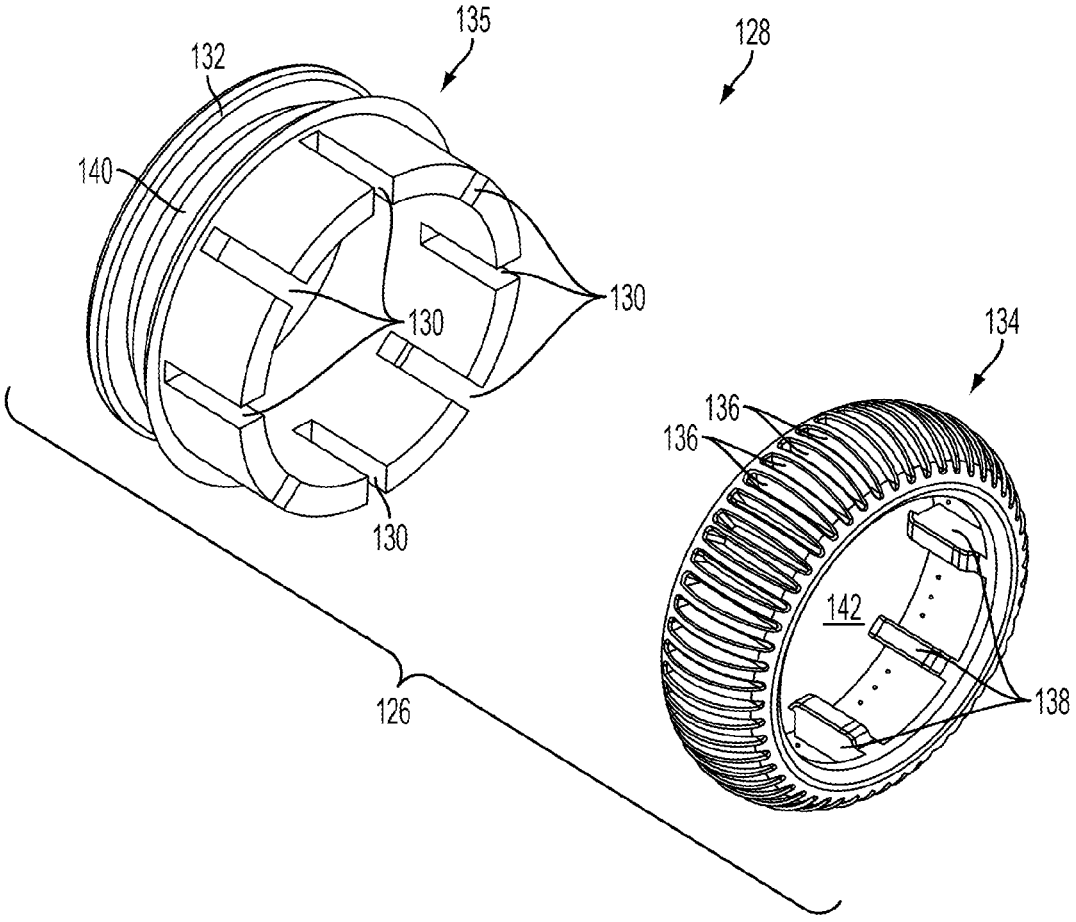


FIG. 9

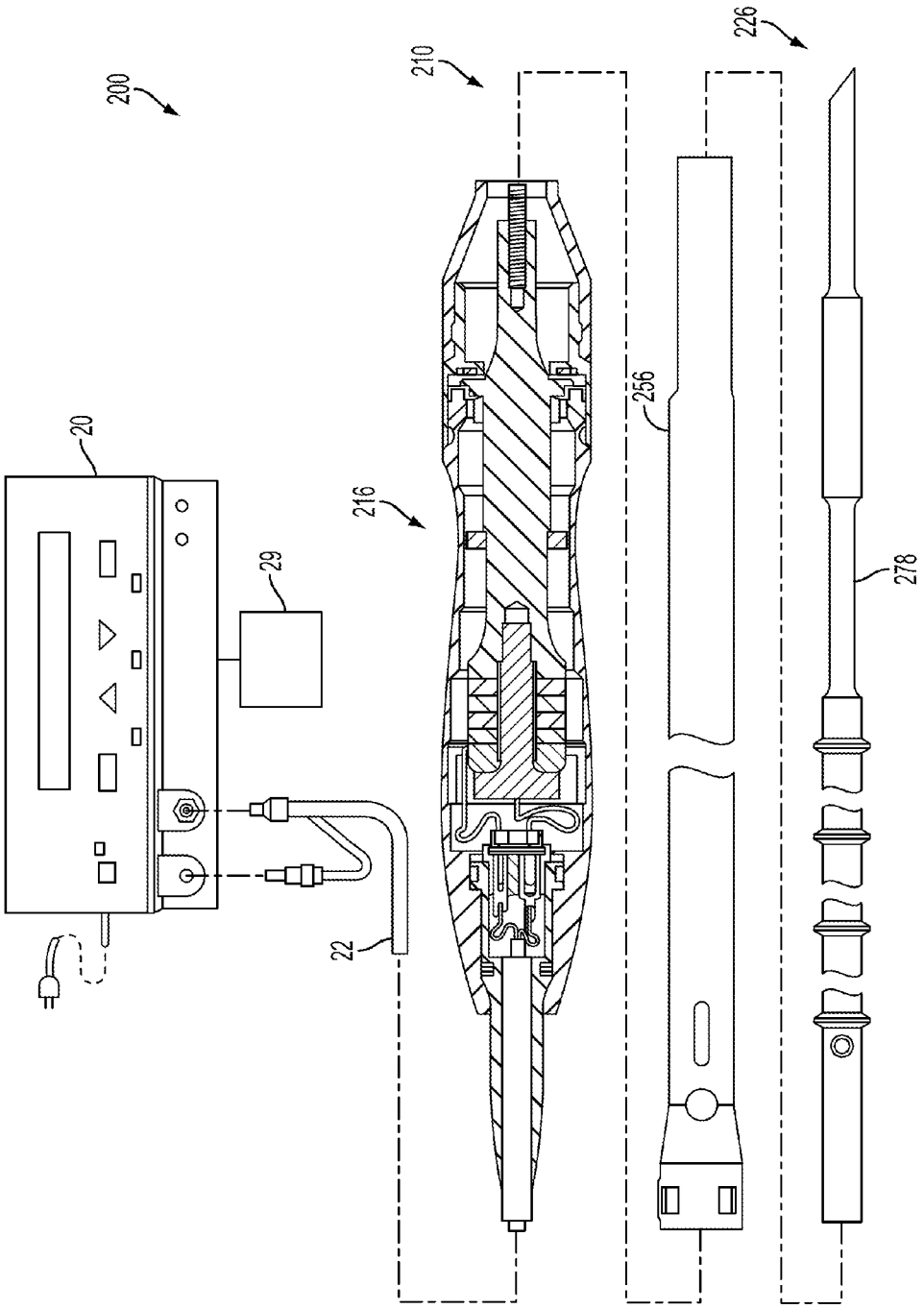


FIG. 10

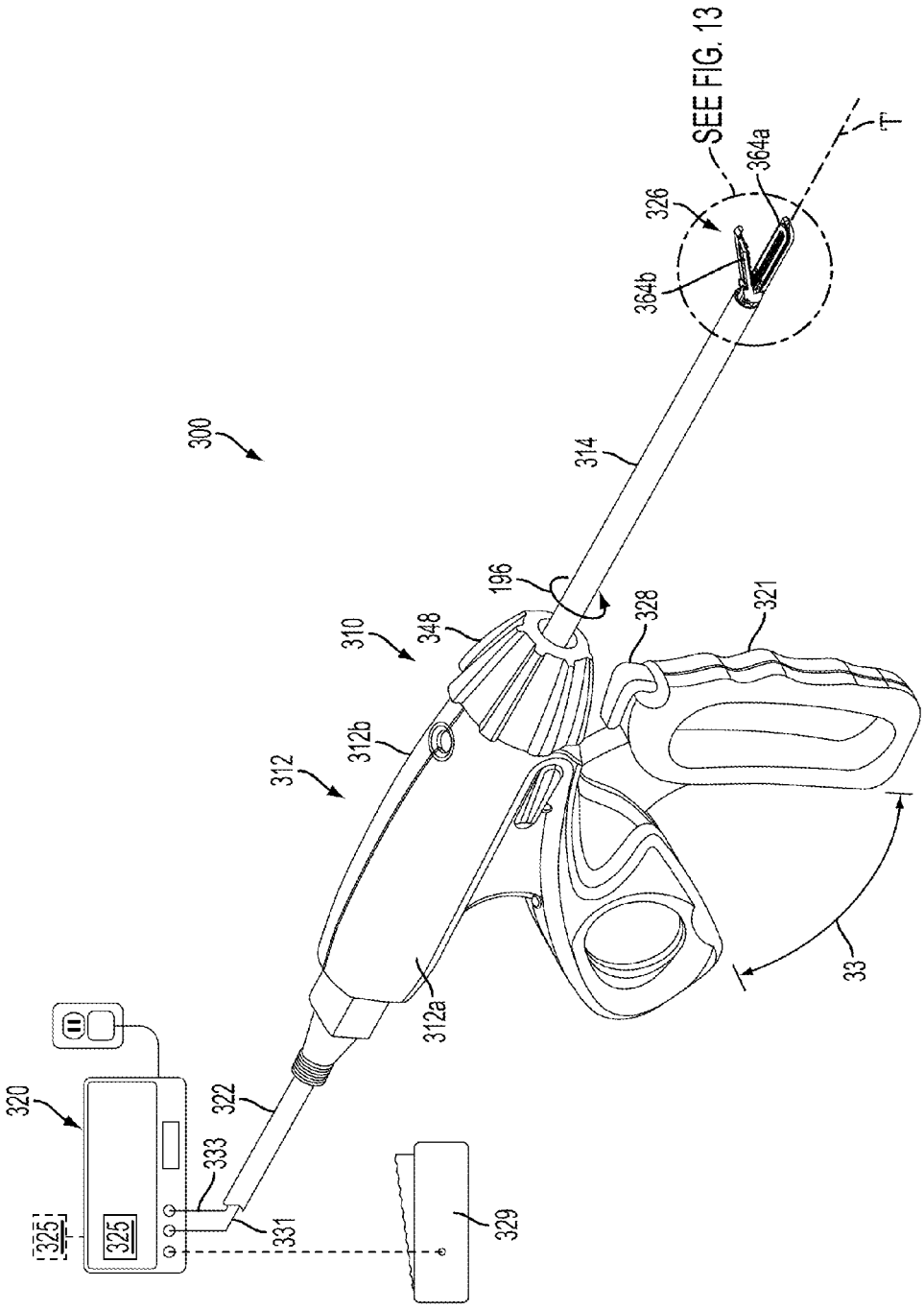

SEE FIG. 13
364a
T
326
364b
300
314
196
310
348
328
321
312
312b
312a
33
320
322
333
325
331
329

FIG. 11

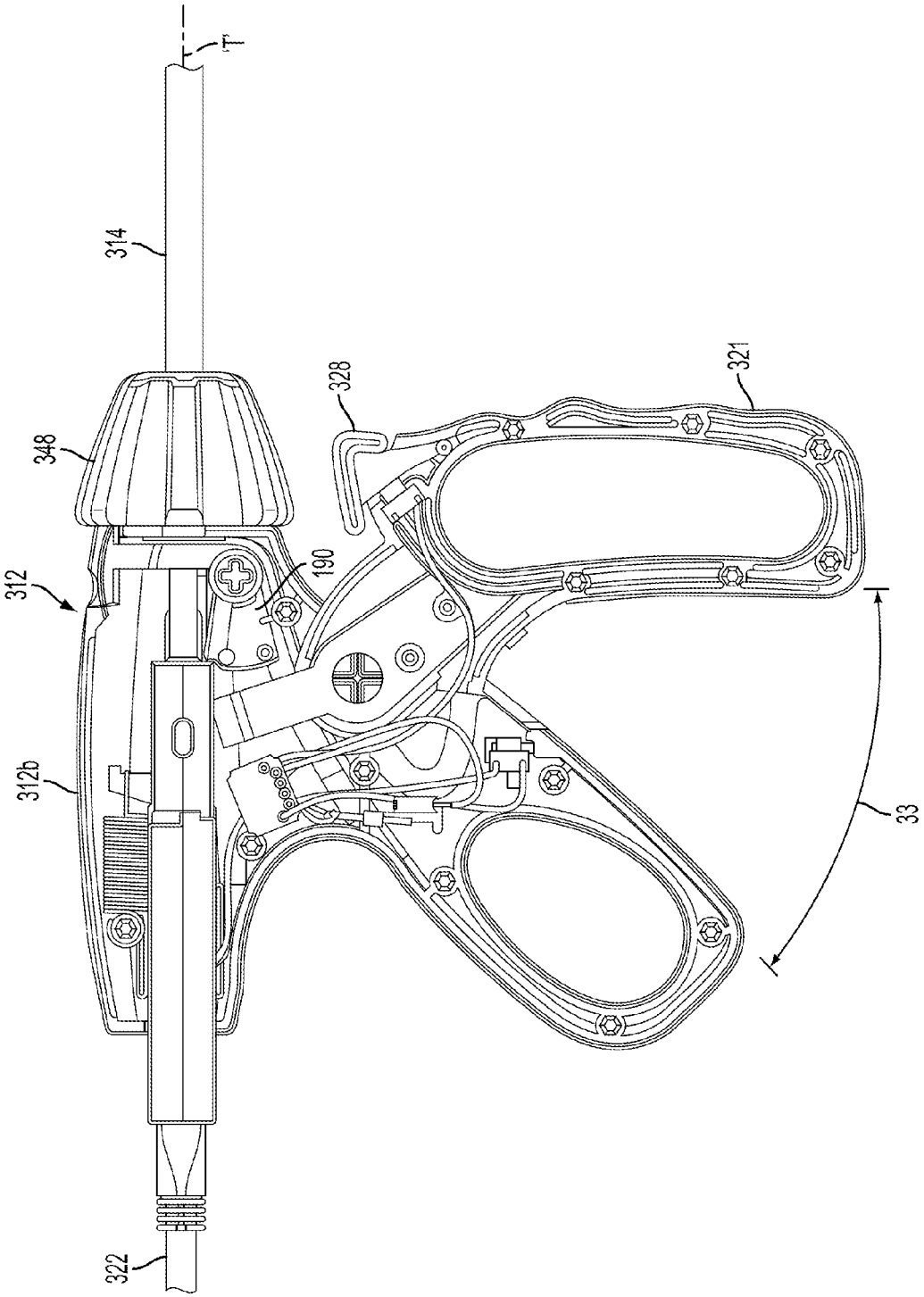


FIG. 12

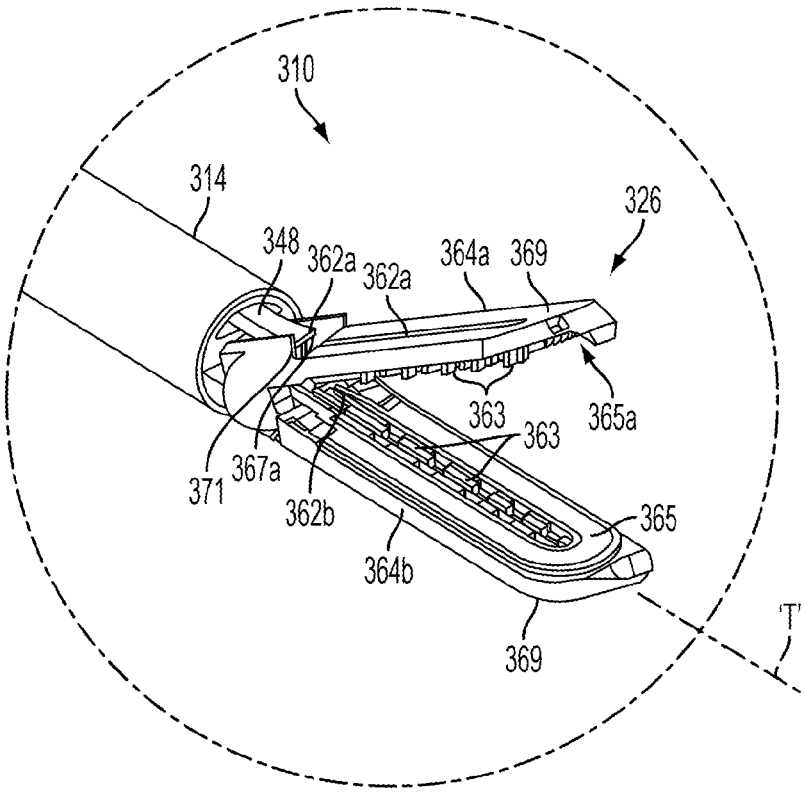
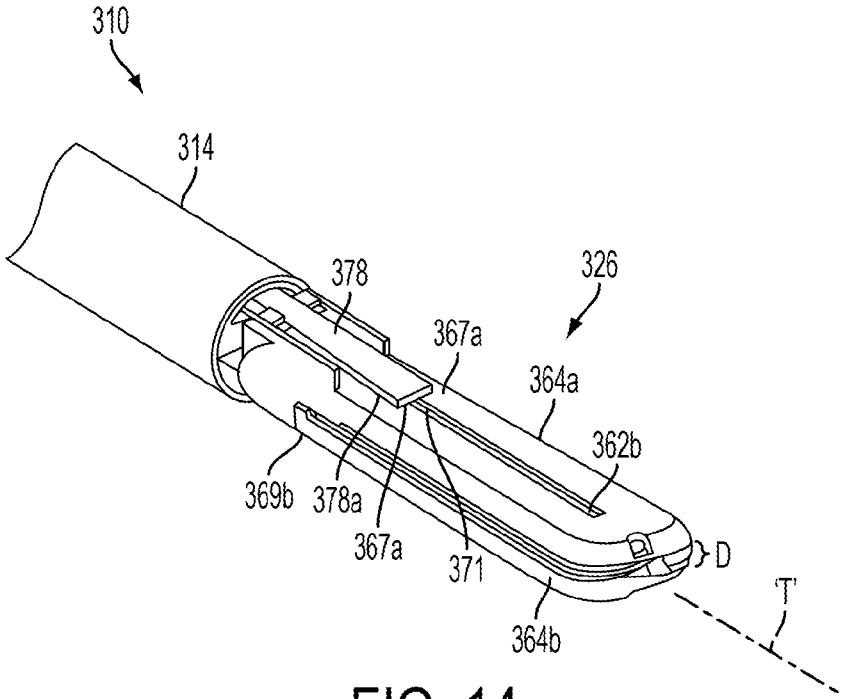

310
314
326
348
362a
362a
364a
369
363
363
365a
371
367a
362b
365
364b
369
T

FIG. 13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314
378
326
367a
364a
362b
369b
378a
367a
371
D
364b
T

FIG. 14

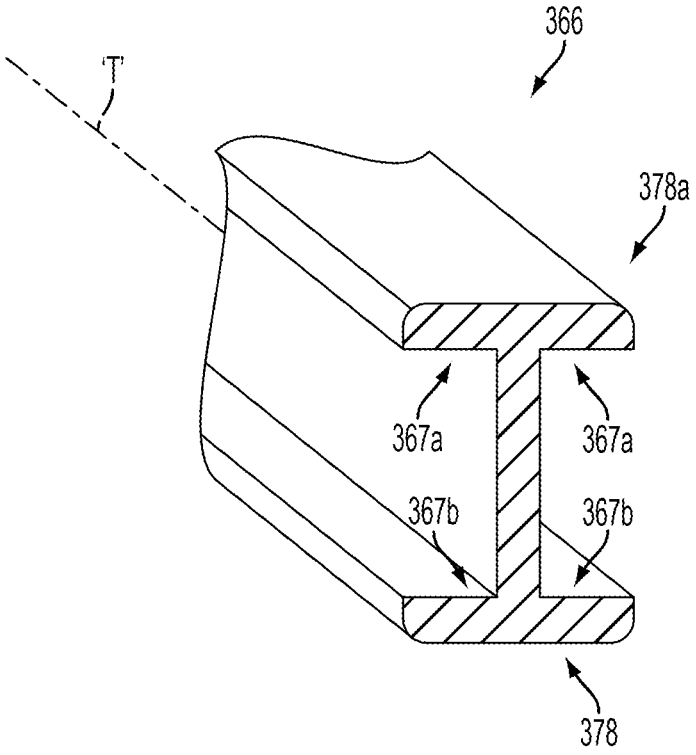


FIG. 15

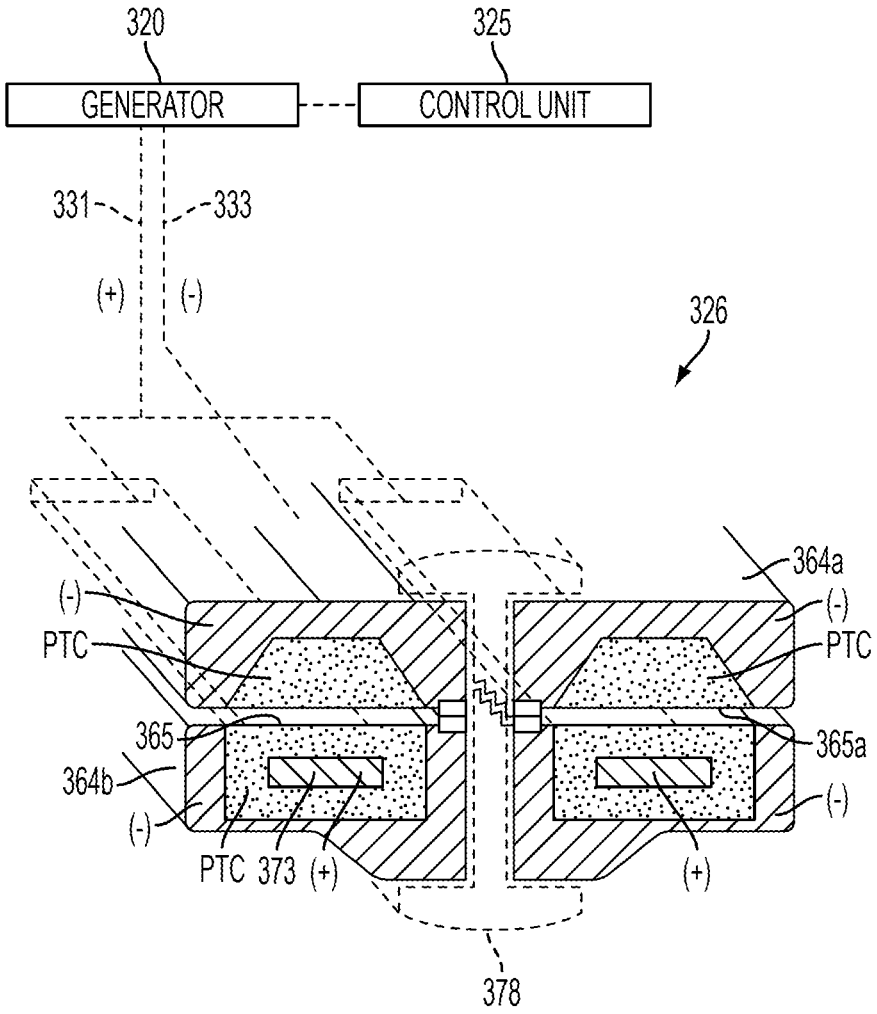

320
325
GENERATOR
CONTROL UNIT
331
333
(+)
(-)
326
364a
(-)
PTC
(-)
PTC
365
365a
364b
(-)
(-)
PTC
373
(+)
(+)
378

FIG. 16

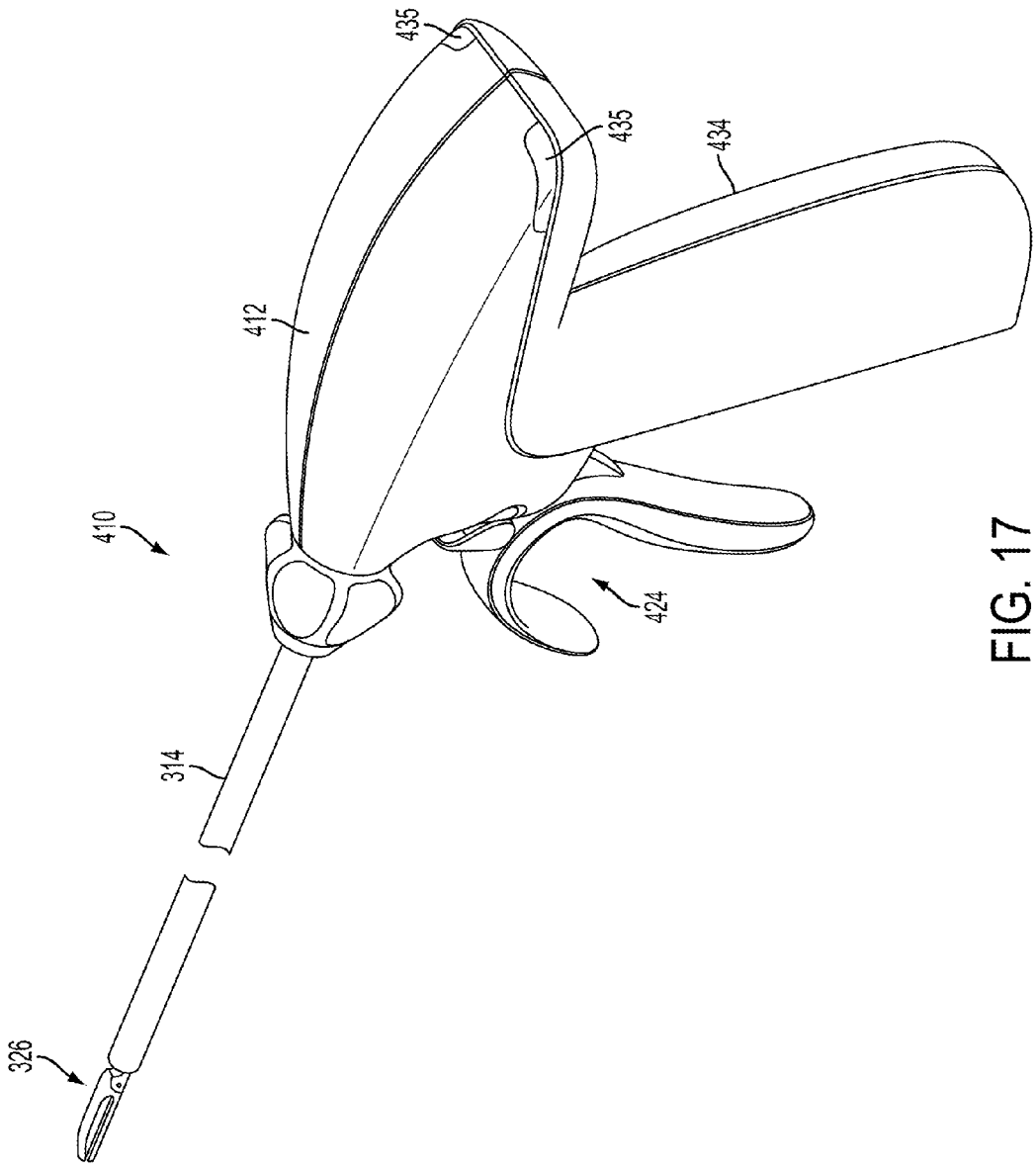


FIG. 17

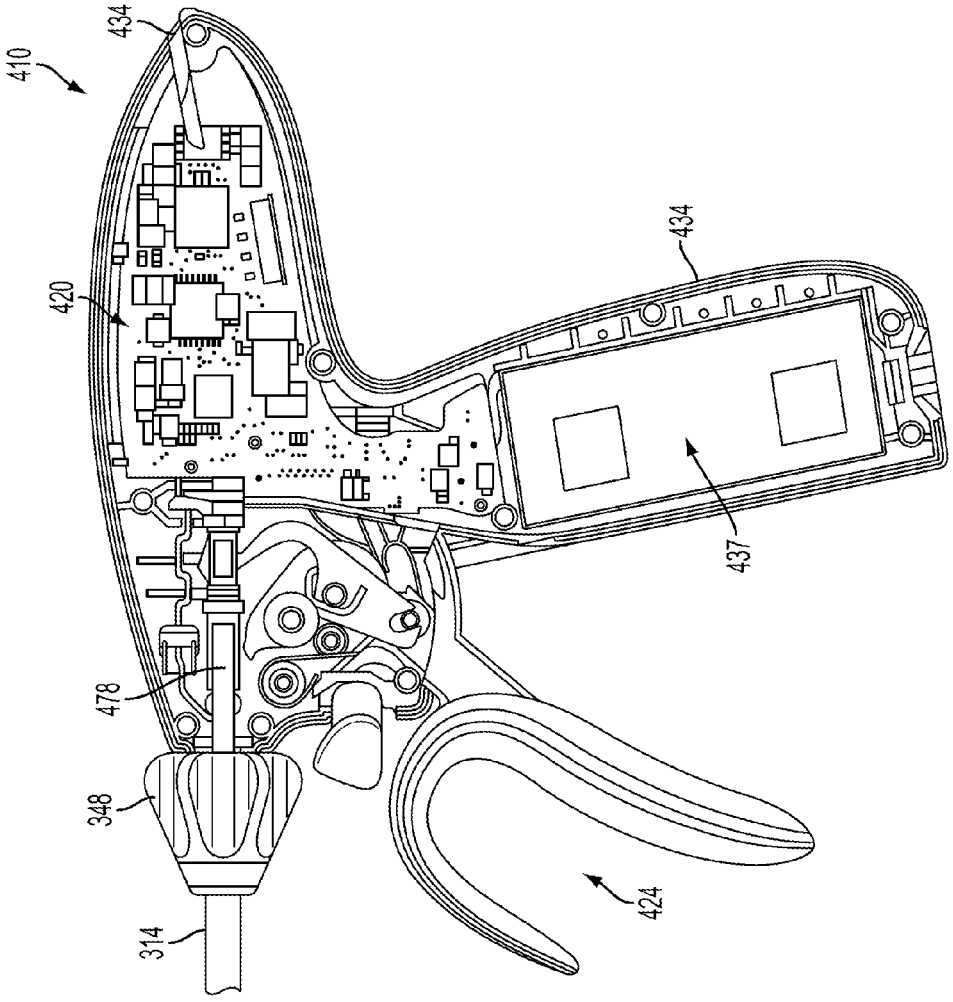


FIG. 18A

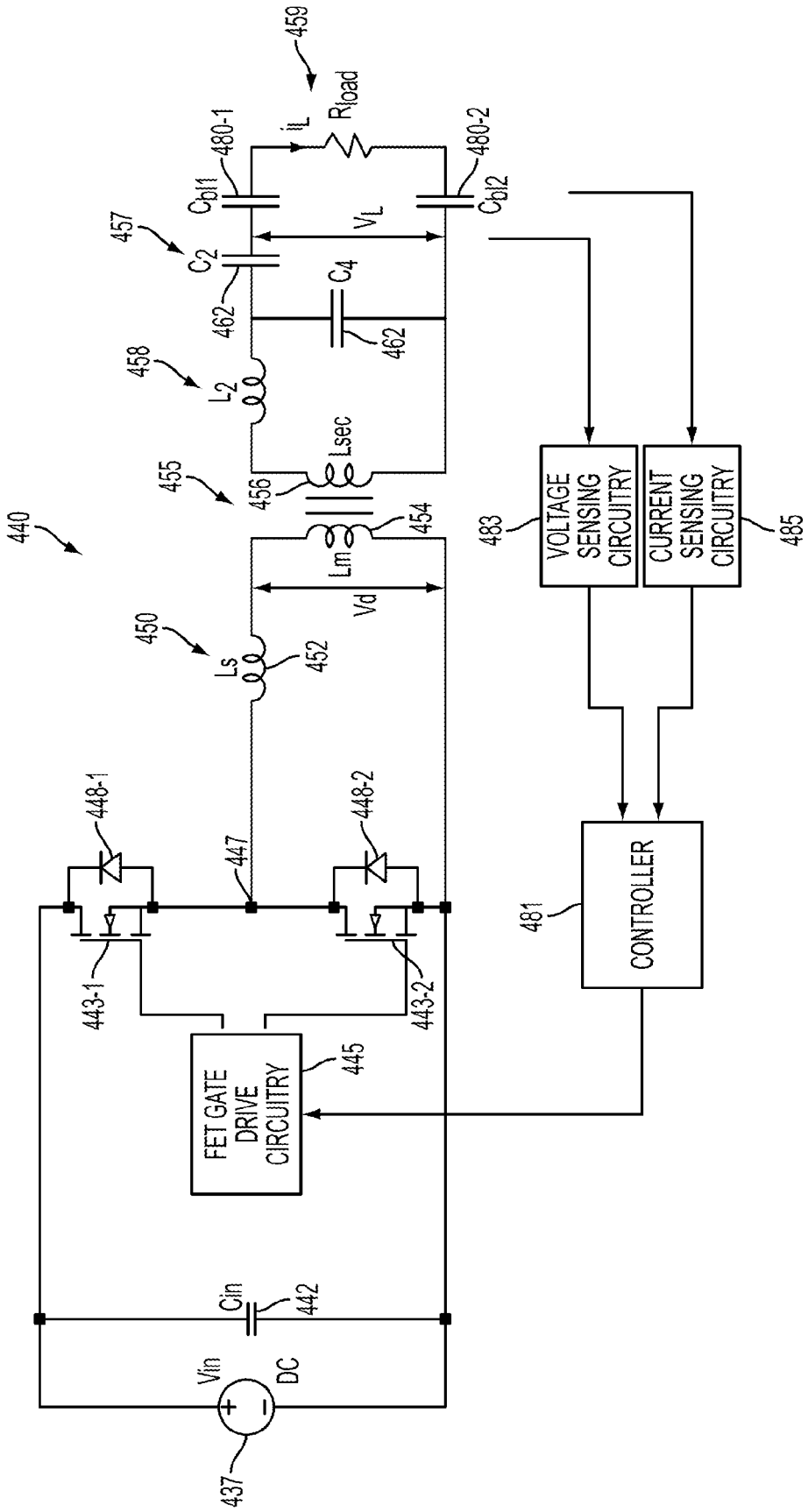

459
Rload
iL
480-1
480-2
Cbl1
Cbl2
VL
457
C2
C4
462
462
458
L2
Lsec
455
456
454
440
Lm
Vd
450
Ls
452
483
VOLTAGE SENSING CIRCUITRY
CURRENT SENSING CIRCUITRY
485
448-1
448-2
447
481
CONTROLLER
443-1
443-2
445
FET GATE DRIVE CIRCUITRY
Cin
442
Vin DC
437

FIG. 18B

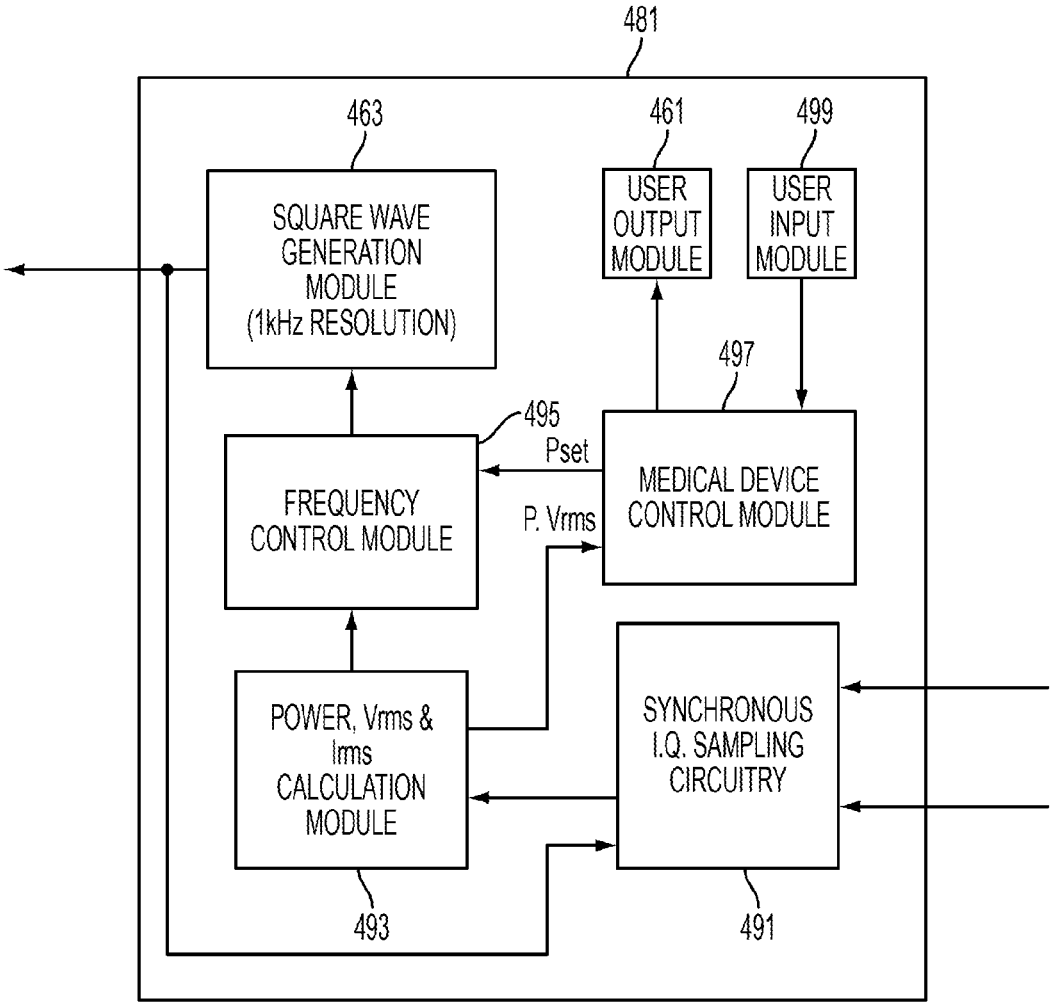

481
463
461
499
SQUARE WAVE GENERATION MODULE (1kHz RESOLUTION)
USER OUTPUT MODULE
USER INPUT MODULE
497
495
Pset
FREQUENCY CONTROL MODULE
MEDICAL DEVICE CONTROL MODULE
P. Vrms
POWER, Vrms & Irms CALCULATION MODULE
SYNCHRONOUS I.Q. SAMPLING CIRCUITRY
493
491

FIG. 18C

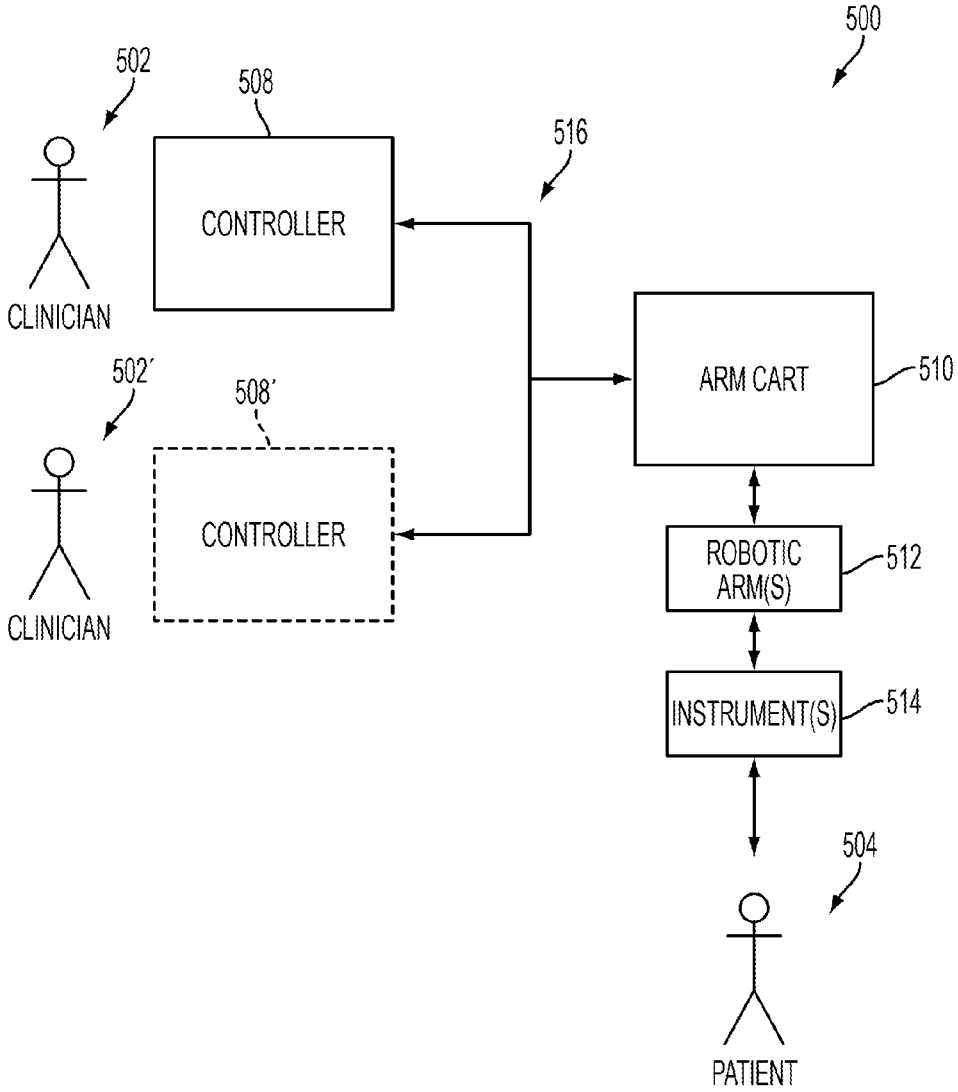

500
502
508
516
CONTROLLER
CLINICIAN
502´
508´
CONTROLLER
CLINICIAN
ARM CART
510
ROBOTIC ARM(S)
512
INSTRUMENT(S)
514
504
PATIENT

FIG. 19

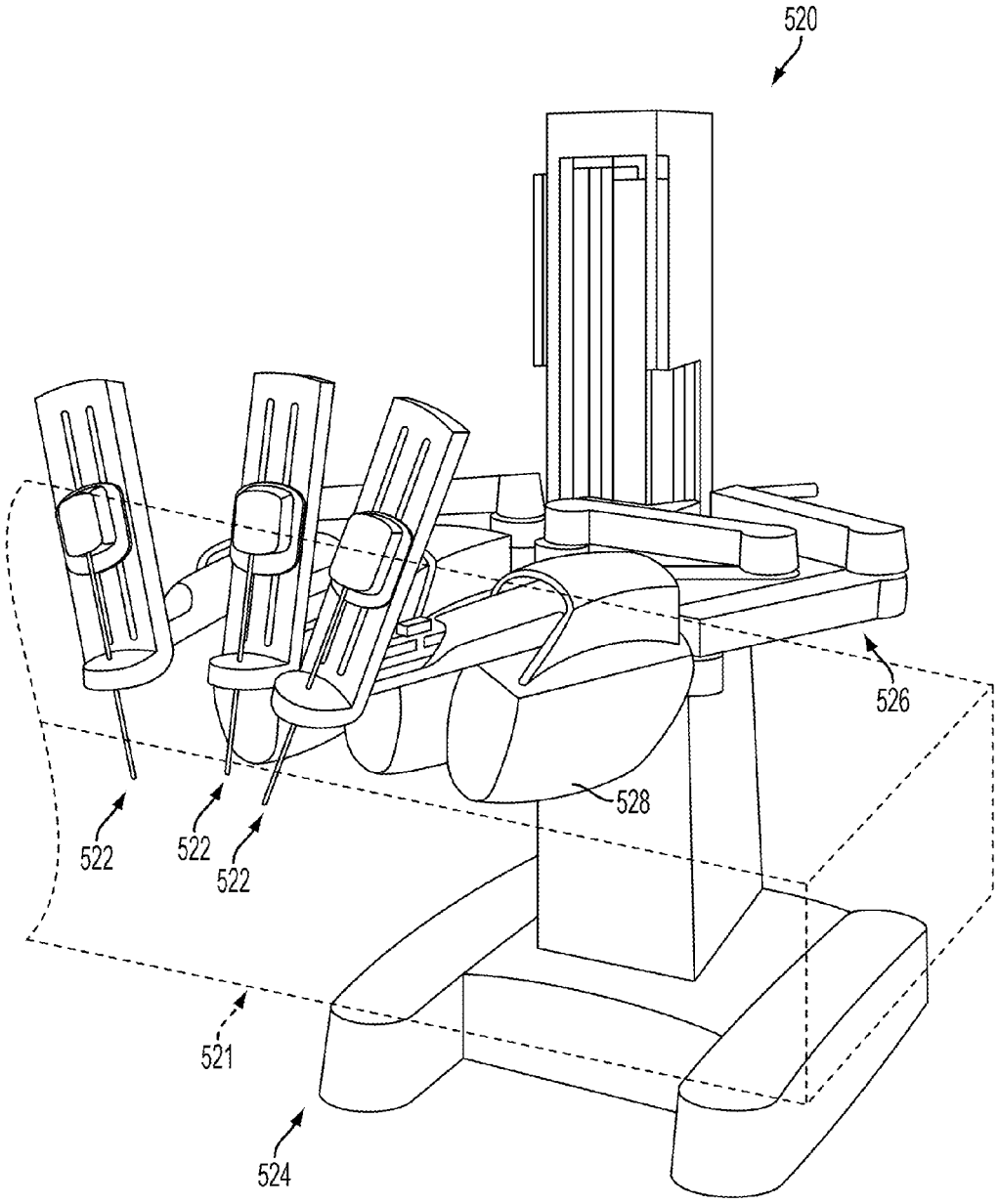


FIG. 20

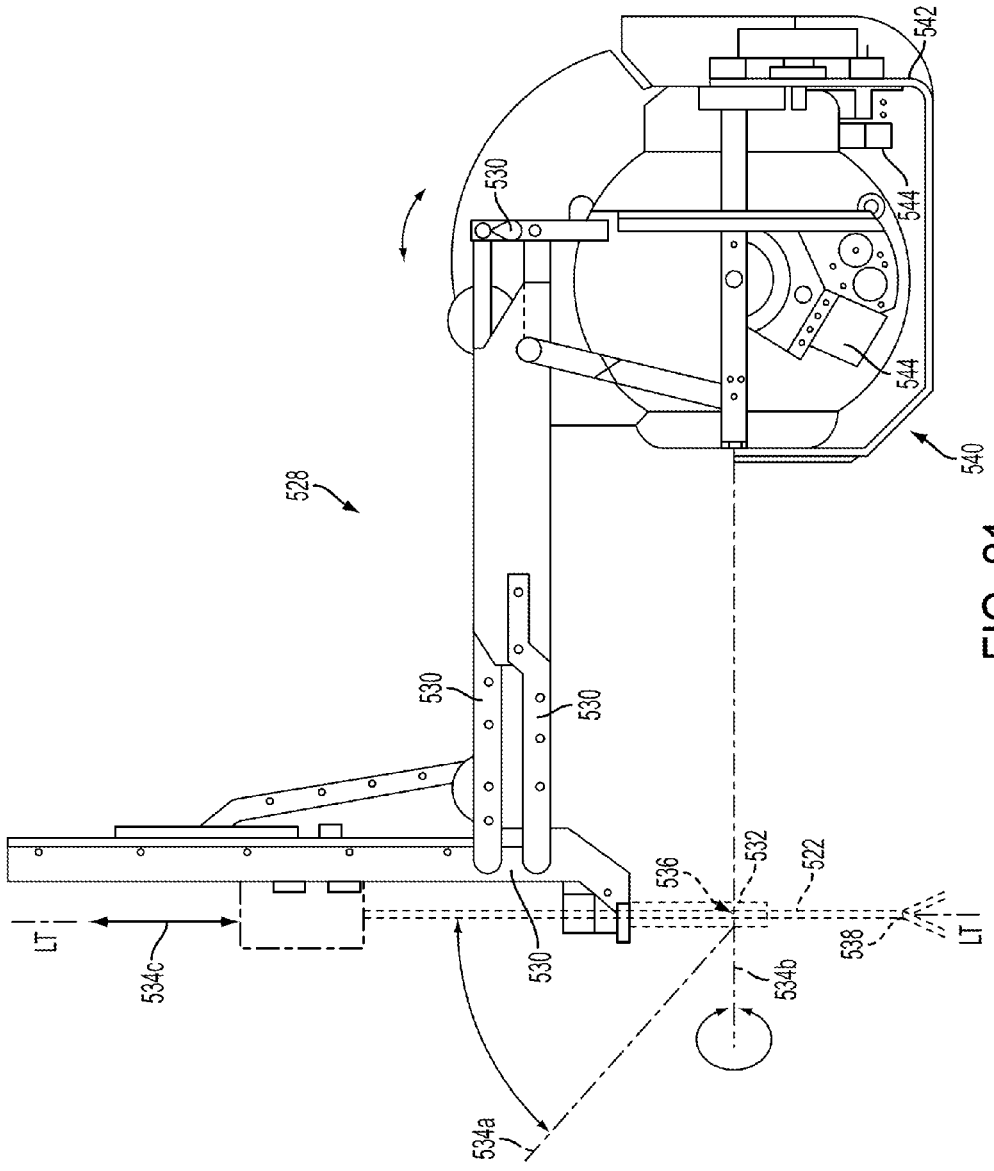

542
530
544
544
540
528
530
530
536
532
522
LT
534c
530
538
LT
534b
534a

FIG. 21

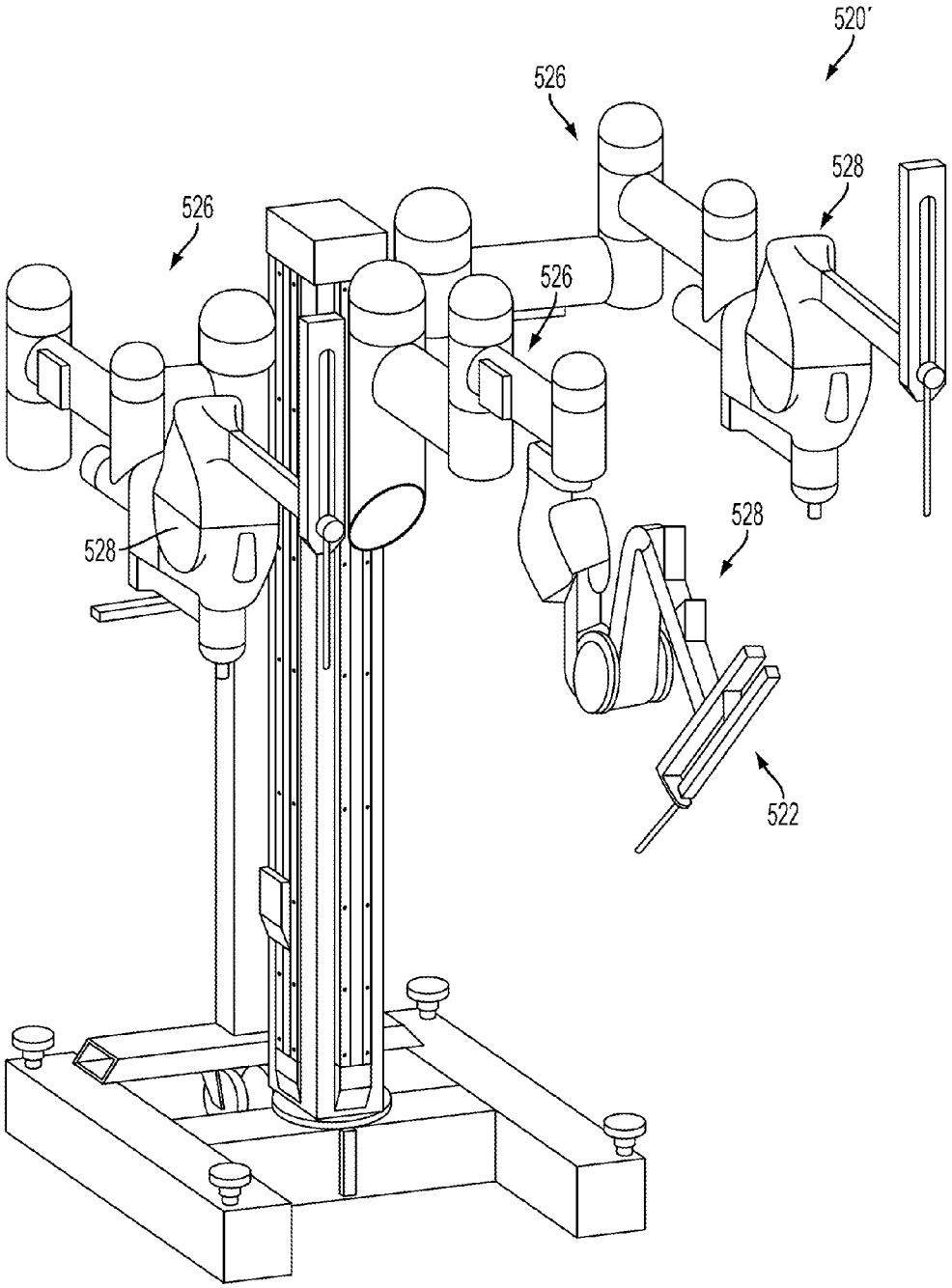


FIG. 22

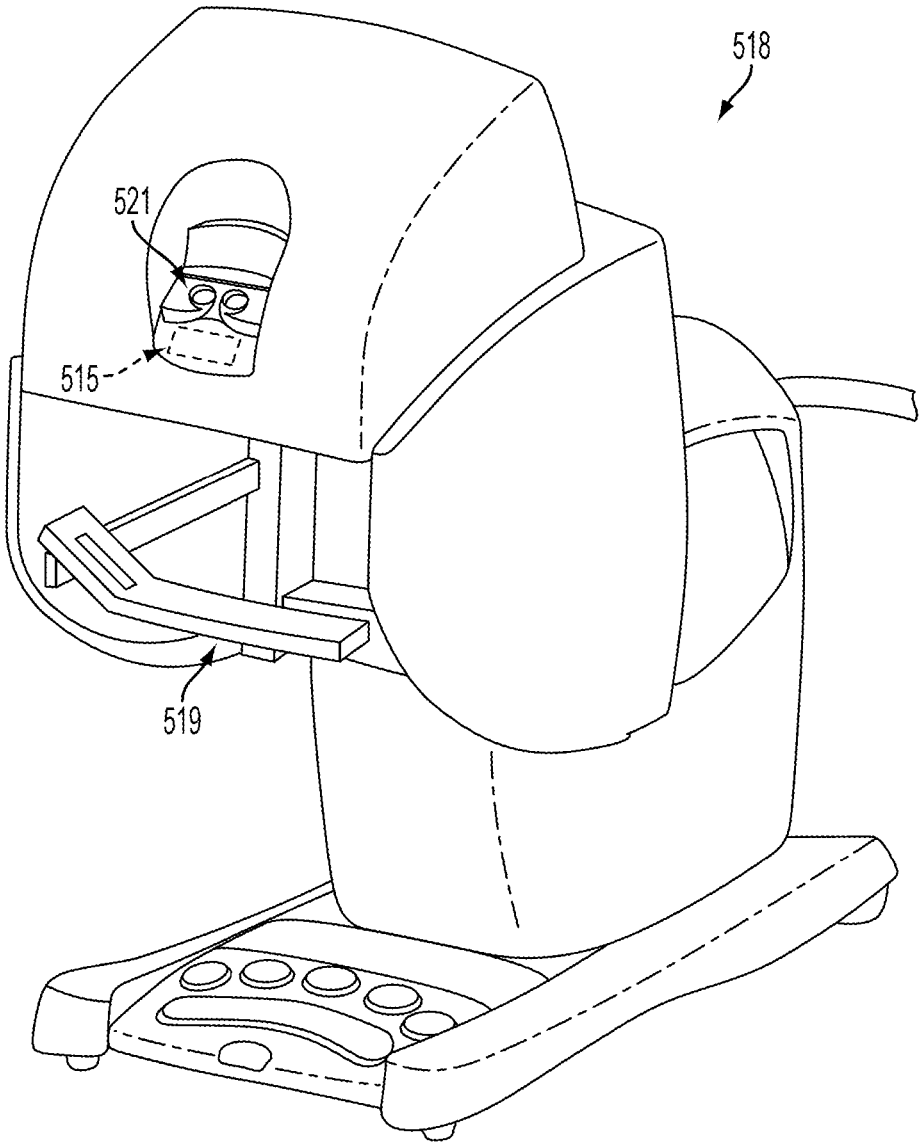


FIG. 23

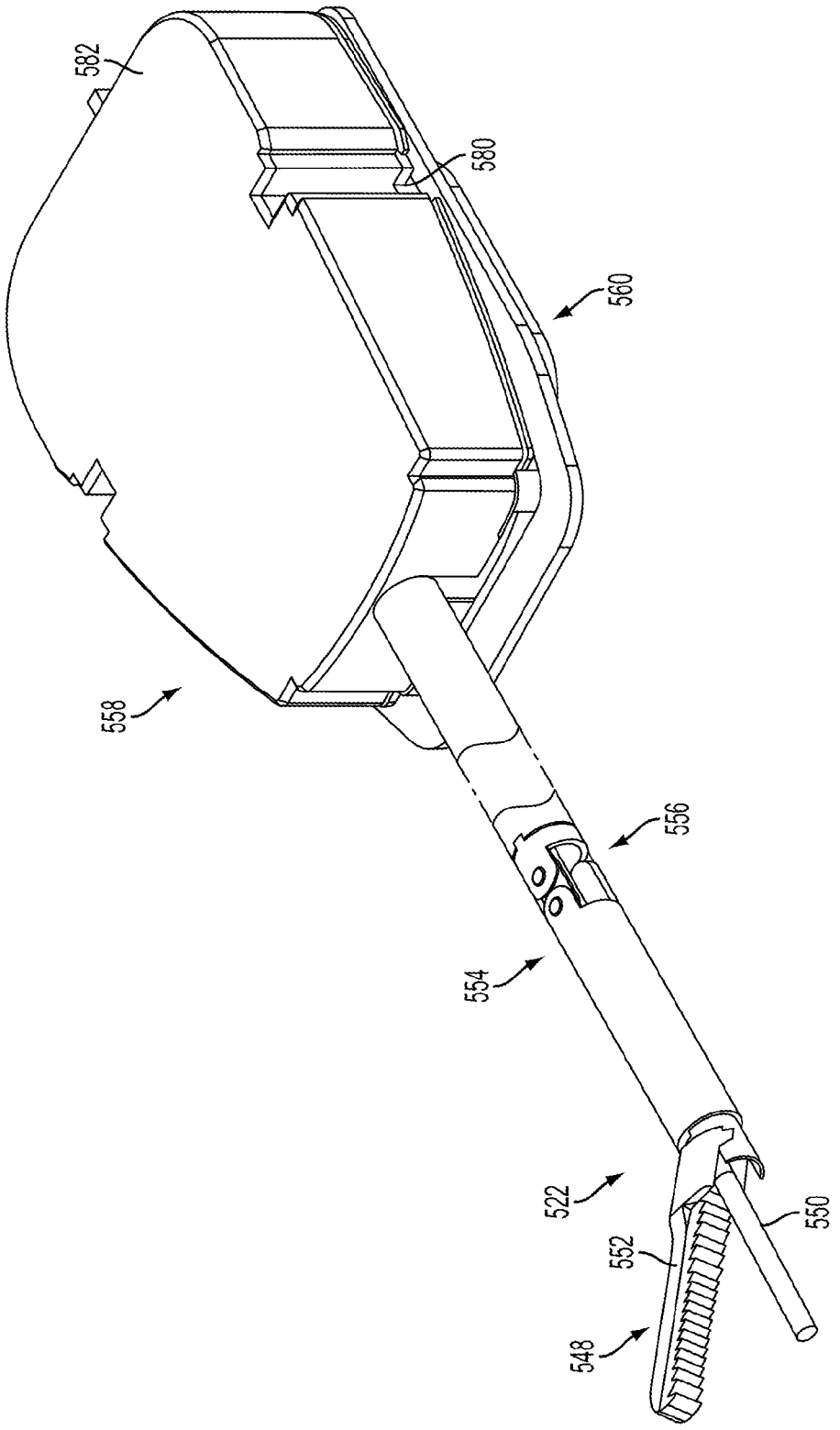


FIG. 24

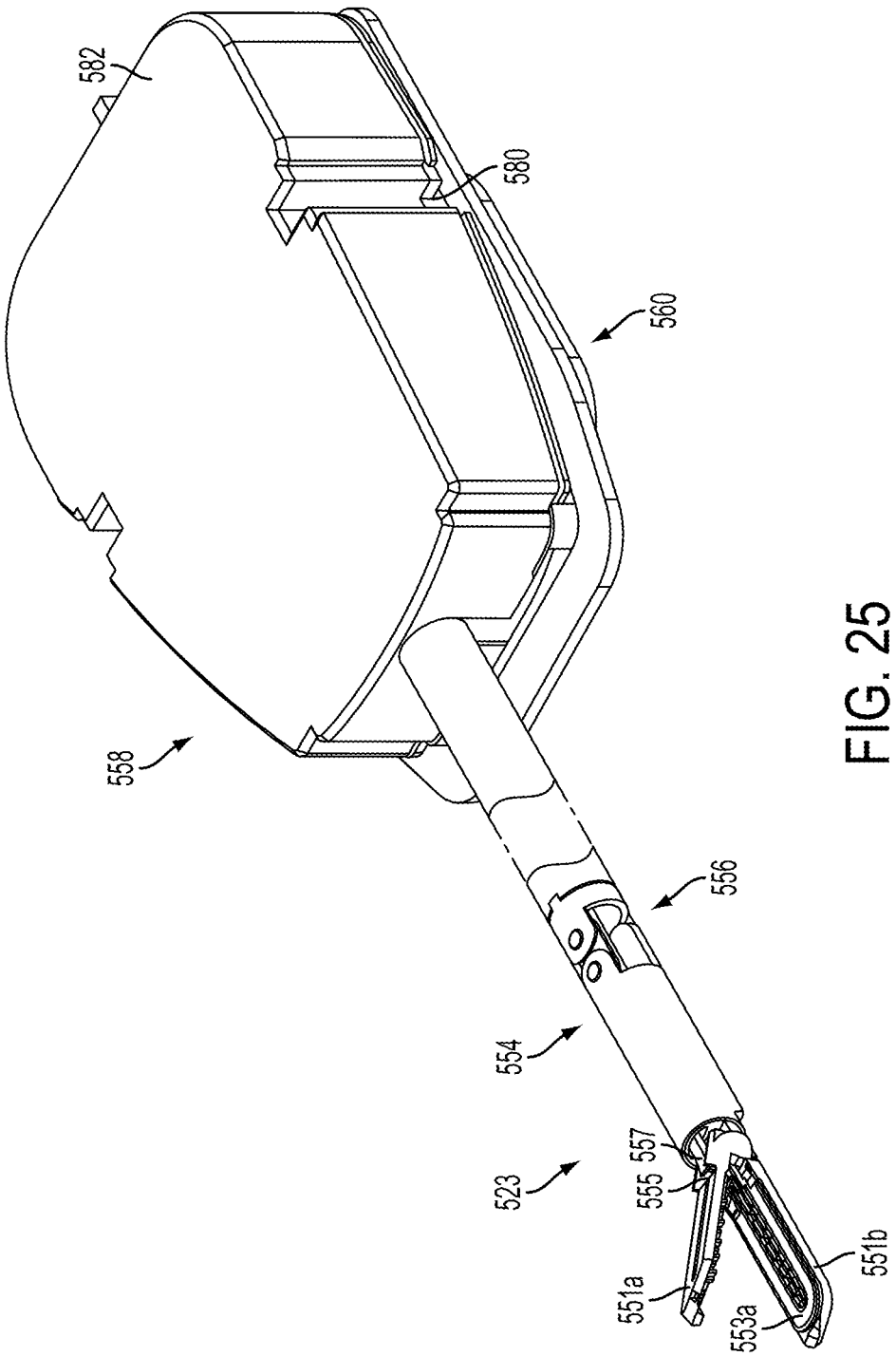
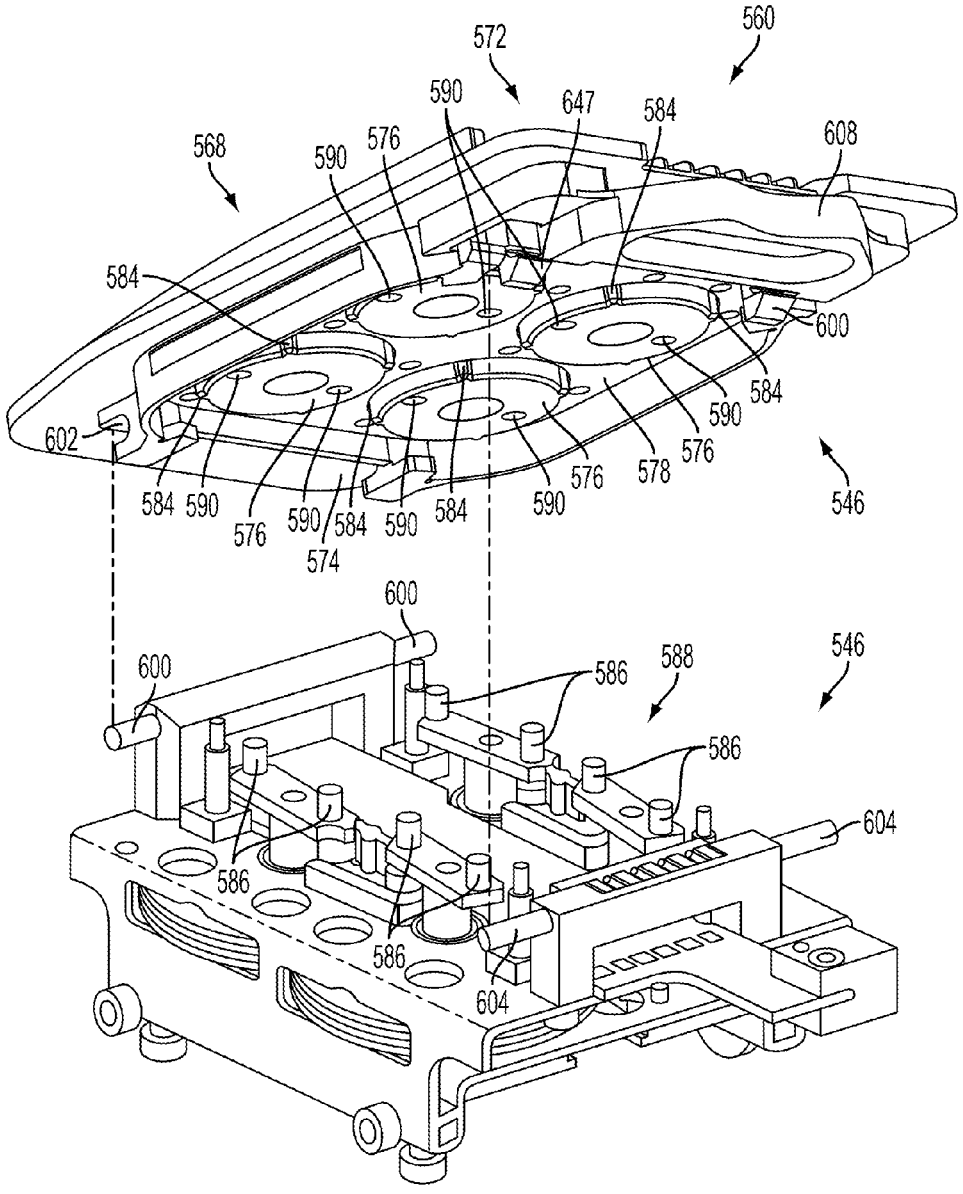


FIG. 25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572
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647
584
568
590
576
608
584
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584
590
602
576
578
576
546
584
590
576
590
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574
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588
546
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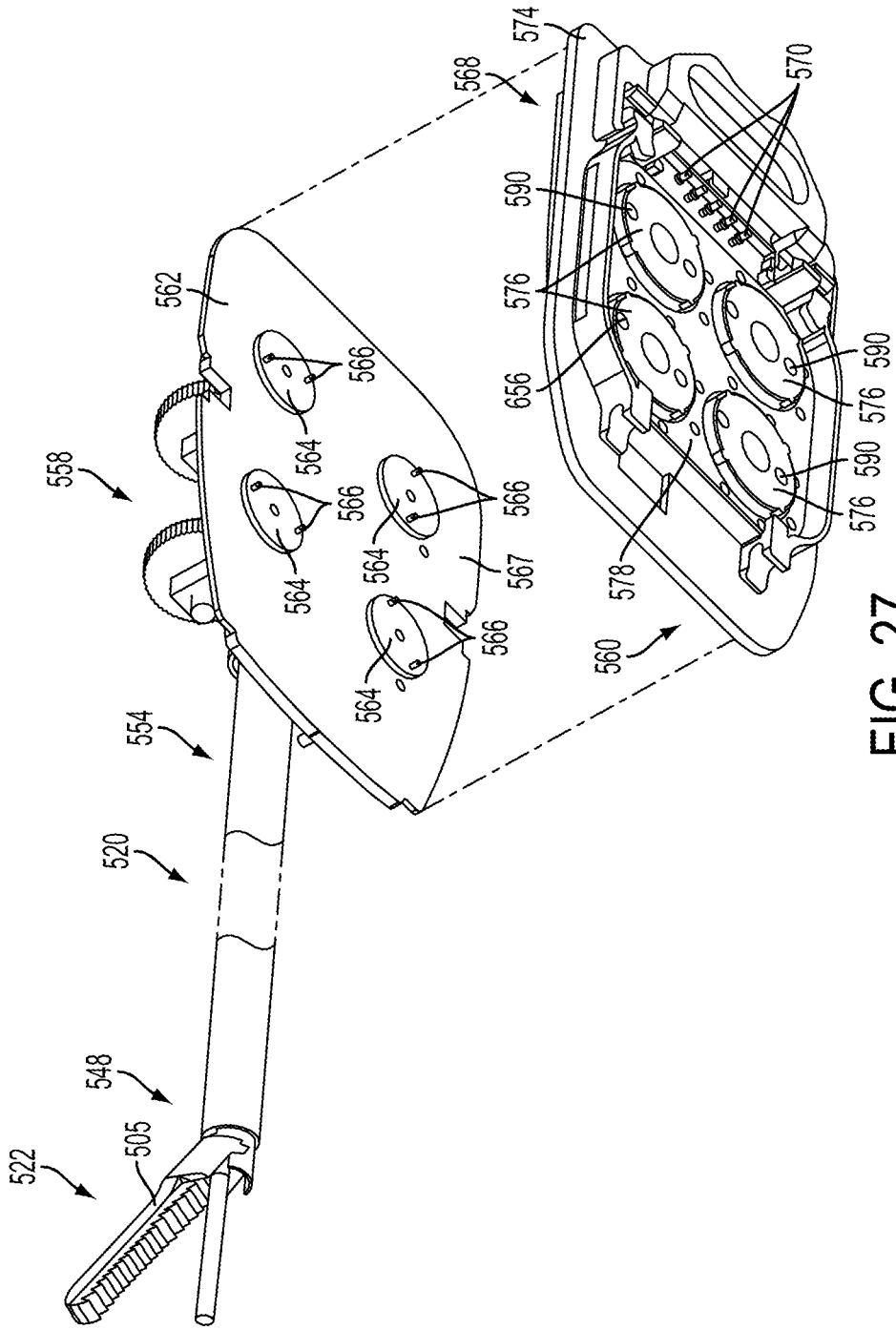
586
604

FIG. 26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568
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566
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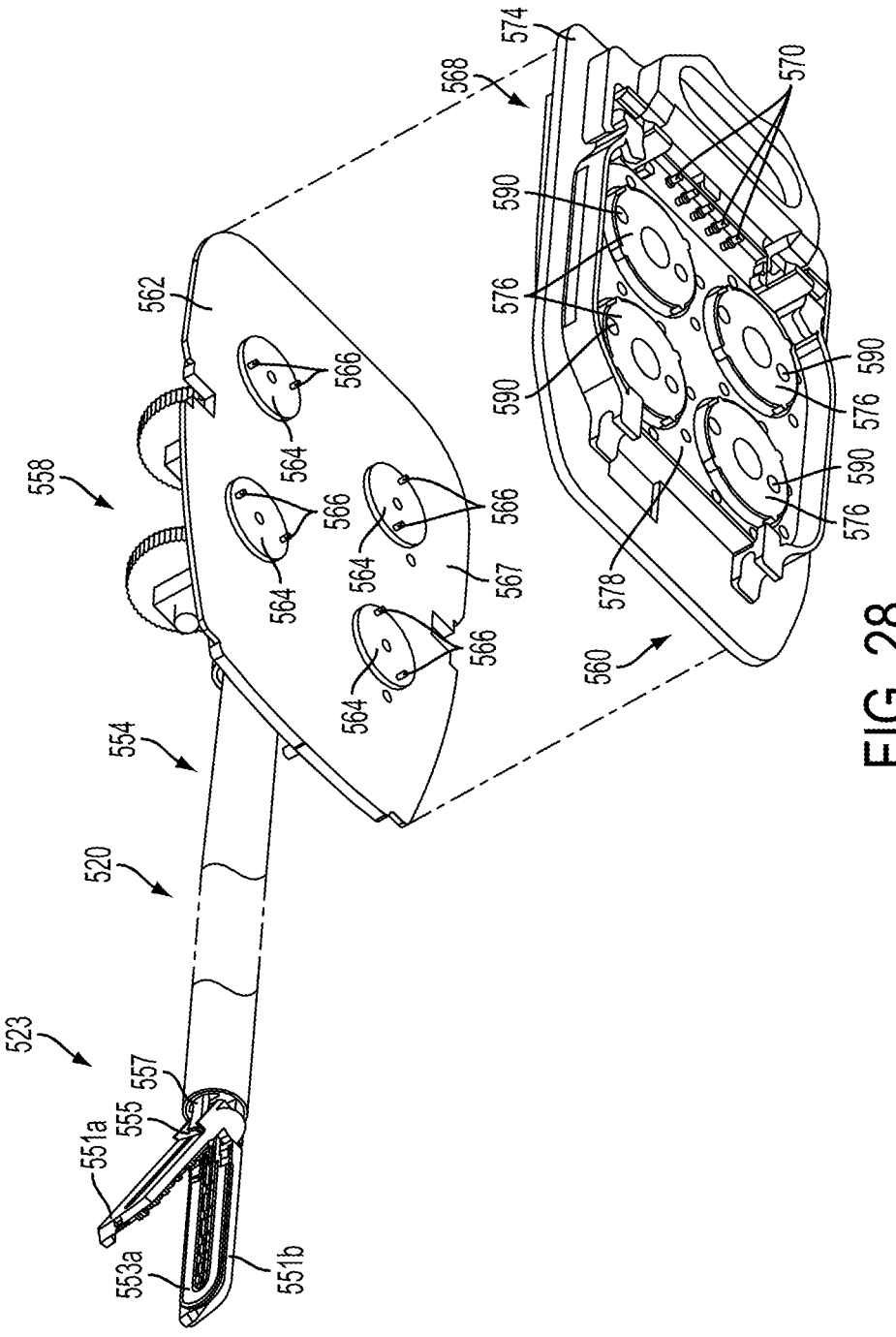
567
578
566
564
560
554
520
548
505
522

FIG. 27


574
568
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523
557
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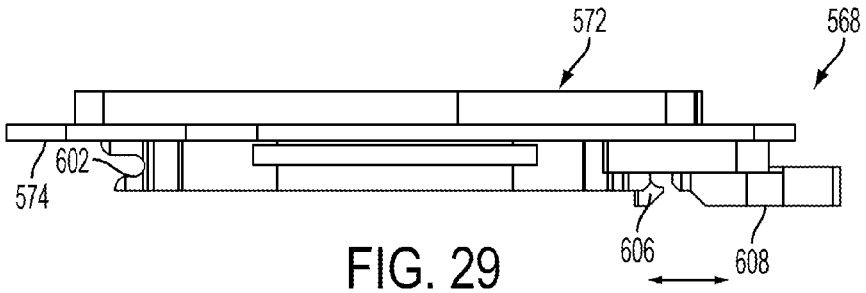
551a
553a
551b

FIG. 28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602
574
606
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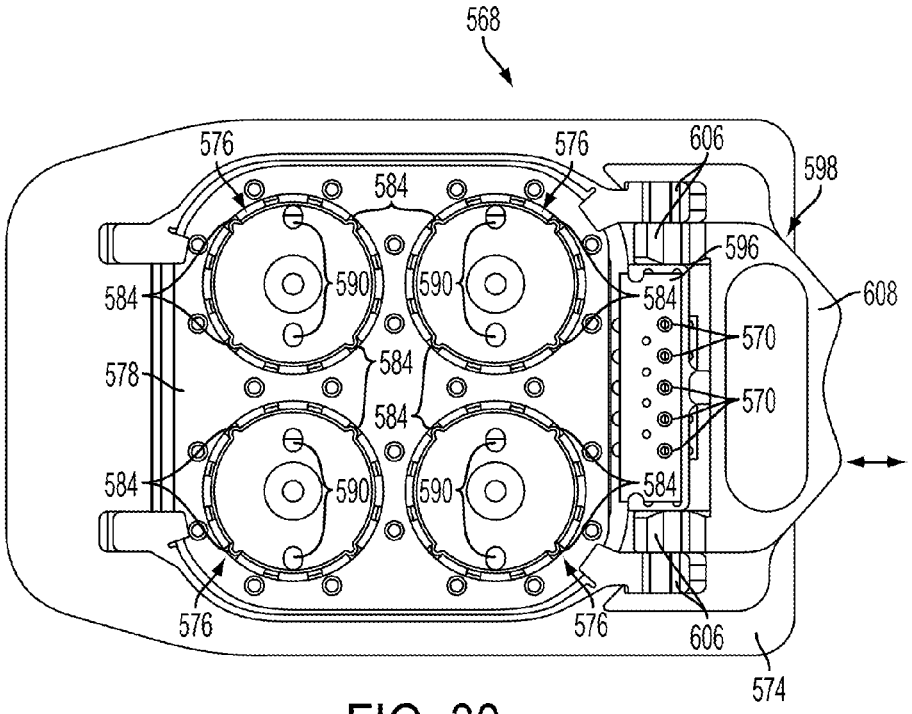
FIG. 29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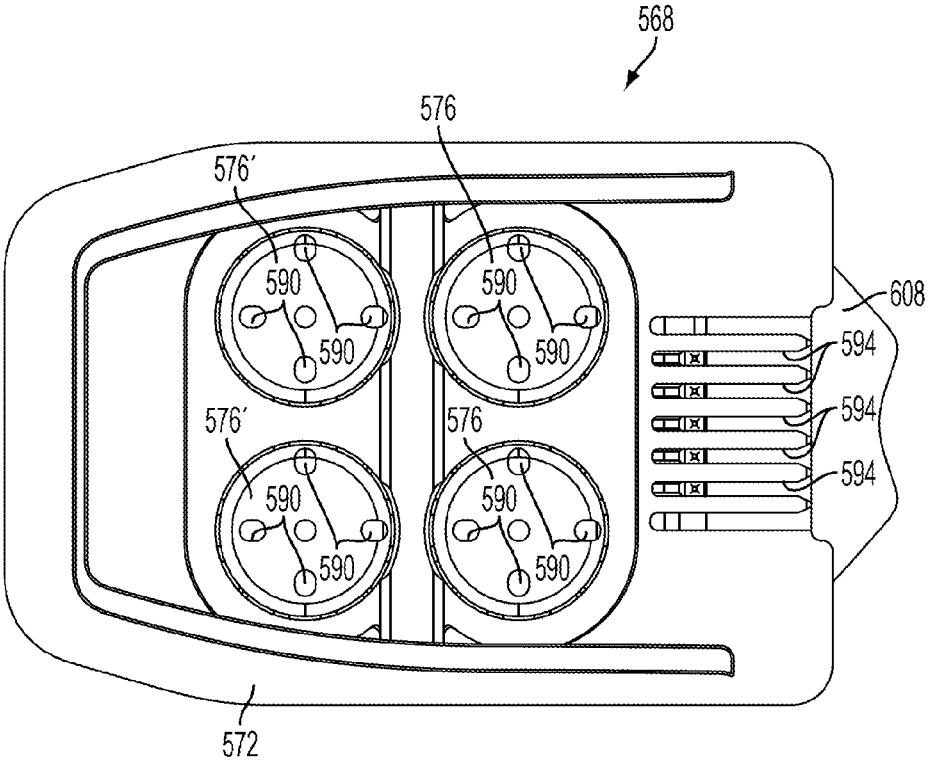
606
574

FIG. 30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576′
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594
594
576′
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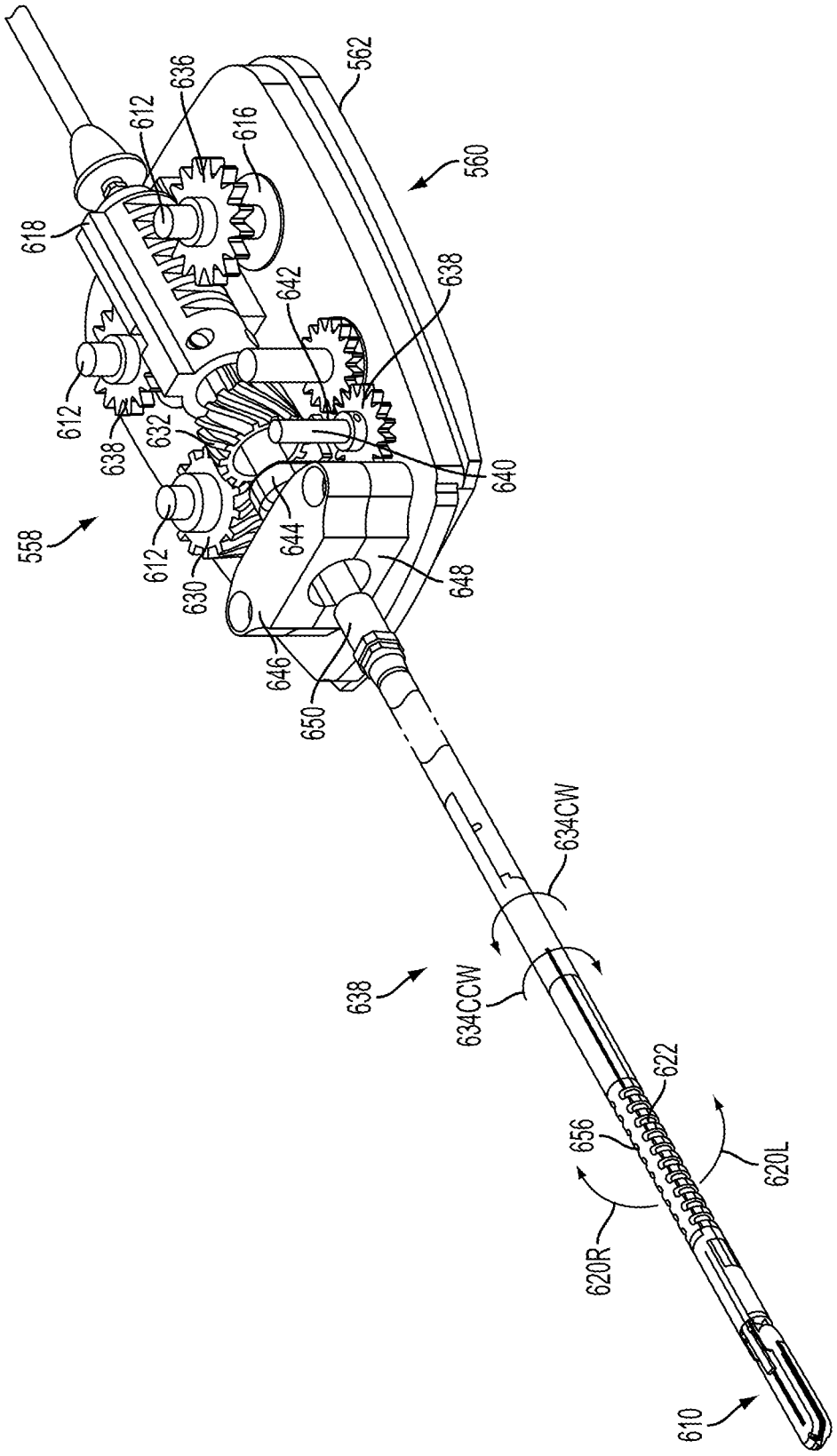
590
590
590
590
572

FIG. 31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636
612
616
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618
642
638
612
632
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558
612
644
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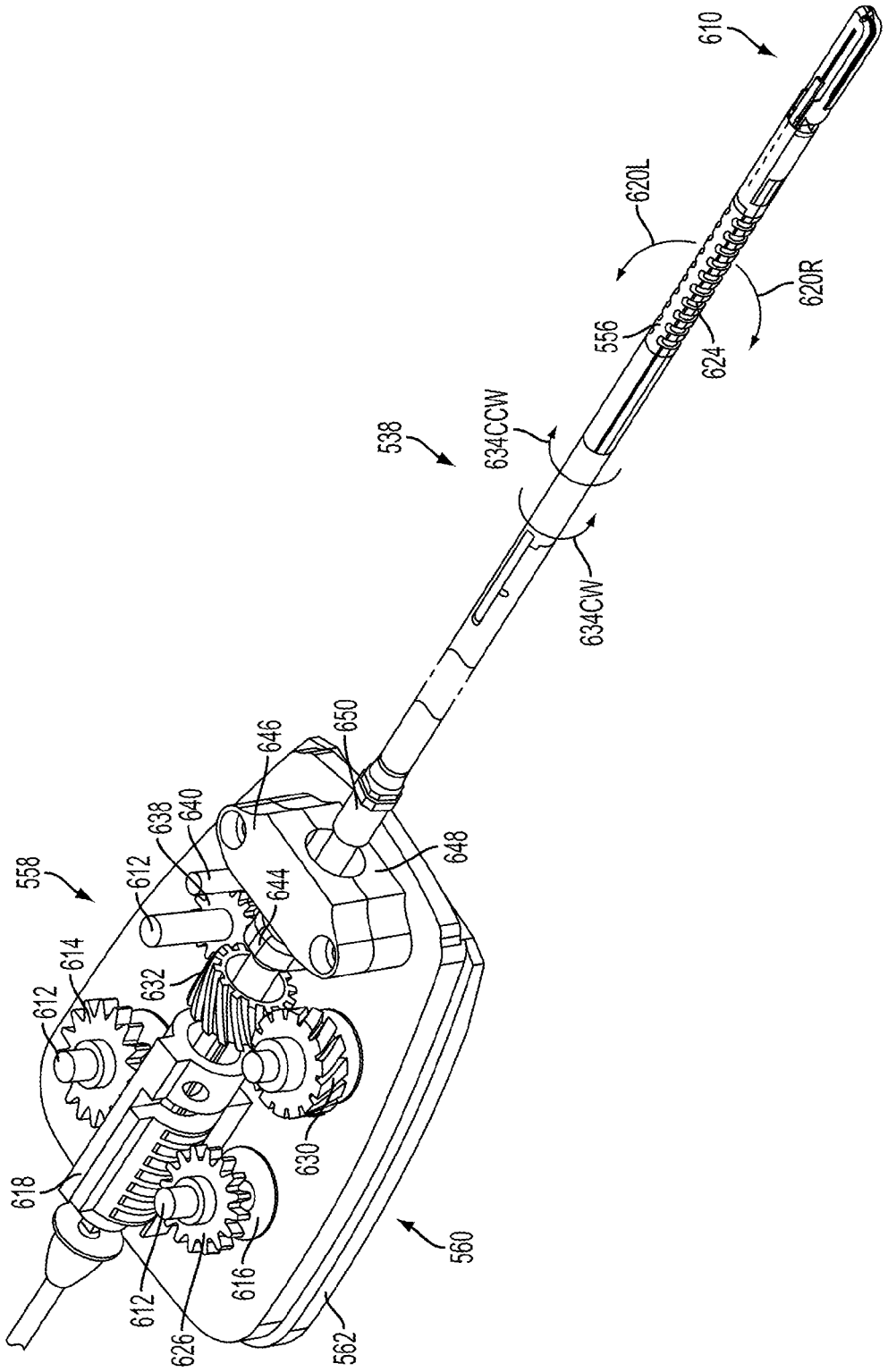
648
646
650
634CW
638
634CCW
622
656
620L
620R
610

FIG. 32


610
620L
620R
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634CCW
634CW
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630
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626
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560

FIG. 33

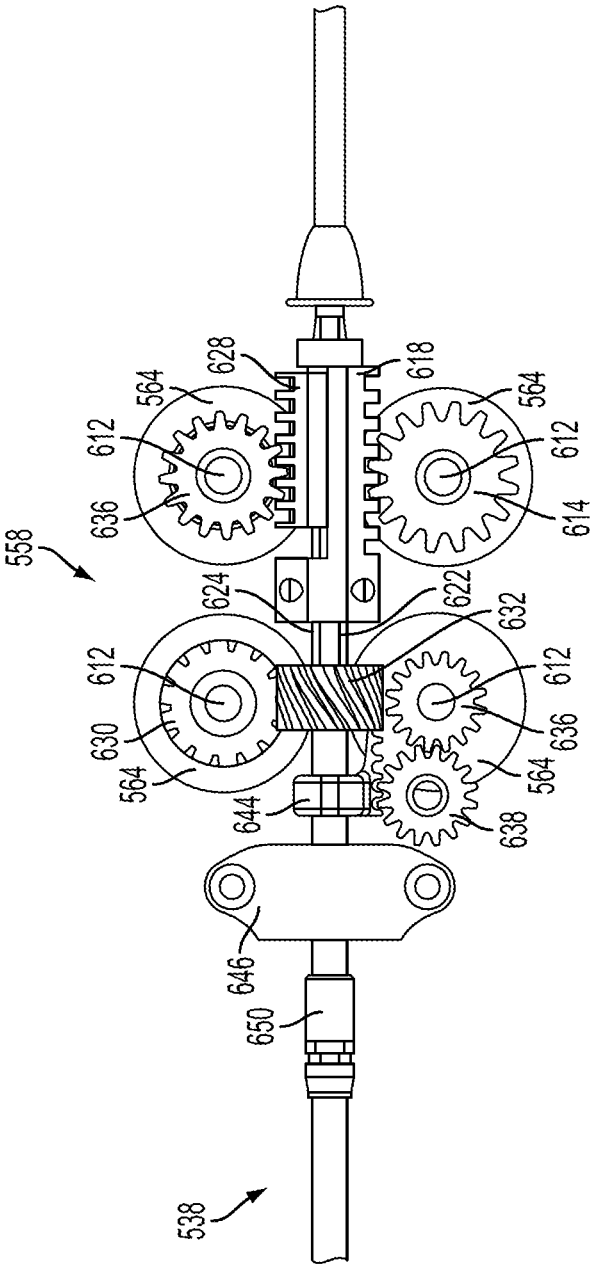
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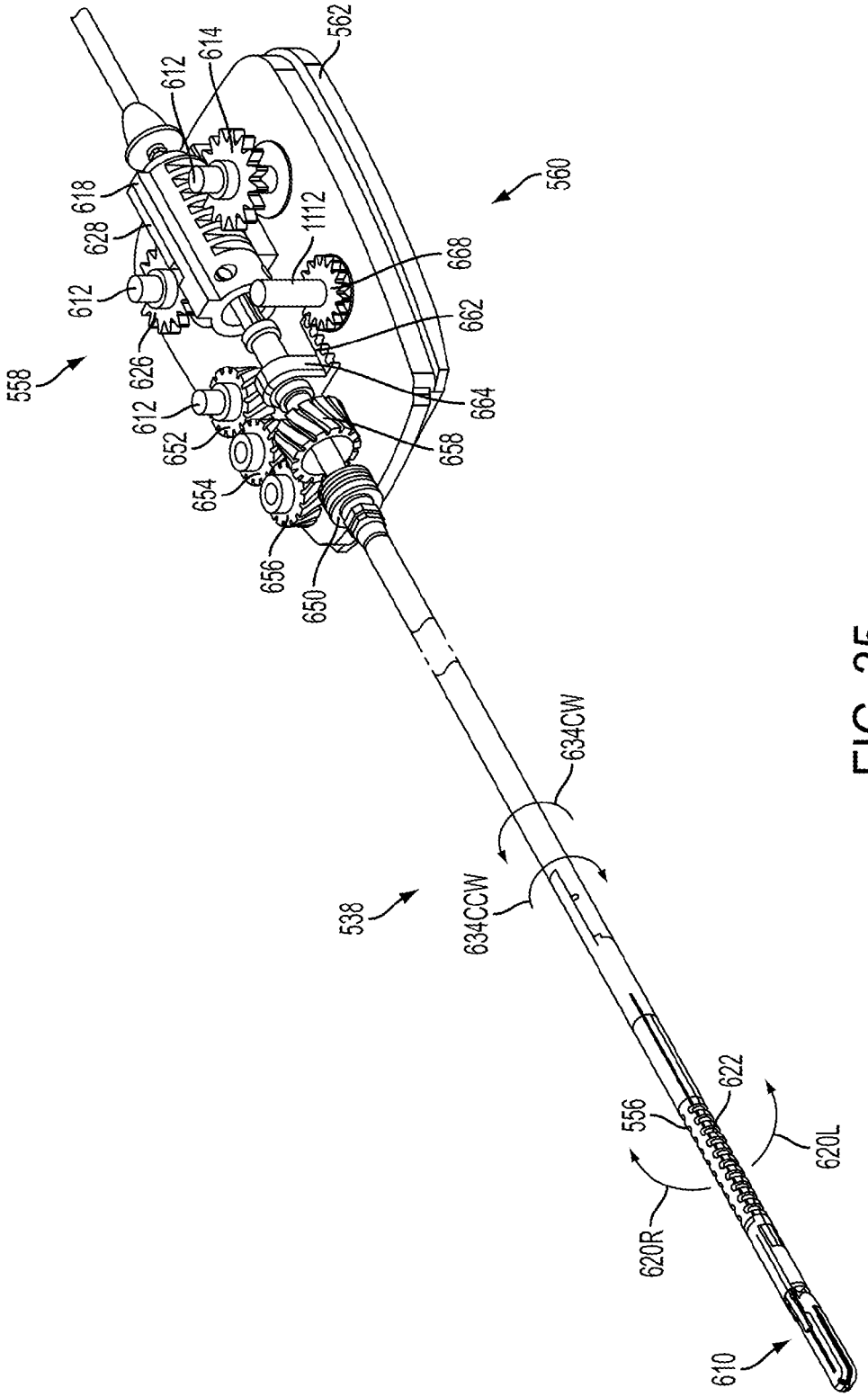
FIG. 34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634CCW
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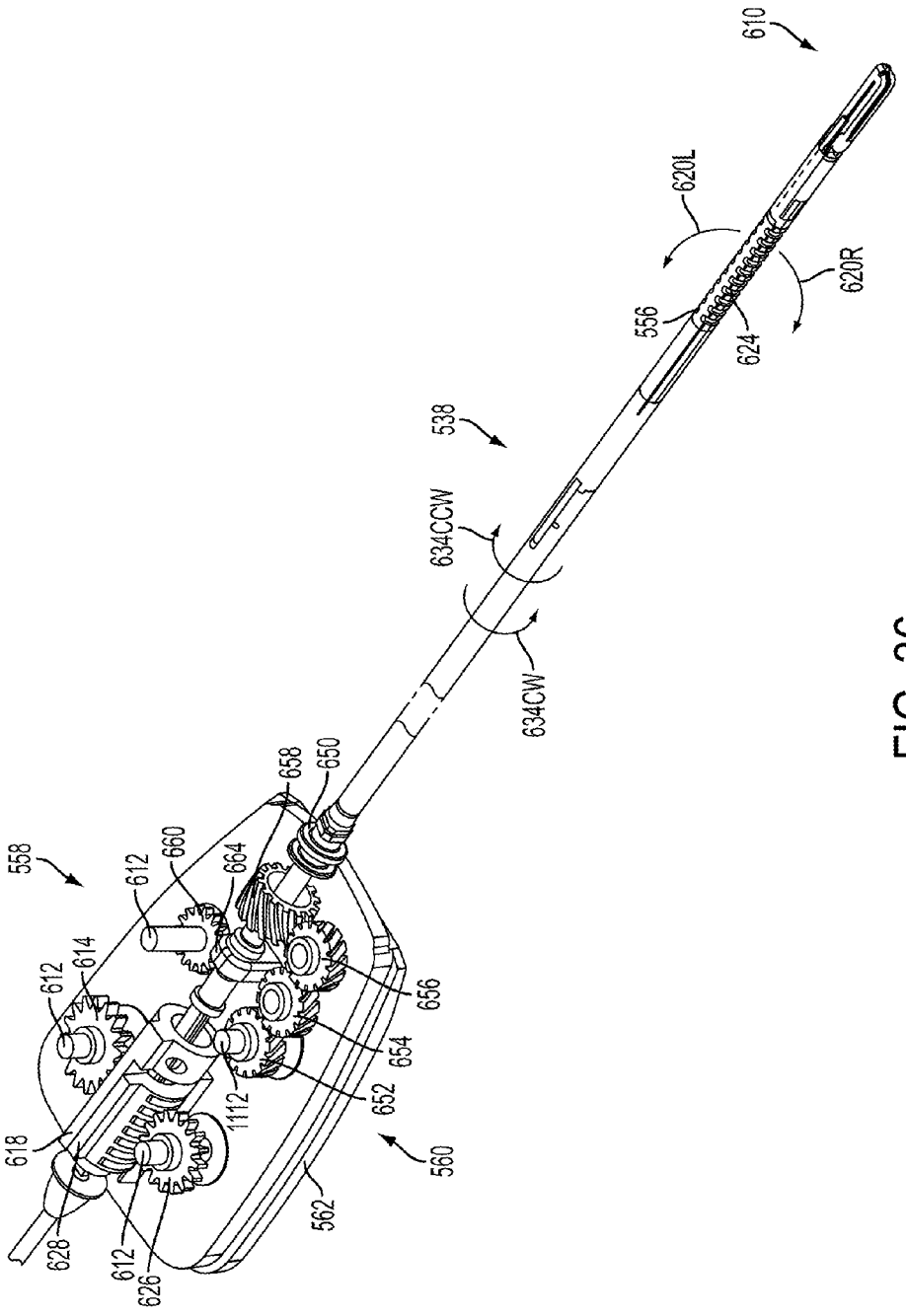
620L
620R
610

FIG. 35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634CCW
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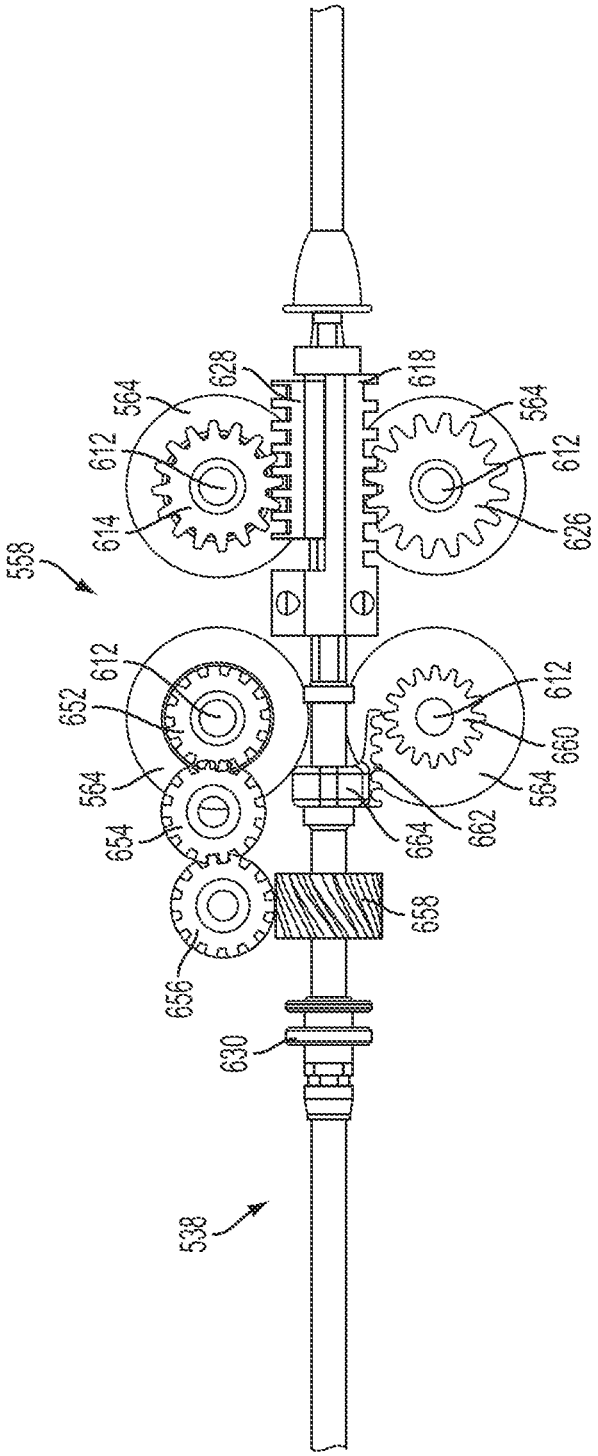
FIG. 36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630
538

FIG. 37

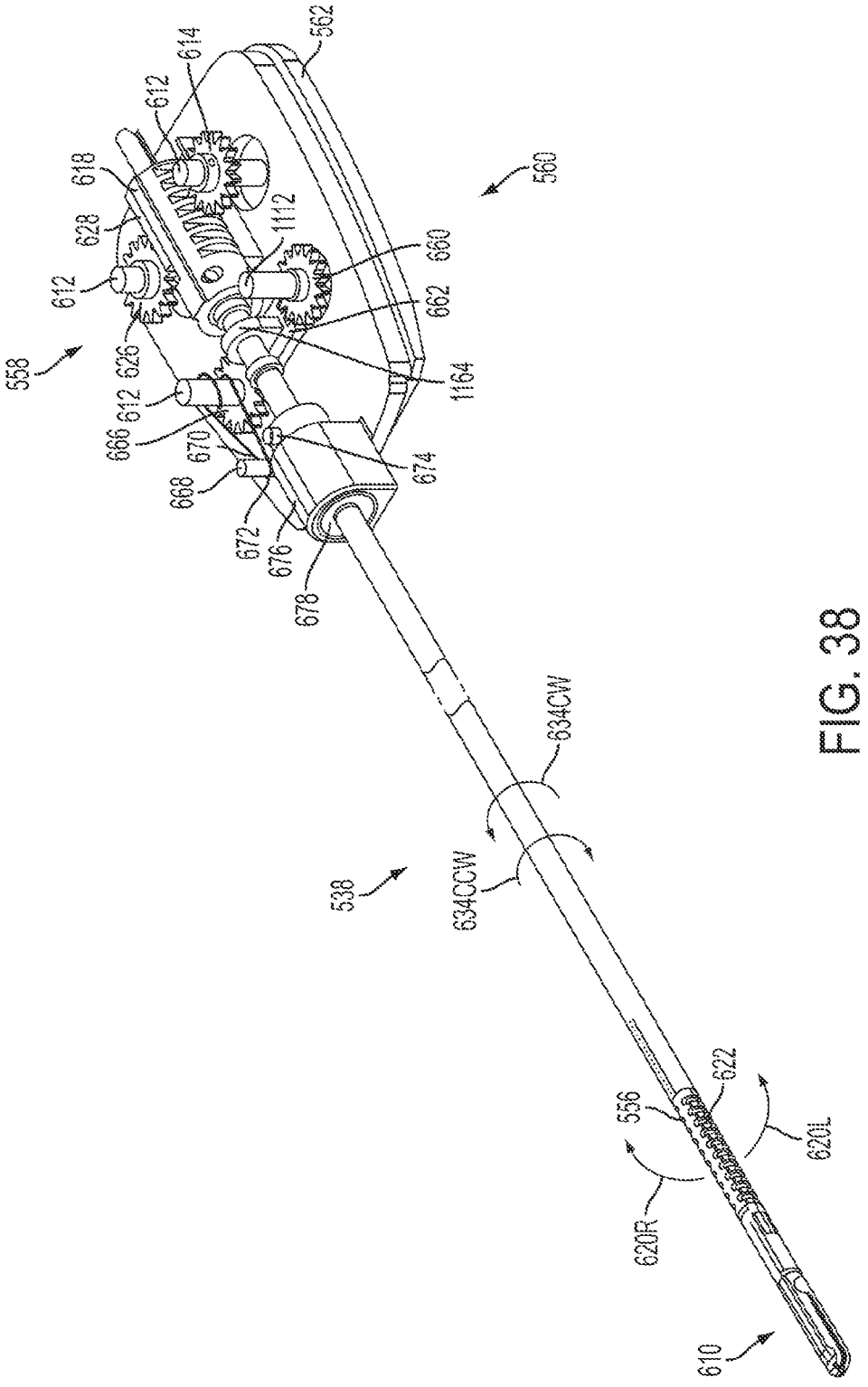
562
614
612
618
628
612
626
612
666
670
668
672
676
678
674
1164
662
660
1112
560
558
538
634CW
634CCW
622
556
620L
620R
610

FIG. 38

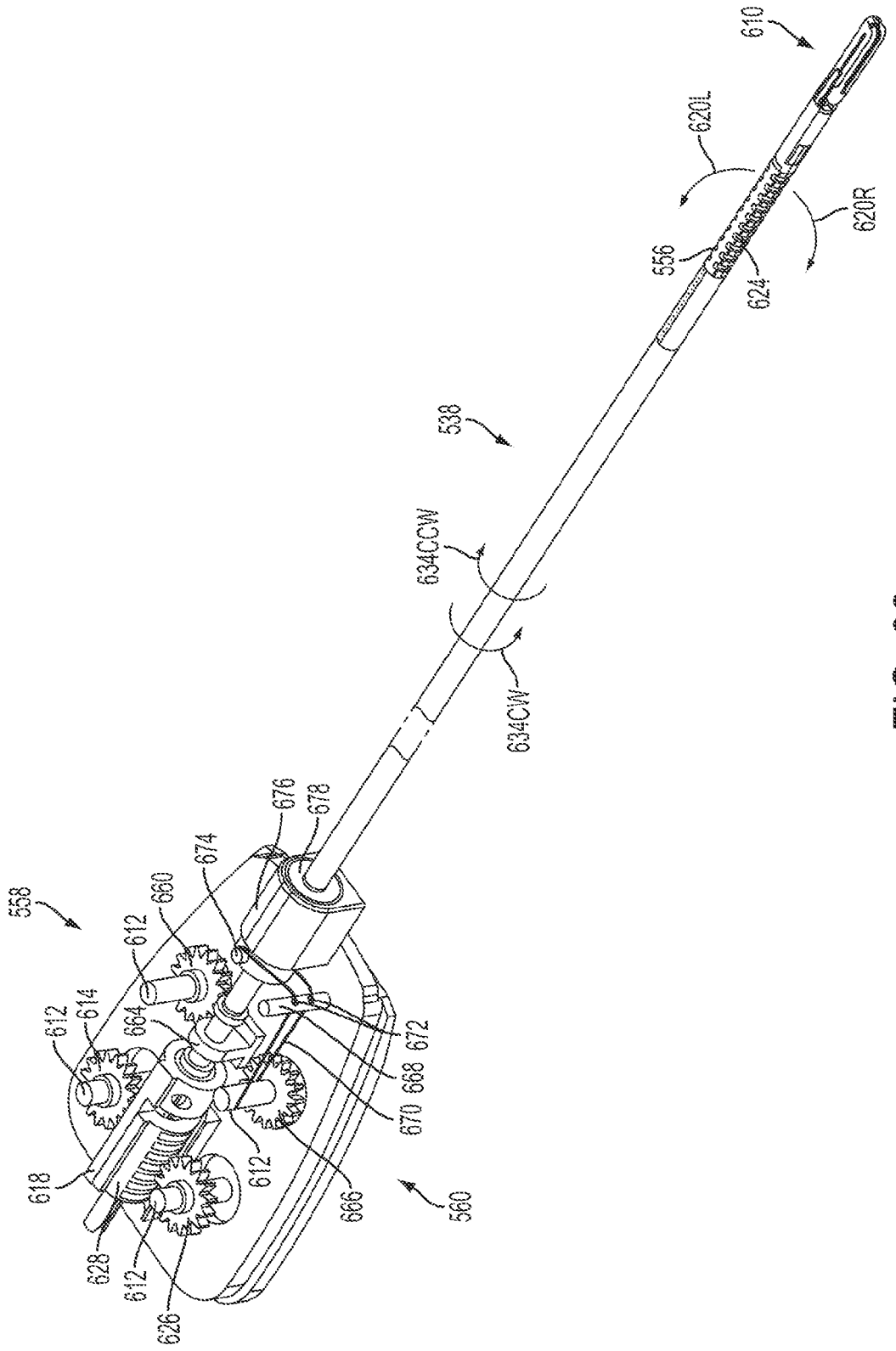
610
620L
620R
556
624
538
634CCW
634CW
558
676
678
674
660
612
614
664
672
668
670
666
560
618
628
626

FIG. 39

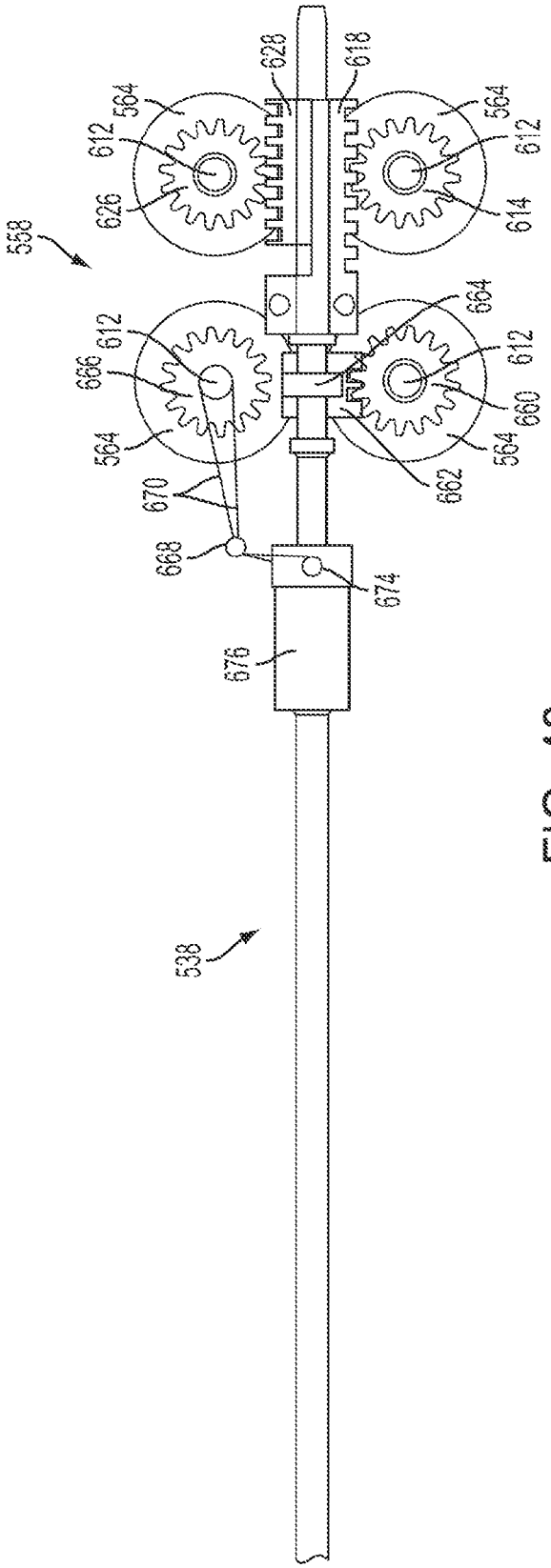

FIG. 40

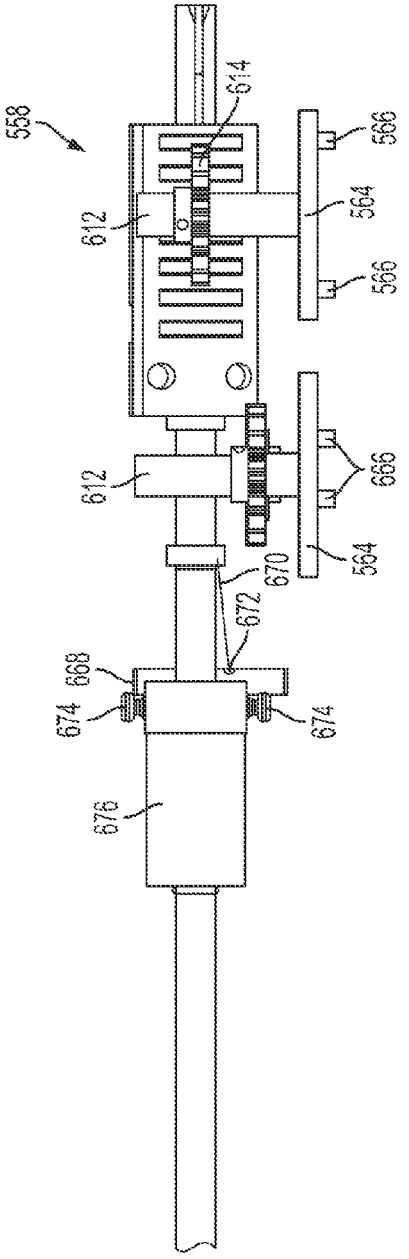
558
614
566
564
612
566
612
666
564
670
672
668
674
674
676

FIG. 41

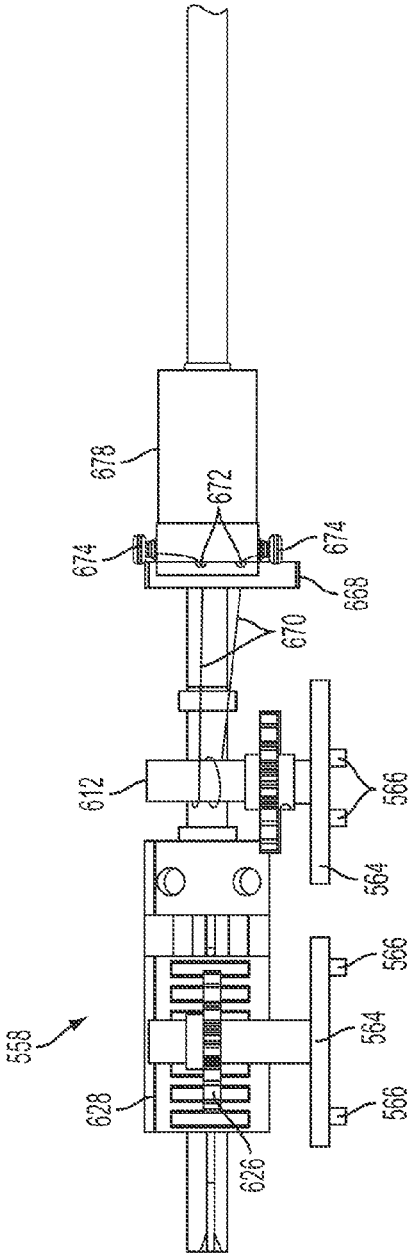
678
672
674
674
668
670
612
566
564
566
558
564
628
566
626

FIG. 42

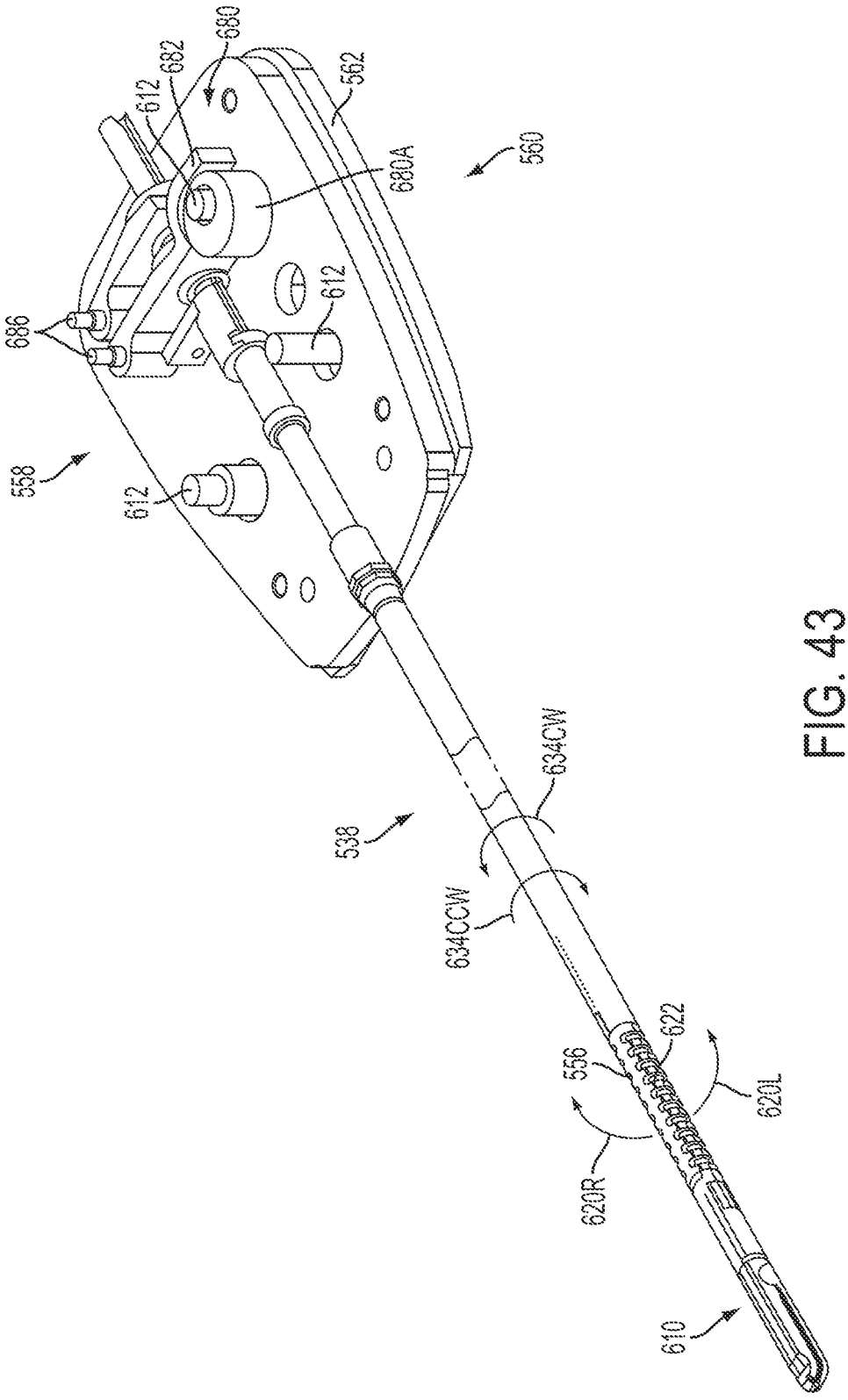
680
682
612
562
560
680A
612
686
558
612
538
634CW
634CCW
622
556
620L
620R
610

FIG. 43

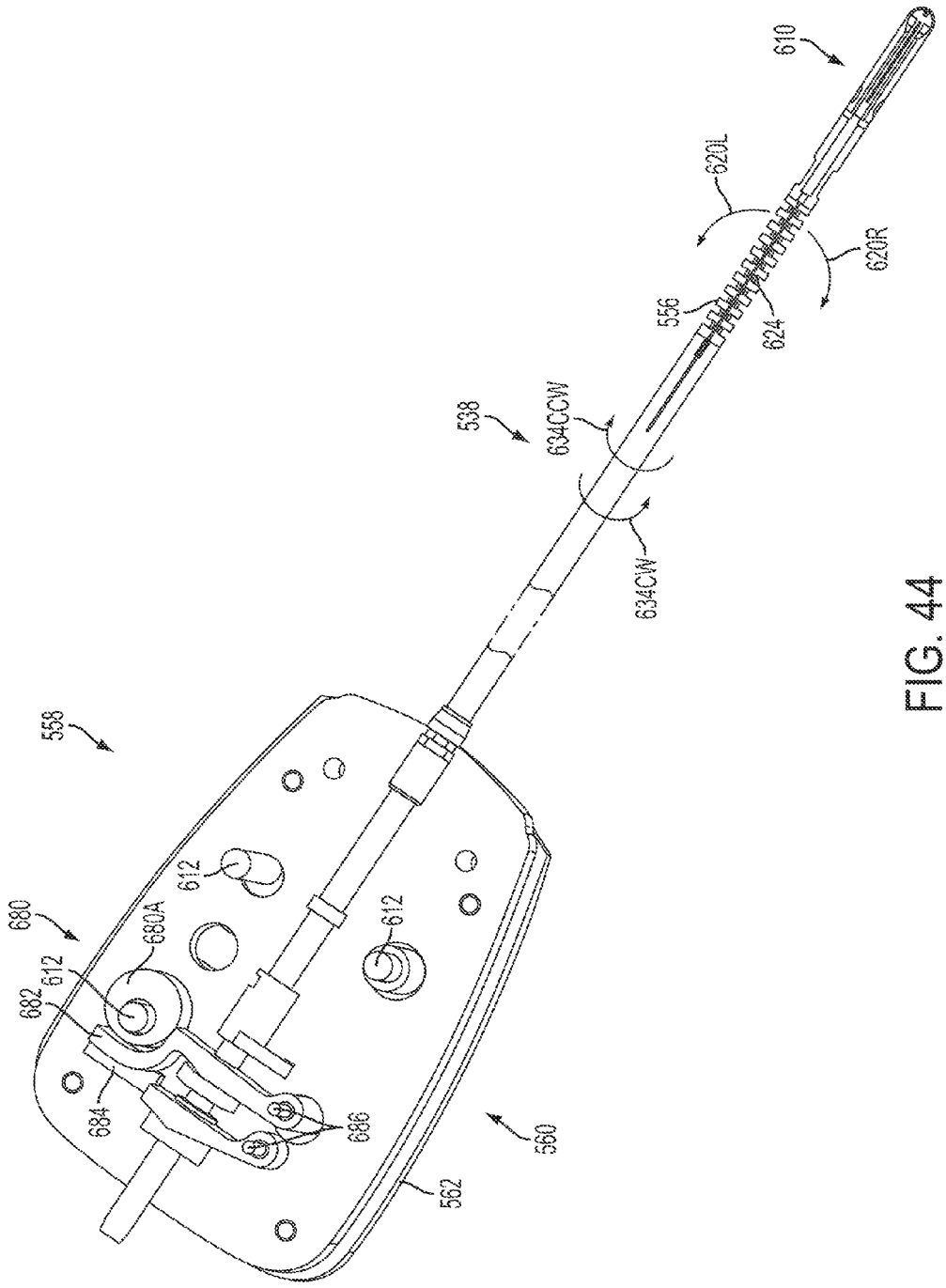
610
620L
620R
556
624
538
634CCW
634CW
558
680
680A
612
682
684
686
560
562

FIG. 44

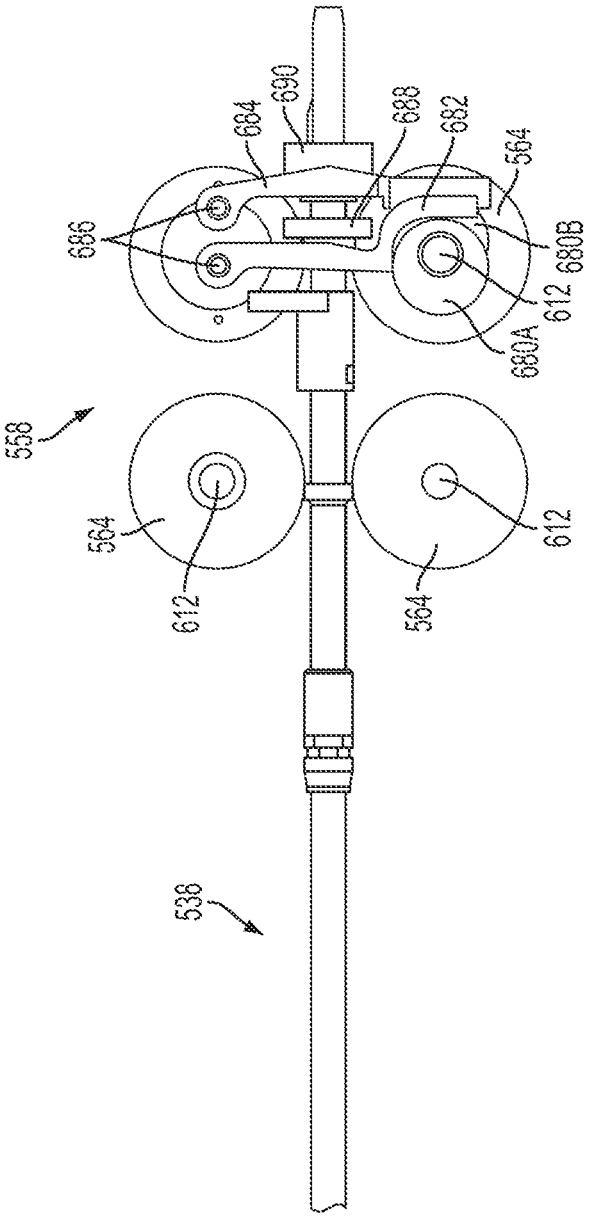

FIG. 45

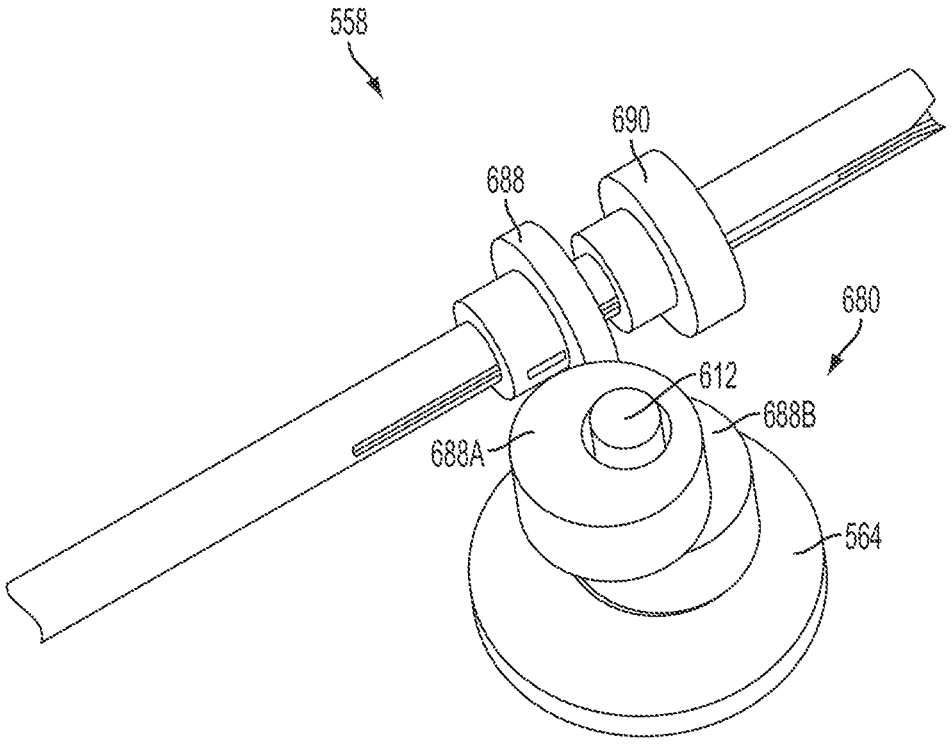

FIG. 46A

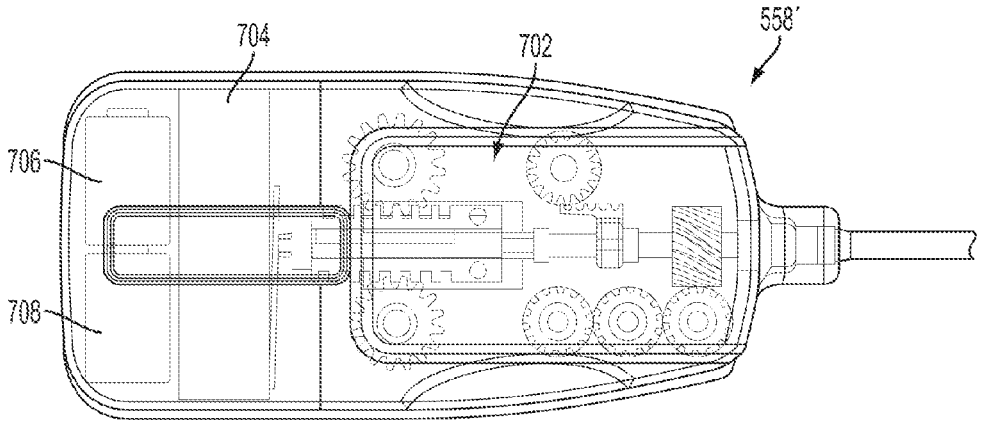

FIG. 46B

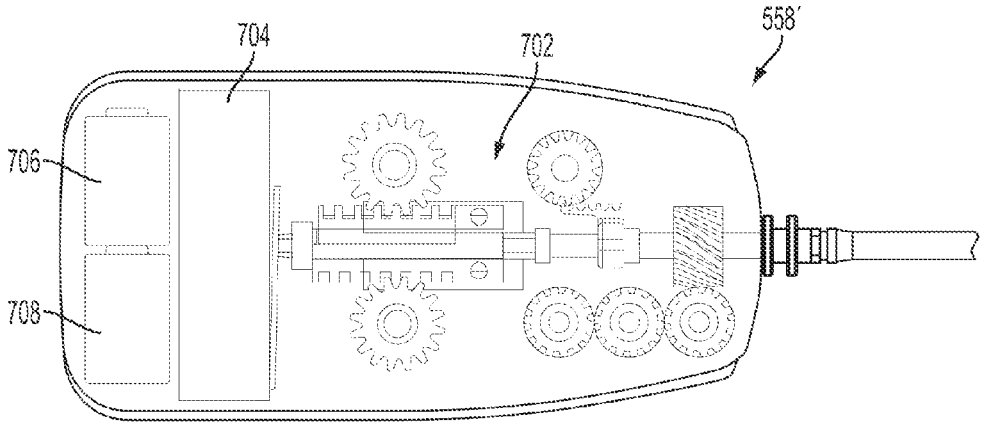

FIG. 46C

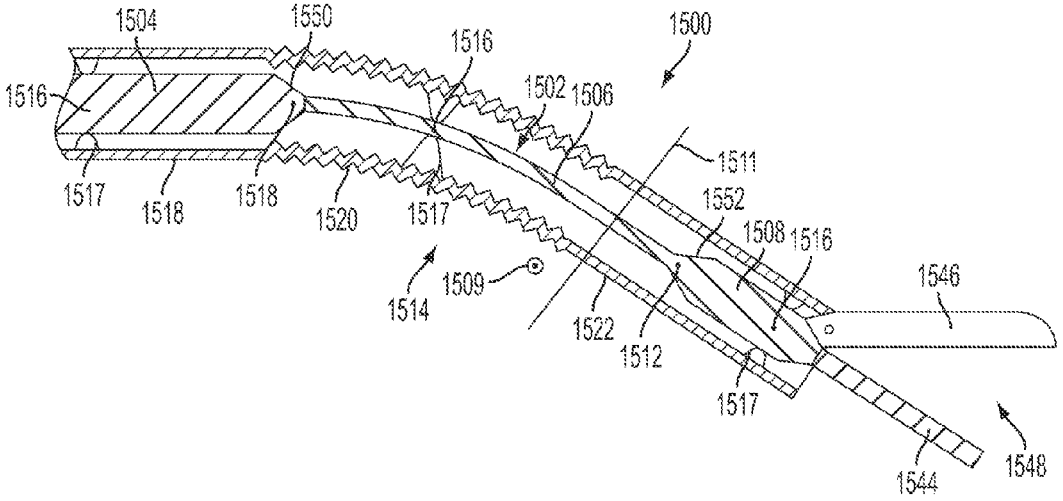

FIG. 47

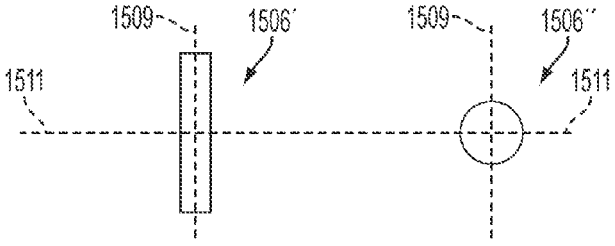

FIG. 47A

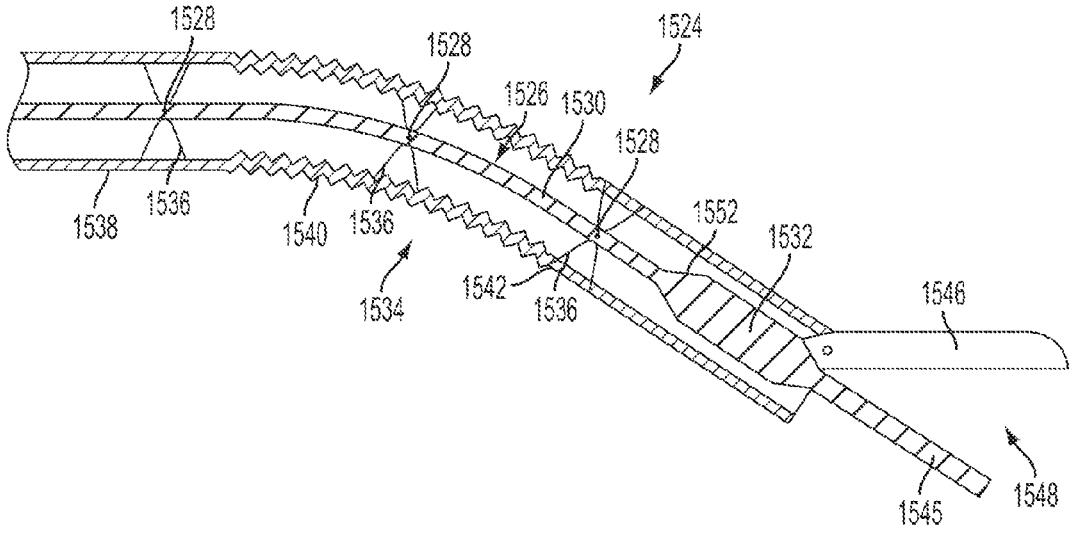
1528
1528
1524
1526
1530
1528
1538
1536
1540
1536
1552
1532
1534
1542
1536
1546
1545
1548

FIG. 48

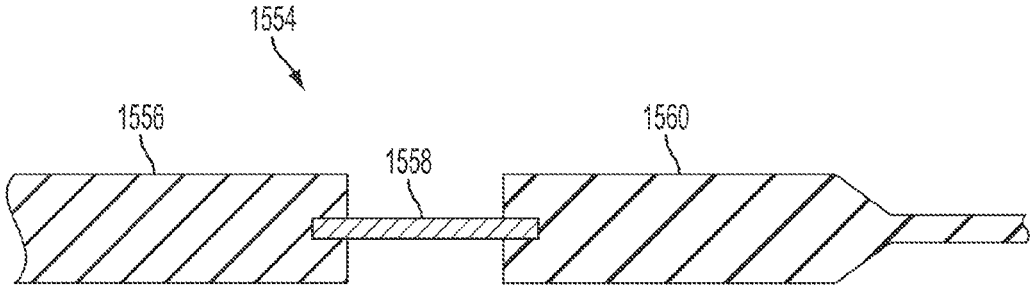

FIG. 49

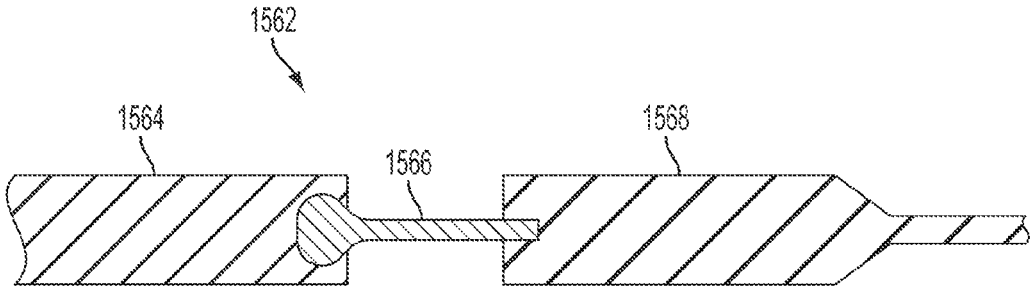

FIG. 50

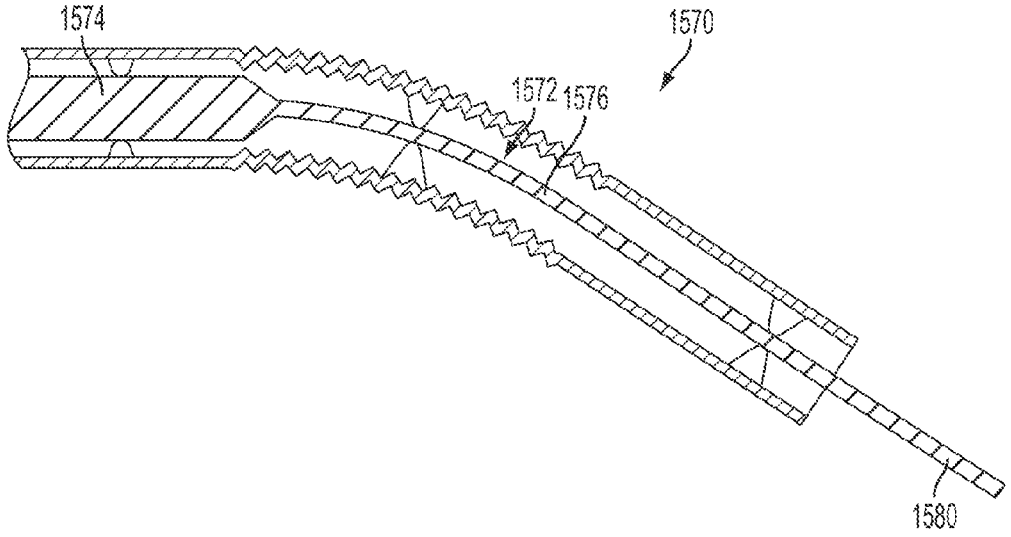

FIG. 51

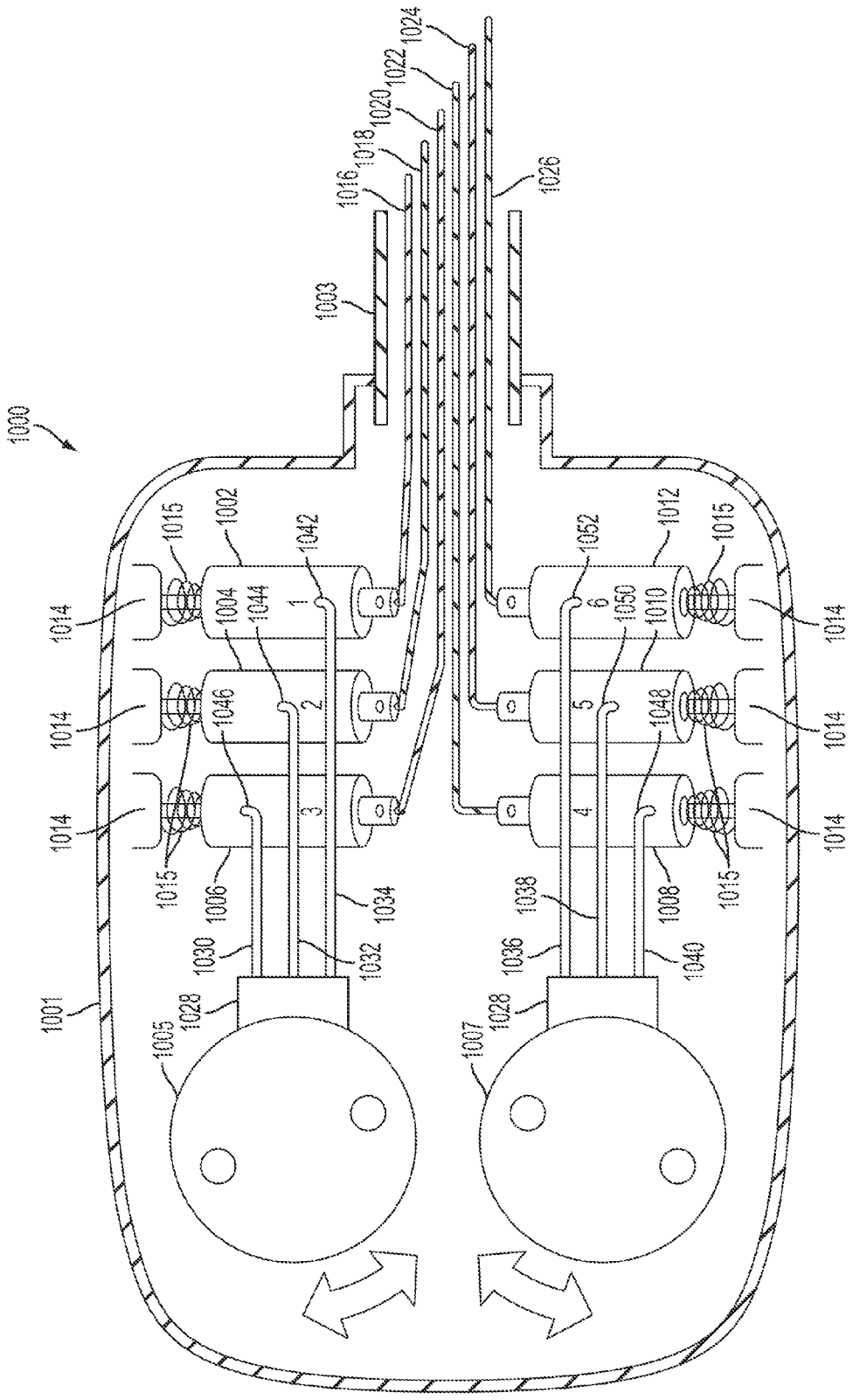
1000
1001
1002
1003
1004
1005
1006
1007
1008
1010
1012
1014
1015
1016
1018
1020
1022
1024
1026
1028
1030
1032
1034
1036
1038
1040
1042
1044
1046
1048
1050
1052
1
2
3
4
5
6

FIG. 52

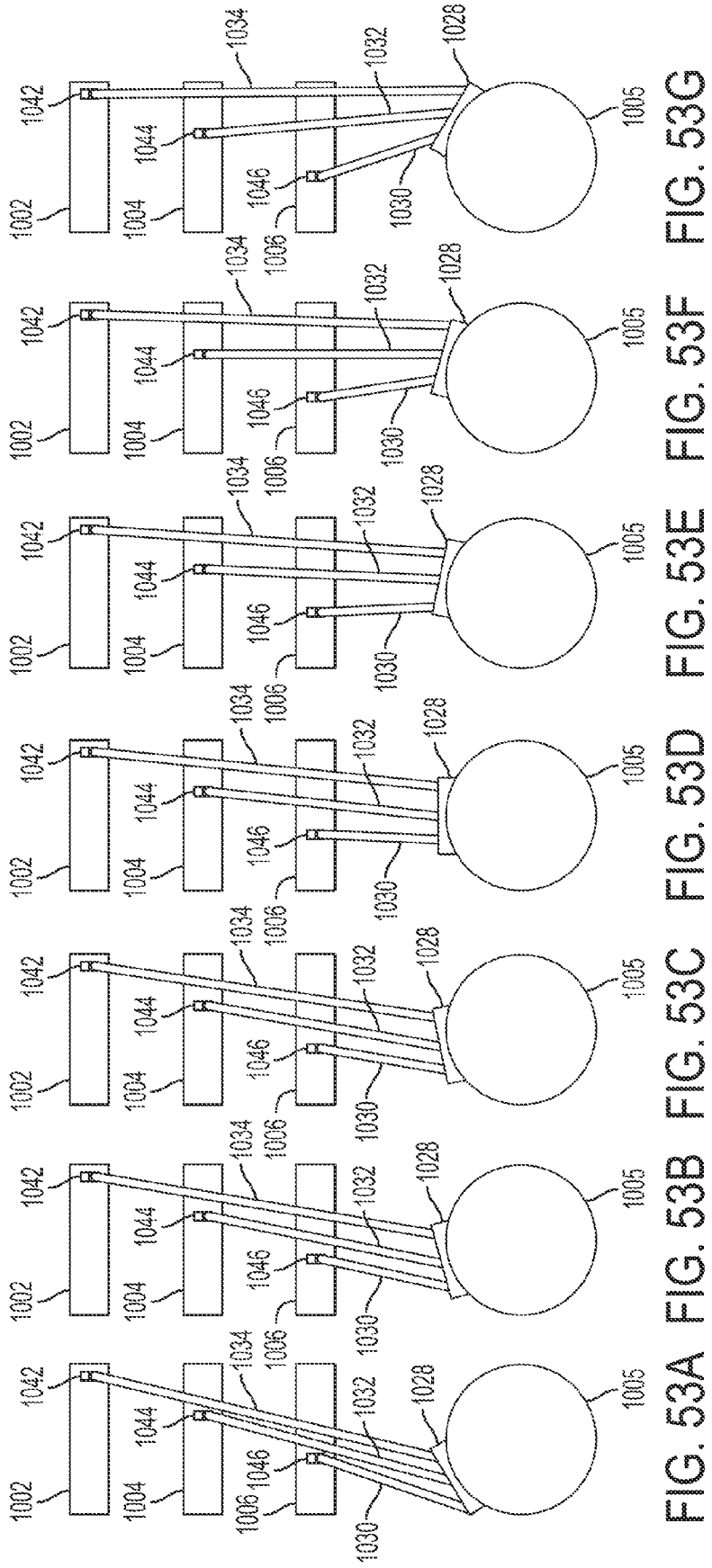

FIG. 53A FIG. 53B FIG. 53C FIG. 53D FIG. 53E FIG. 53F FIG. 53G

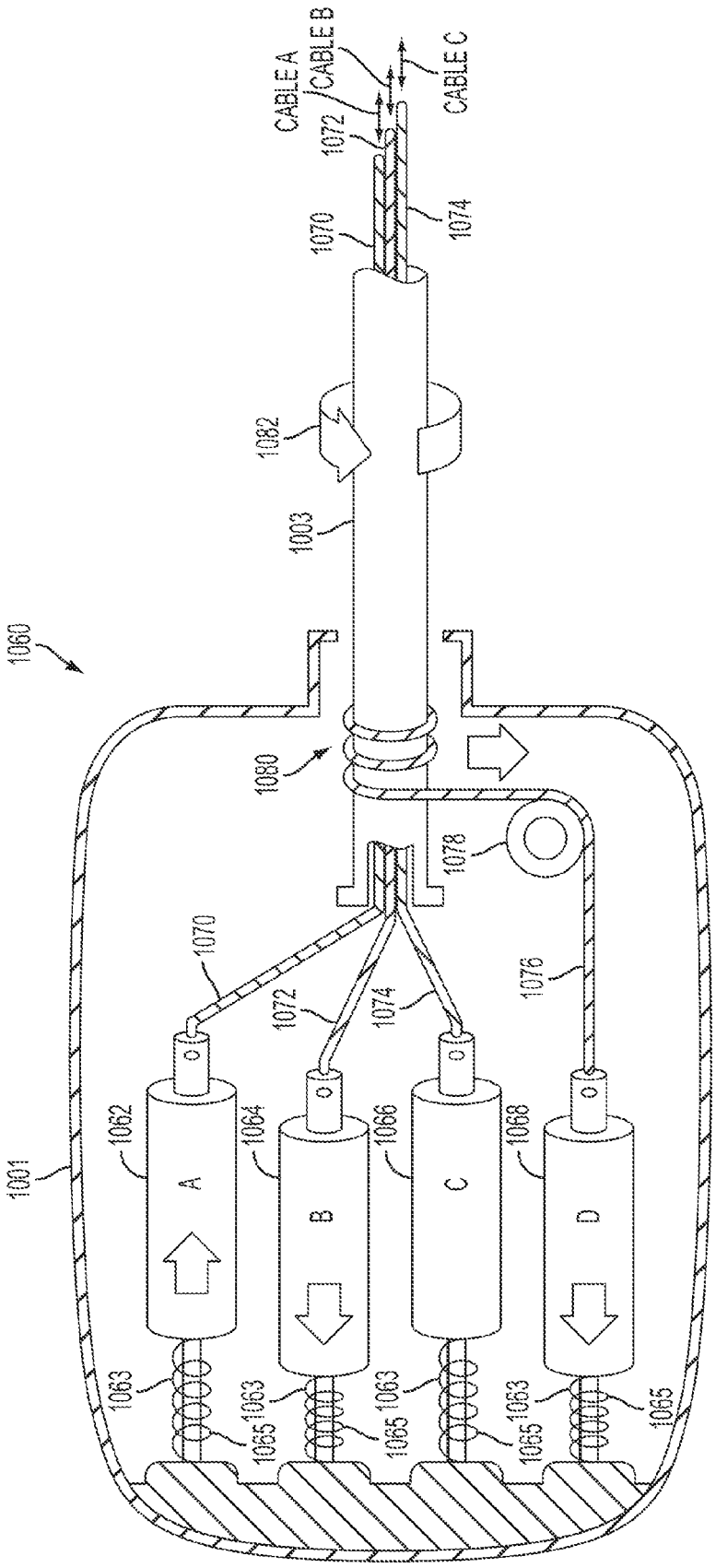
CABLE A
CABLE B
CABLE C
1072
1074
1070
1082
1003
1060
1080
1078
1076
1001
1062
1064
1066
1068
A
B
C
D
1063
1065

FIG. 54

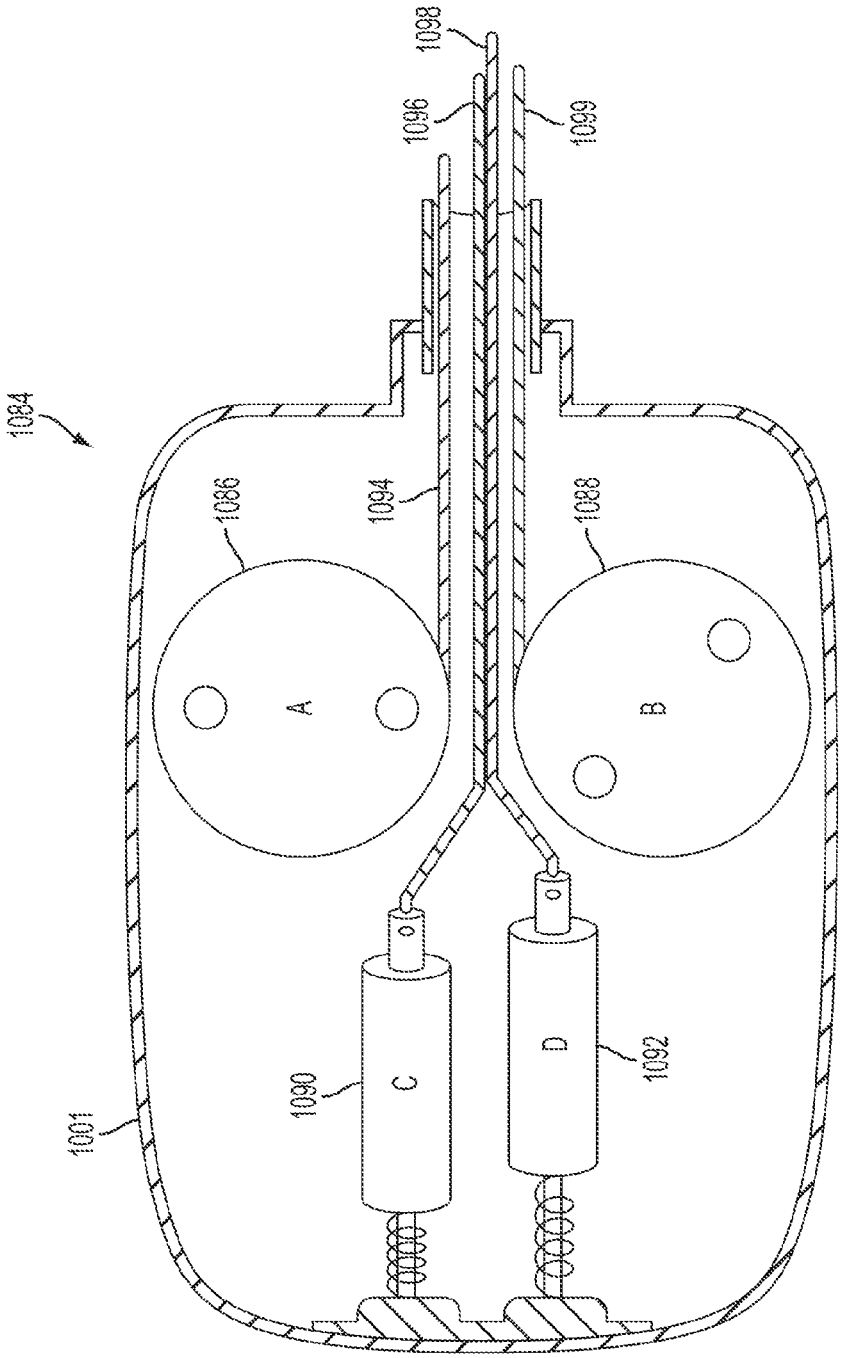

FIG. 55

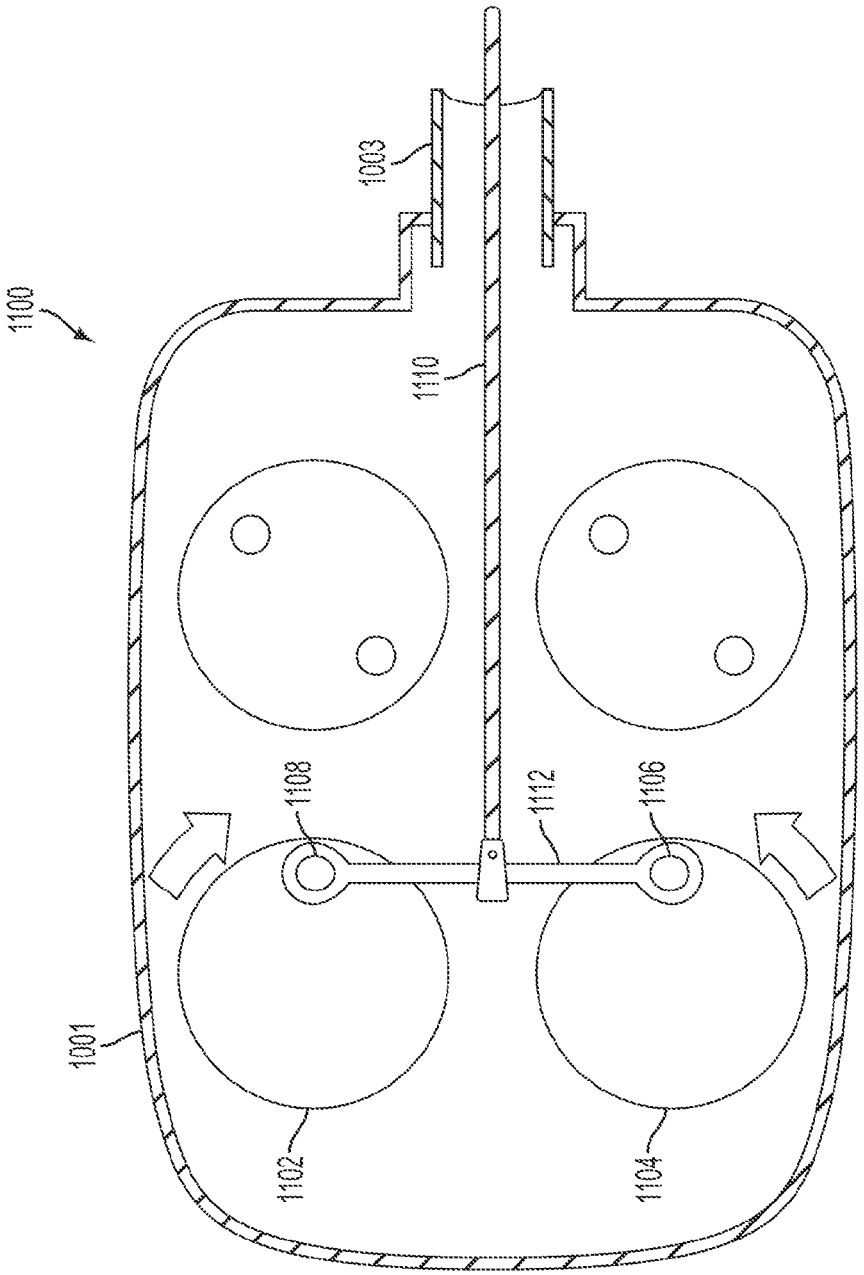

FIG. 56

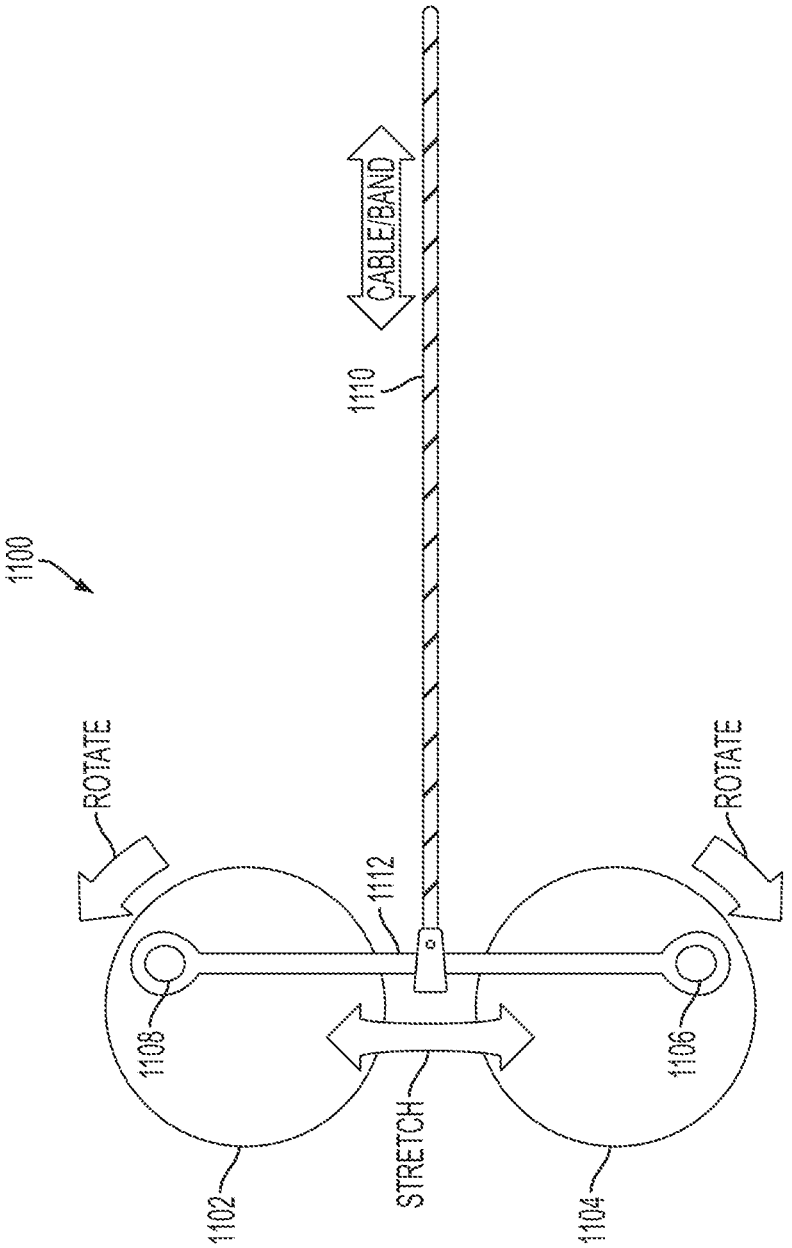
1100
CABLE/BAND
1110
ROTATE
1112
ROTATE
1108
1106
STRETCH
1102
1104

FIG. 57

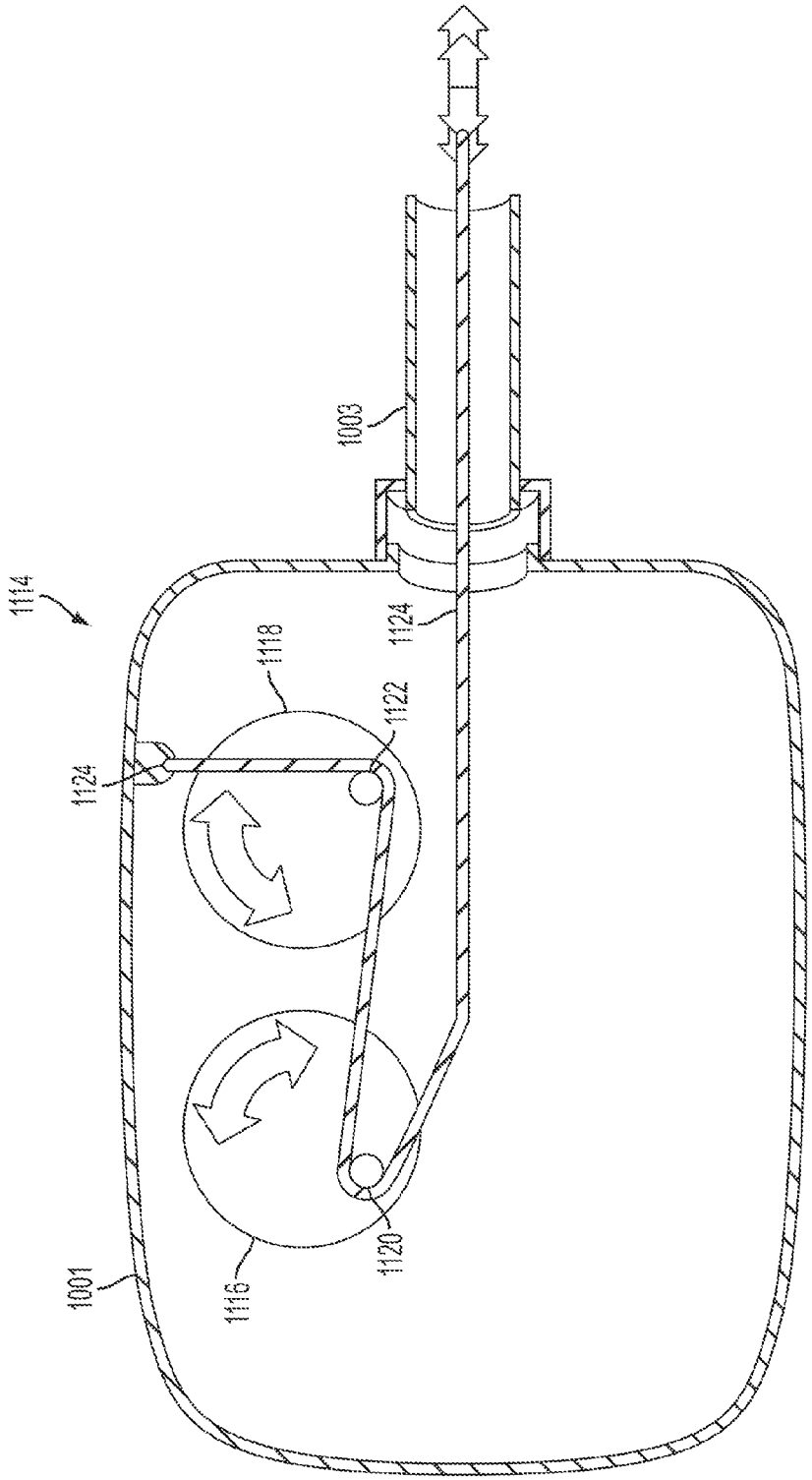

FIG. 58

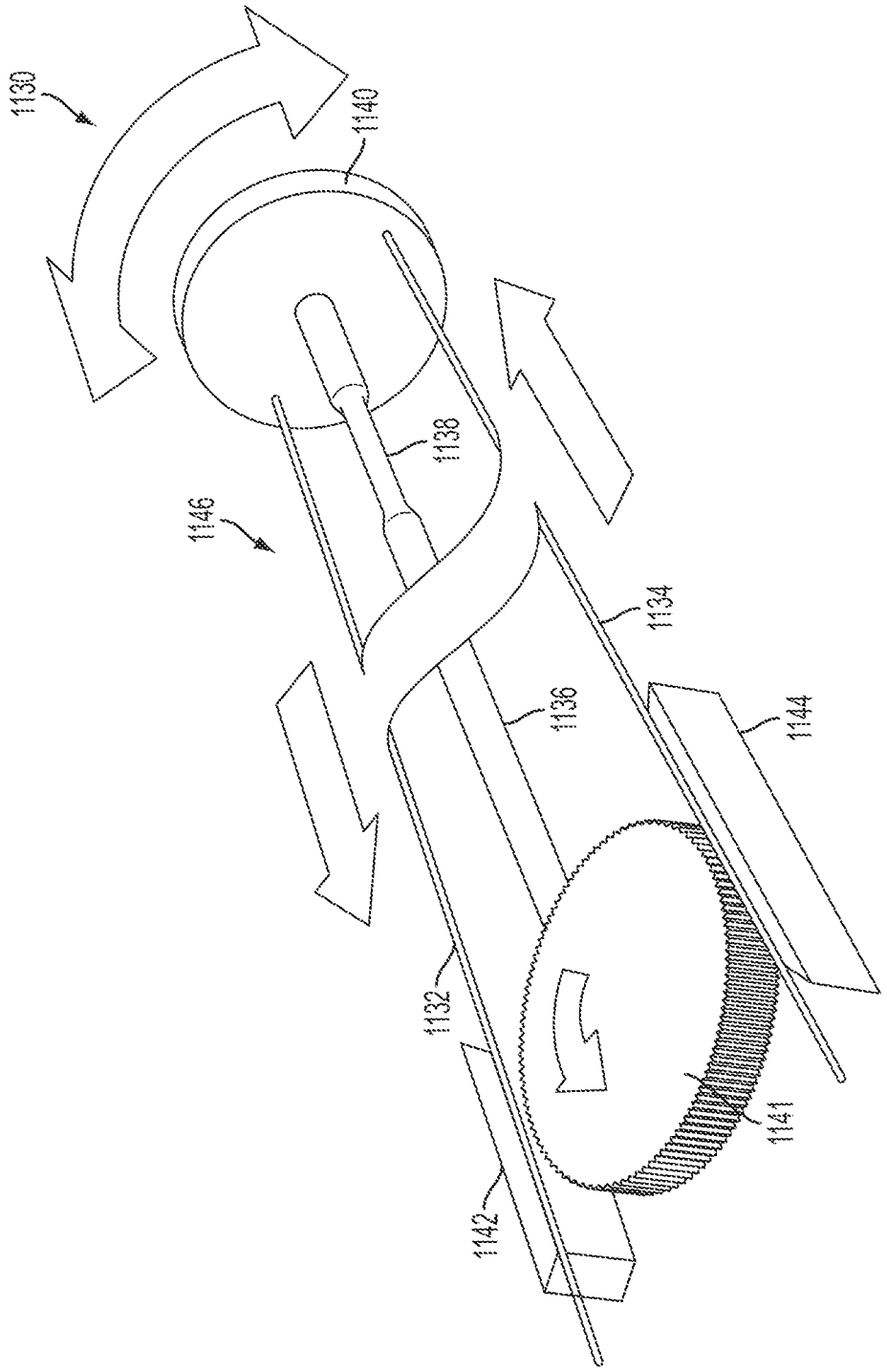

FIG. 59

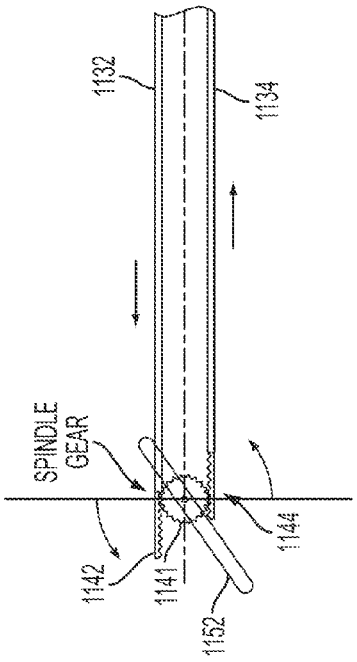
1132
1134
SPINDLE GEAR
1142
1141
1152
1144

FIG. 60

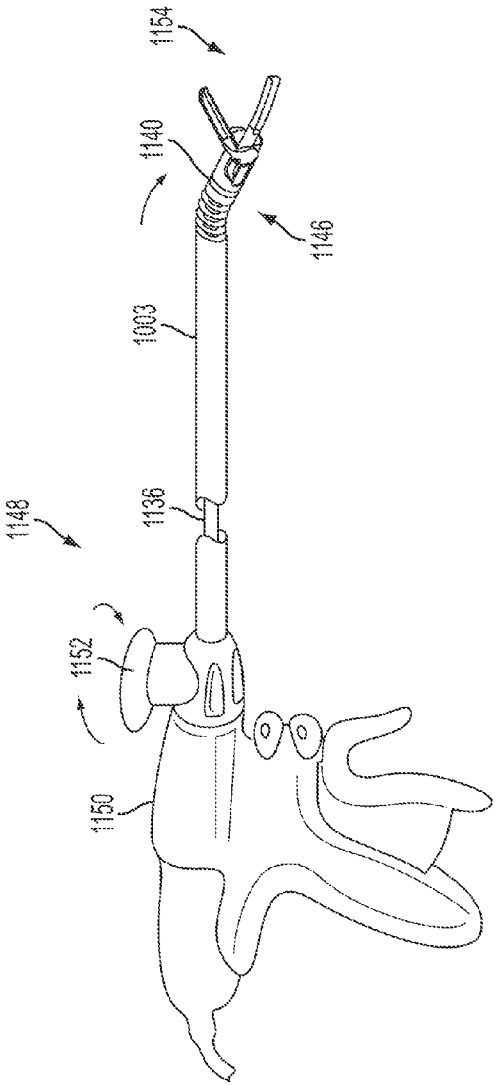
1154
1140
1146
1003
1136
1148
1152
1150

FIG. 61

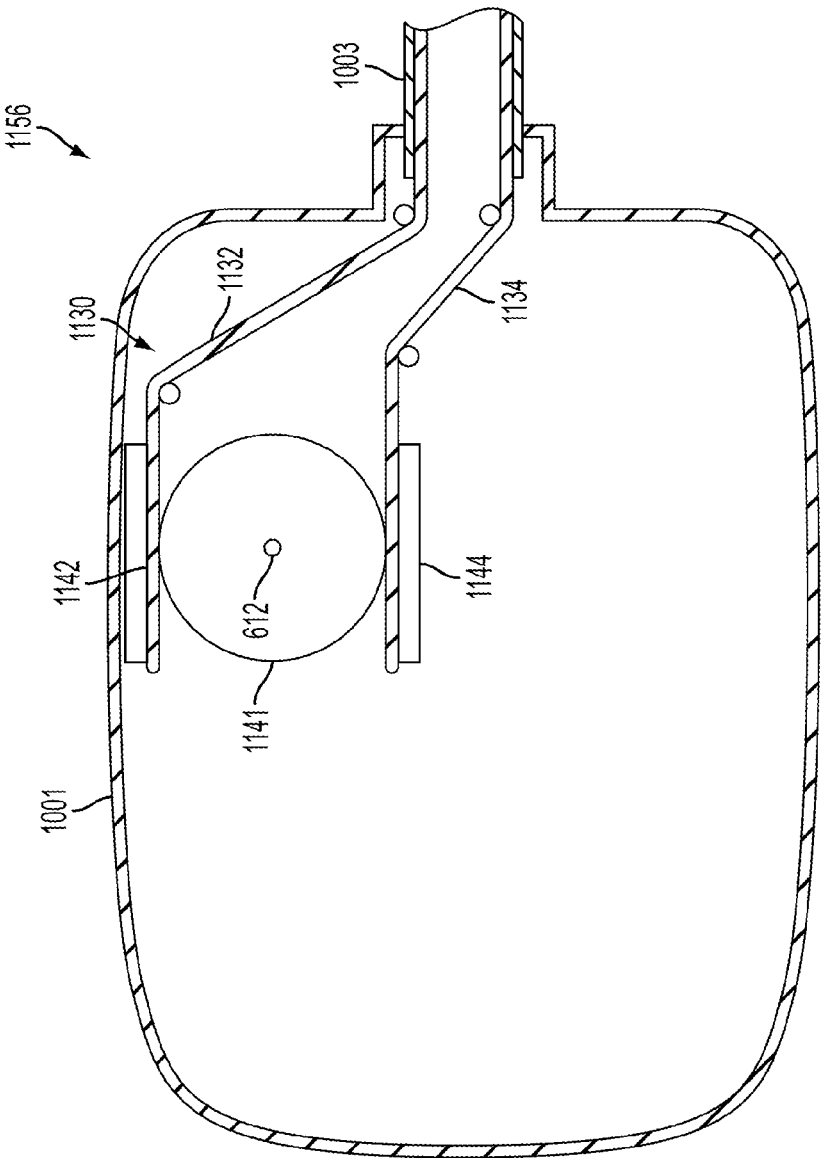

FIG. 62

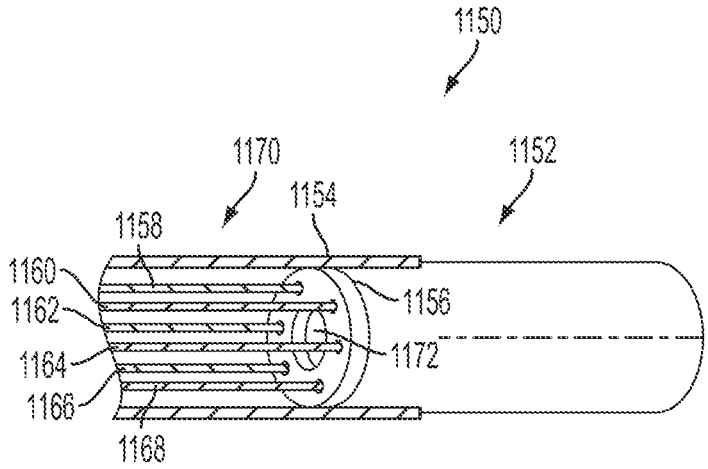

FIG. 63A

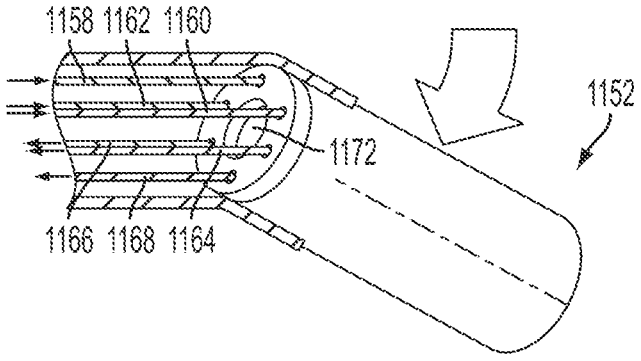

FIG. 63B

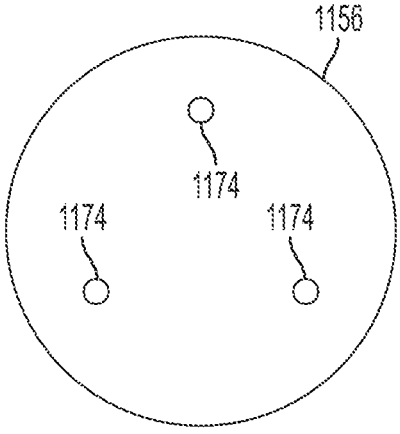

FIG. 64

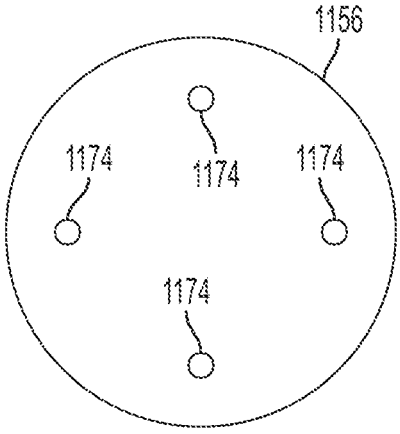

FIG. 65

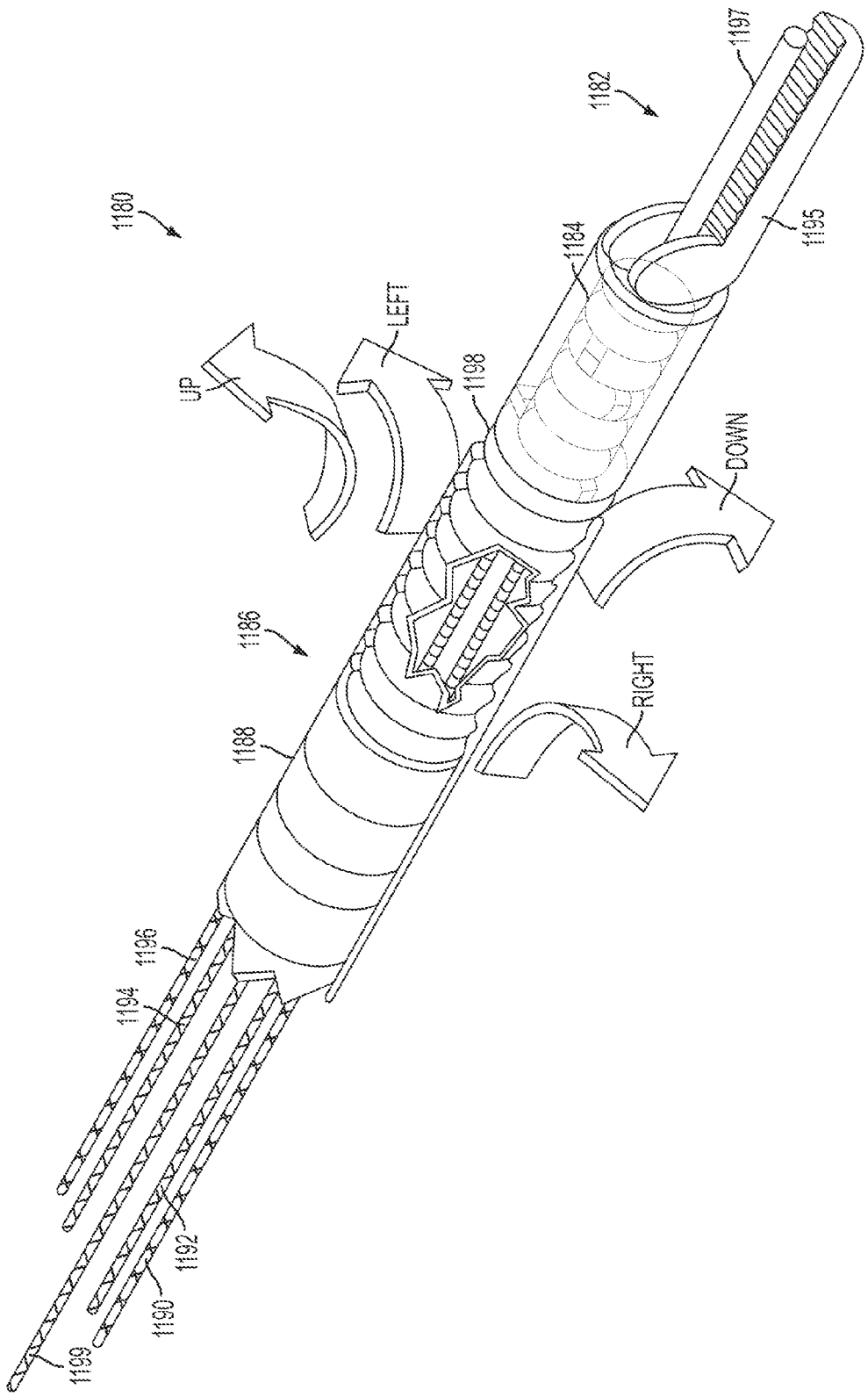
1180
1182
1184
1186
1188
1190
1192
1194
1196
1197
1198
1199
1195
UP
LEFT
DOWN
RIGHT

FIG. 66

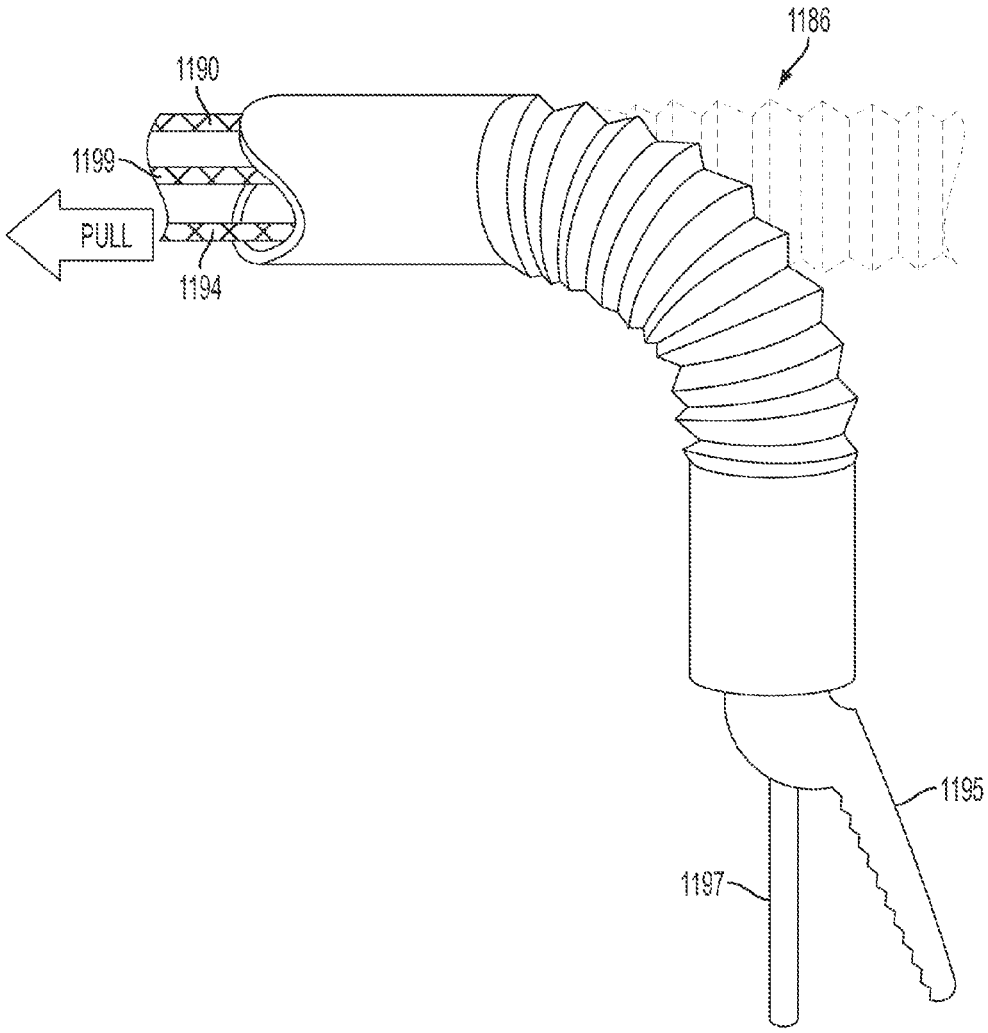

FIG. 67

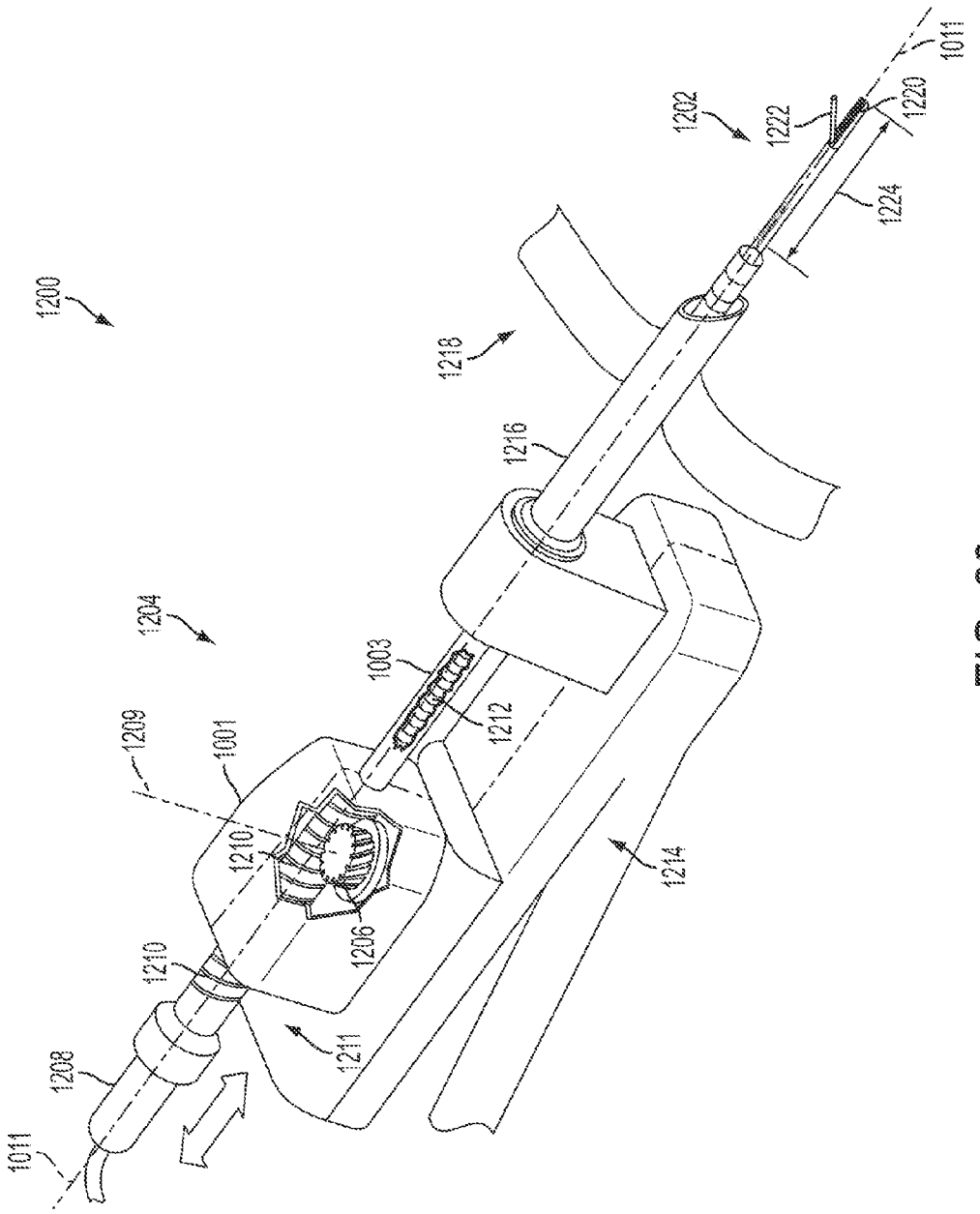
1200
1202
1204
1206
1208
1209
1210
1211
1212
1214
1216
1218
1220
1222
1224
1001
1003
1011

FIG. 68

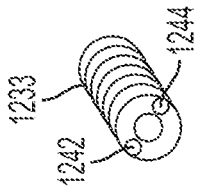

FIG. 69B

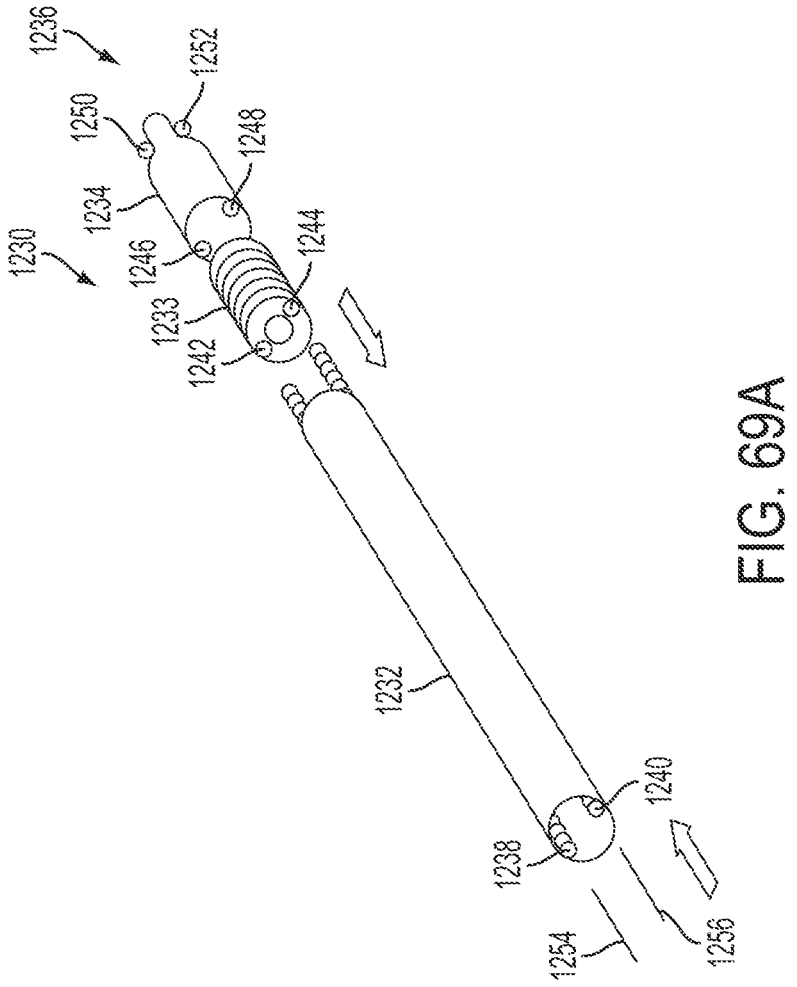

FIG. 69A

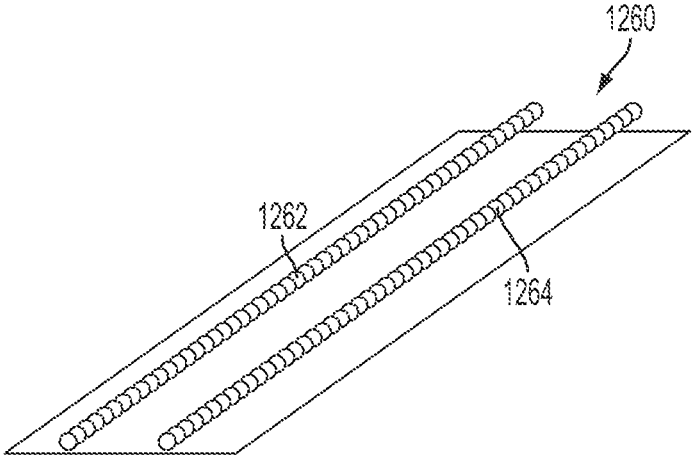

FIG. 70

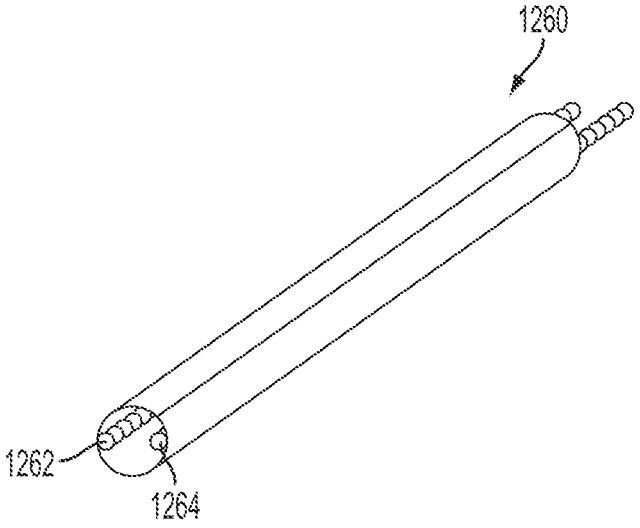

FIG. 71

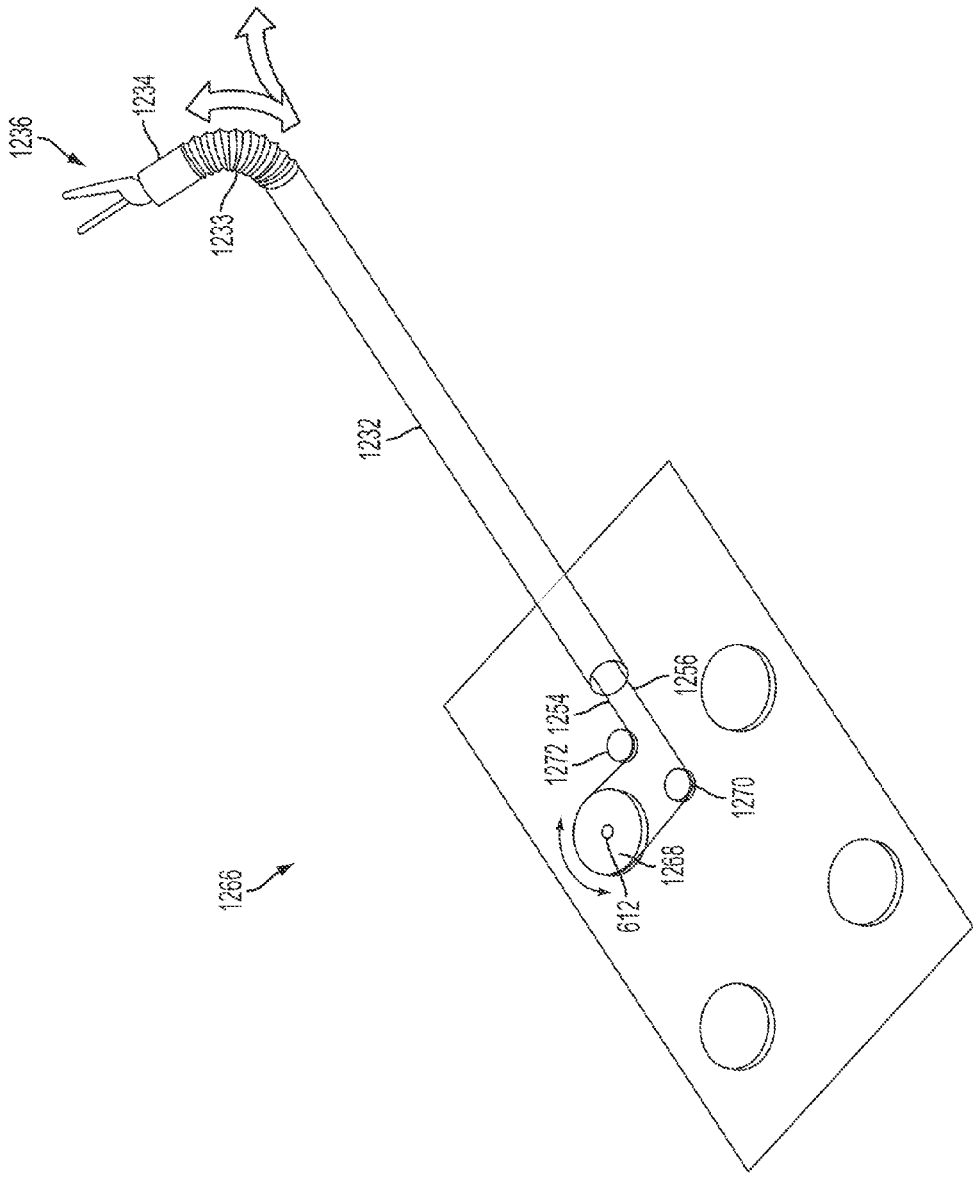

FIG. 72

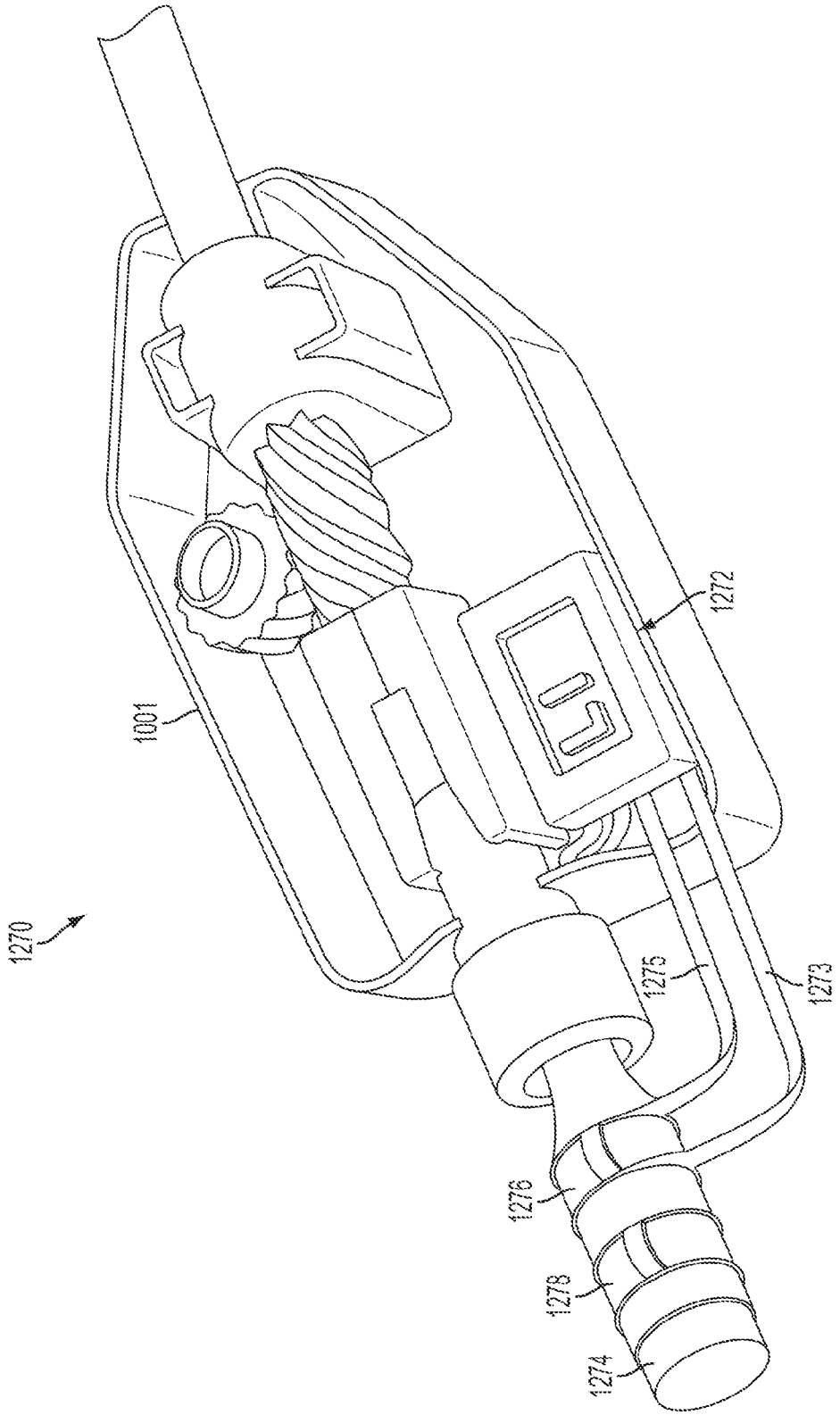

FIG. 73

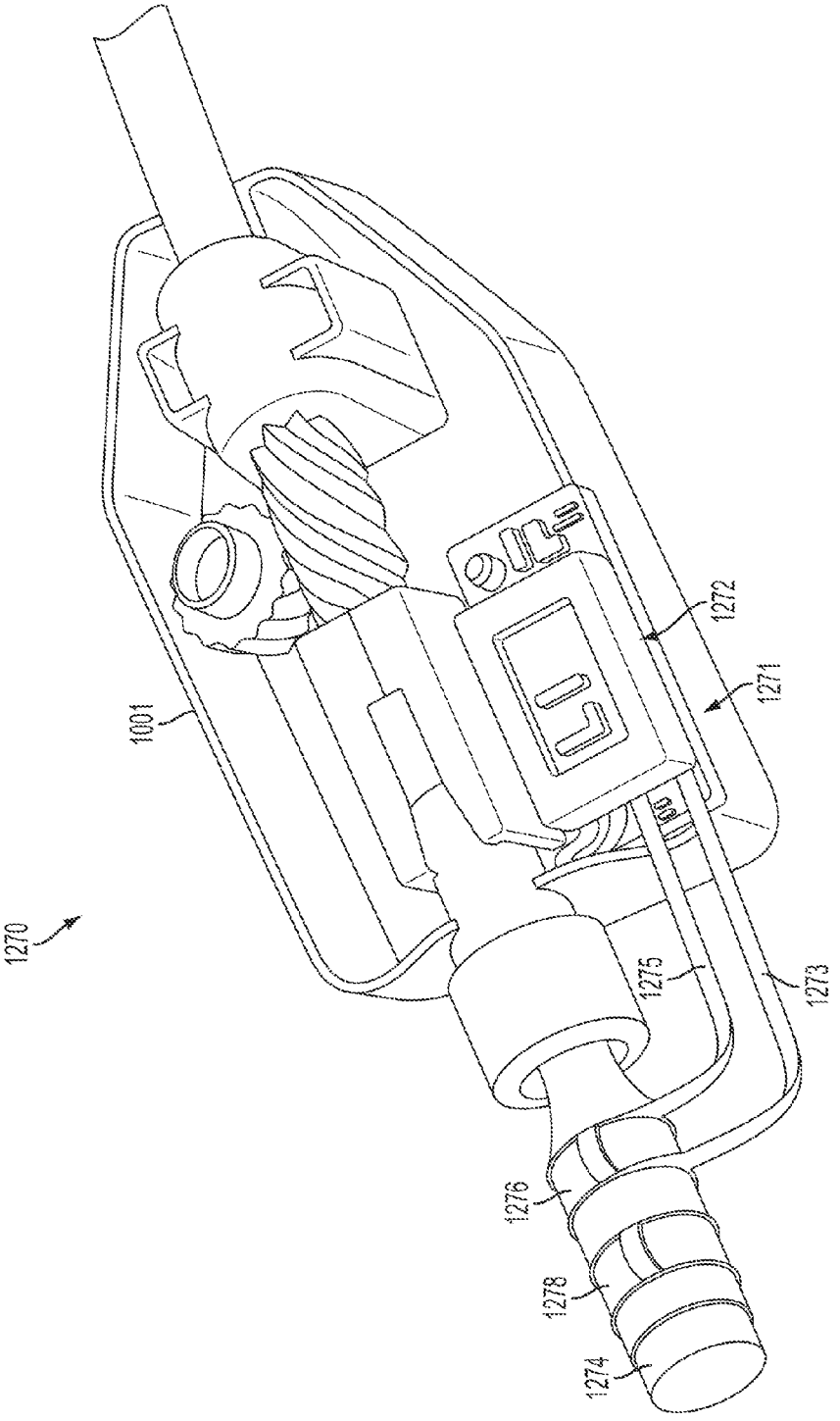

FIG. 74

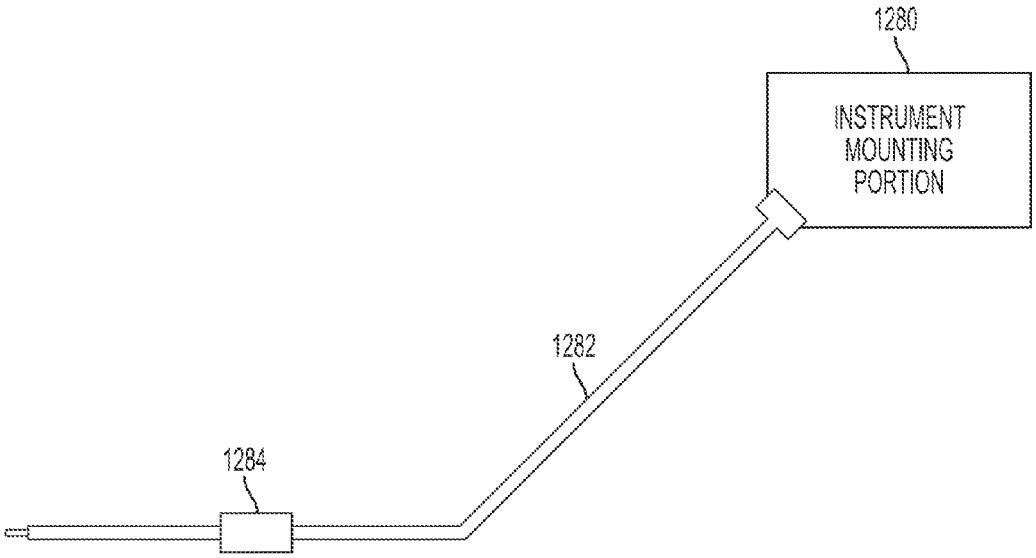

FIG. 75

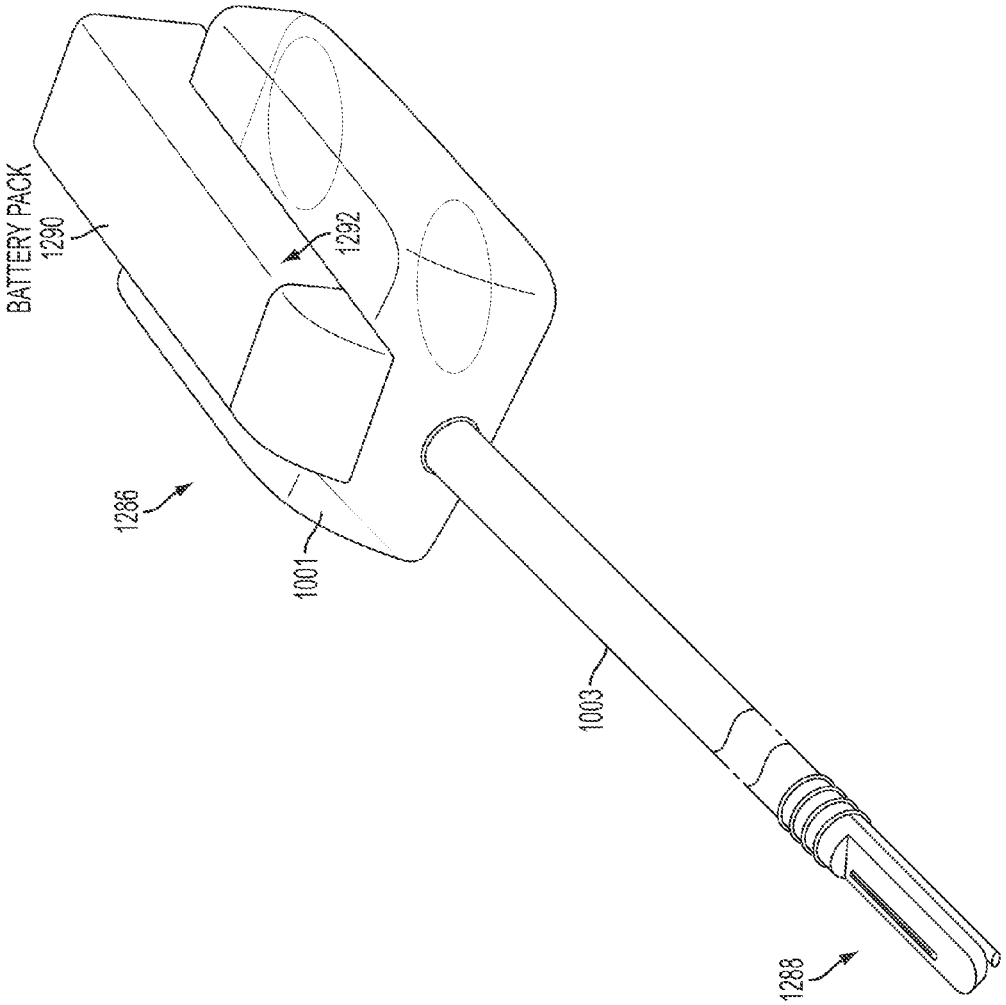

FIG. 76

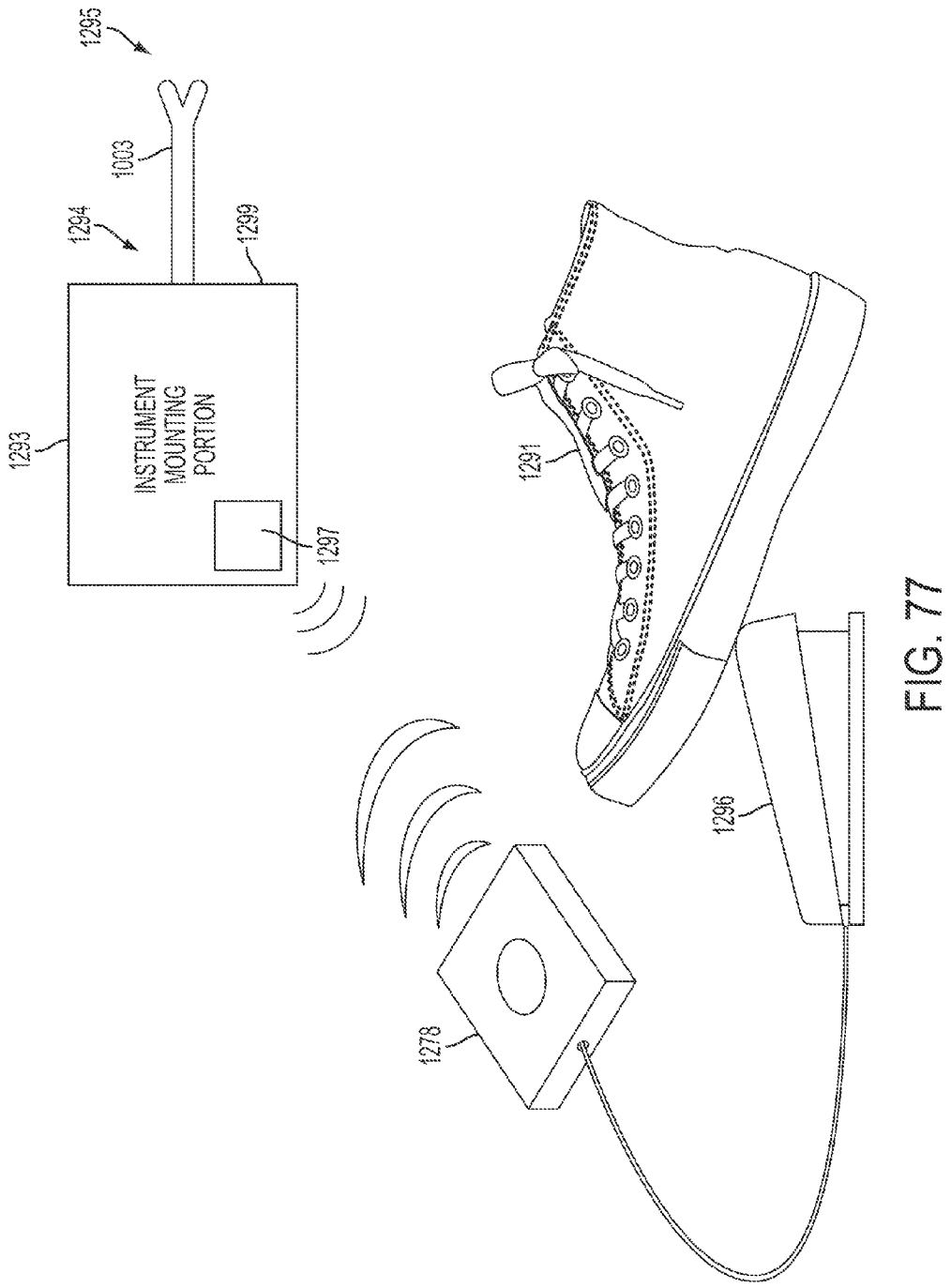
1295
1003
1294
1299
1293
INSTRUMENT MOUNTING PORTION
1297
1291
1296
1278

FIG. 77

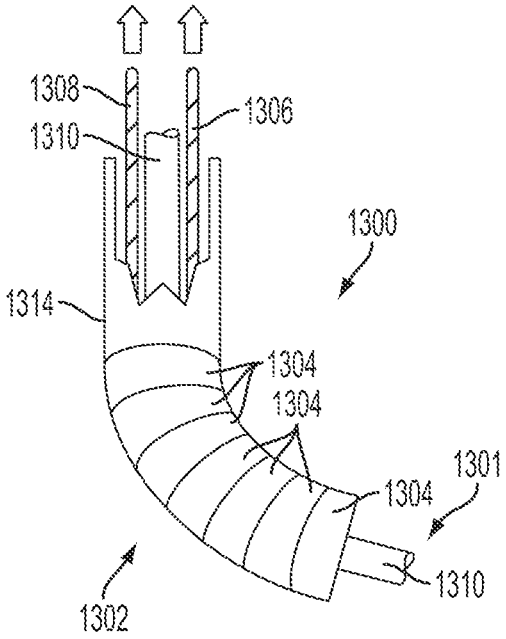

FIG. 78

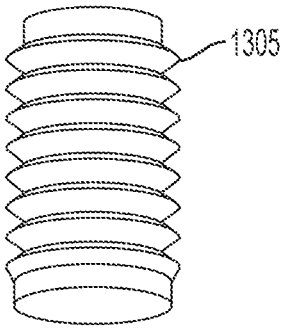

FIG. 79

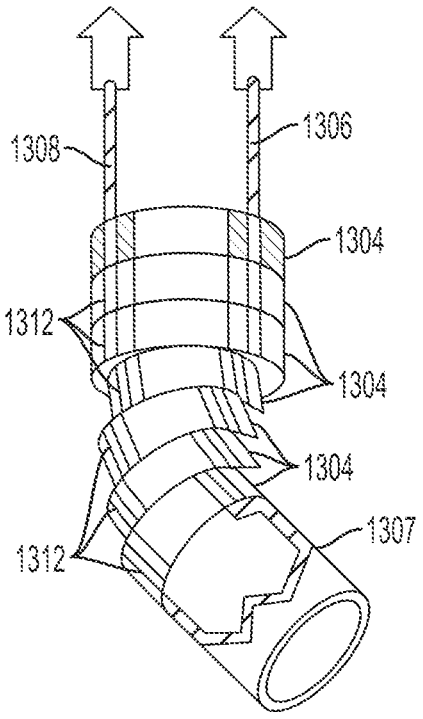

FIG. 80

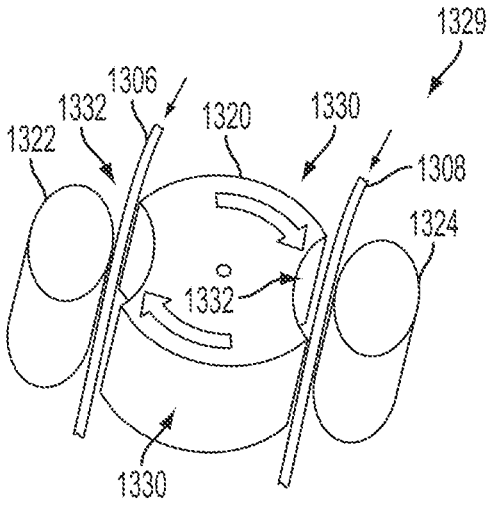
1329
1306
1332
1320
1330
1322
1308
1324
1332
1330

FIG. 81

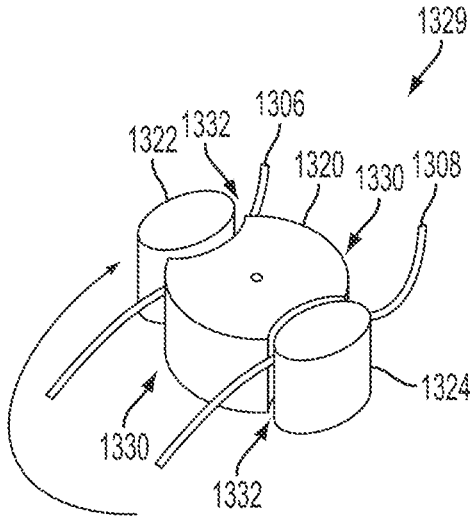
1329
1322
1332
1306
1320
1330
1308
1324
1330
1332

FIG. 82

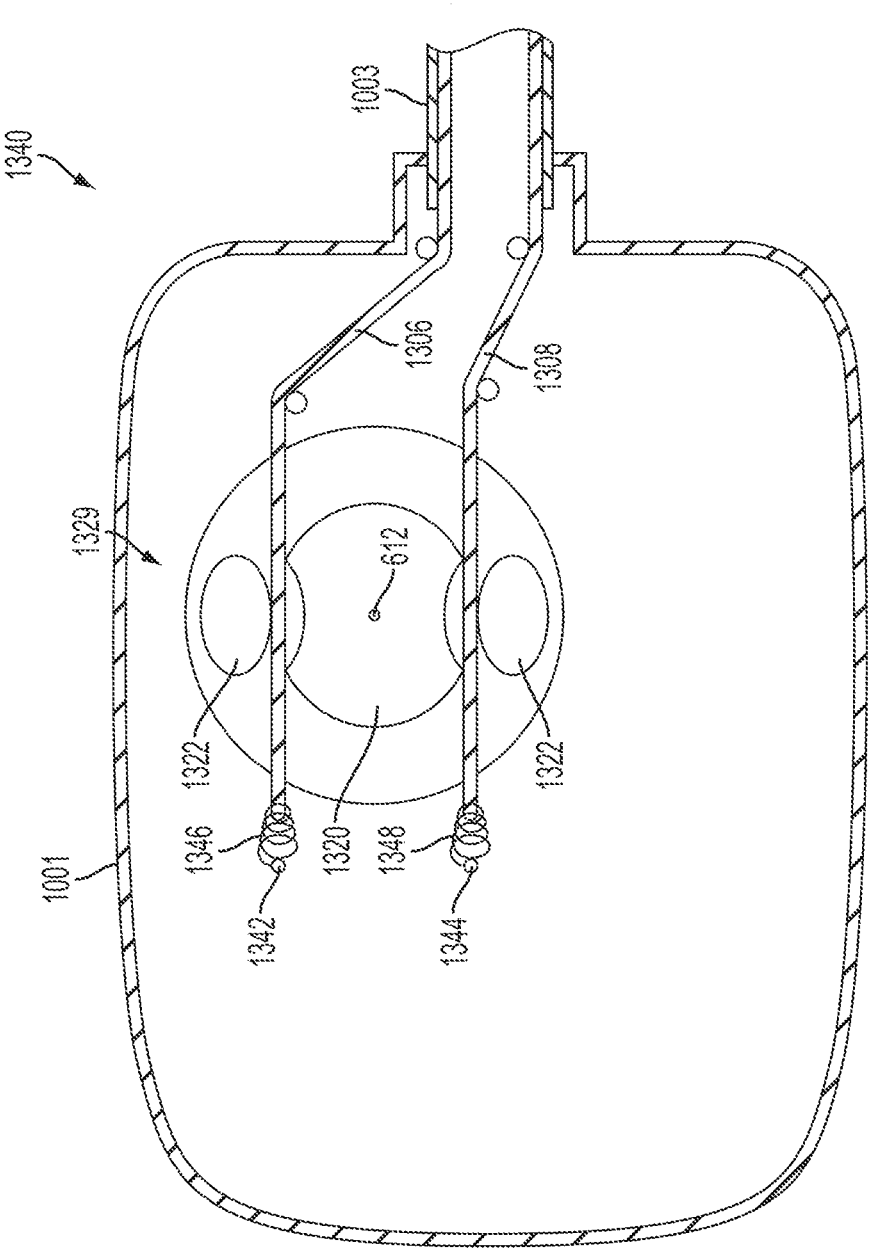
1340
1003
1306
1308
1329
612
1322
1322
1346
1320
1348
1001
1342
1344

FIG. 83

ULTRASONIC SURGICAL INSTRUMENTS WITH CONTROL MECHANISMS

CROSS-REFERENCE TO RELATED APPLICATIONS

U.S. application Ser. No. 13/539,096, entitled "Haptic Feedback Devices for Surgical Robot," now U.S. Patent Application Publication No. 2014/0005682;

U.S. application Ser. No. 13/539,110, entitled "Lockout Mechanism for Use with Robotic Electrosurgical Device," now U.S. Patent Application Publication No. 2014/0005654;

U.S. application Ser. No. 13/539,117, entitled "Closed Feedback Control for Electrosurgical Device," now U.S. Patent Application Publication No. 2014/0005667;

U.S. application Ser. No. 13/538,588, entitled "Surgical Instruments with Articulating Shafts," now U.S. Patent Application Publication No. 2014/0005701;

U.S. application Ser. No. 13/538,601, entitled "Ultrasonic Surgical Instruments with Distally Positioned Transducers," now U.S. Patent Application Publication No. 2014/0005702;

U.S. application Ser. No. 13/538,700, entitled "Surgical Instruments with Articulating Shafts," now U.S. Patent Application Publication No. 2014/0005703;

U.S. application Ser. No. 13/538,711, entitled "Ultrasonic Surgical Instruments with Distally Positioned Jaw Assemblies," now U.S. Patent Application Publication No. 2014/0005704;

U.S. application Ser. No. 13/538,720, entitled "Surgical Instruments with Articulating Shafts," now U.S. Patent Application Publication No. 2014/0005705; and

U.S. application Ser. No. 13/539,122, entitled "Surgical Instruments With Fluid Management System" now U.S. Patent Application Publication No. 2014/0005668.

BACKGROUND

Various embodiments are directed to surgical instruments including various control mechanisms for surgical instruments.

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.

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.

DRAWINGS

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:

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

FIG. **2** illustrates one embodiment of the surgical instrument shown in FIG. **1**.

FIG. **3** illustrates one embodiment of an ultrasonic end effector.

FIG. **4** illustrates another embodiment of an ultrasonic end effector.

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

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

FIG. **7** illustrates various internal components of one example embodiment of the surgical instrument shown in FIG. **1**

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

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

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

FIG. **11** is a perspective view of one embodiment of an electrical energy surgical instrument.

FIG. **12** is a side view of a handle of one embodiment of the surgical instrument of FIG. **11** with a half of a handle body removed to illustrate some of the components therein.

FIG. **13** illustrates a perspective view of one embodiment of the end effector of the surgical instrument of FIG. **11** with the jaws open and the distal end of an axially movable member in a retracted position.

FIG. **14** illustrates a perspective view of one embodiment of the end effector of the surgical instrument of FIG. **11** with the jaws closed and the distal end of an axially movable member in a partially advanced position.

FIG. **15** illustrates a perspective view of one embodiment of the axially moveable member of the surgical instrument of FIG. **11**.

FIG. **16** illustrates a section view of one embodiment of the end effector of the surgical instrument of FIG. **11**.

FIG. **17** illustrates a section a perspective view of one embodiment of a cordless electrical energy surgical instrument.

FIG. **18**A illustrates a side view of a handle of one embodiment of the surgical instrument of FIG. **17** with a half handle body removed to illustrate various components therein.

FIG. **18**B illustrates an RF drive and control circuit, according to one embodiment.

FIG. **18**C illustrates the main components of the controller, according to one embodiment.

FIG. **19** illustrates a block diagram of one embodiment of a robotic surgical system.

FIG. **20** illustrates one embodiment of a robotic arm cart.

FIG. **21** illustrates one embodiment of the robotic manipulator of the robotic arm cart of FIG. **20**.

FIG. **22** illustrates one embodiment of a robotic arm cart having an alternative set-up joint structure.

FIG. **23** 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. **19-22**.

FIG. **24** 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.

FIG. **26** 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. **24**.

FIG. **27** illustrates another view of the instrument drive assembly embodiment of FIG. **26** including the surgical instrument of FIG. **24**.

FIG. **28** illustrates another view of the instrument drive assembly embodiment of FIG. **26** including the electrosurgical instrument of FIG. **25**.

FIGS. **29-31** illustrate additional views of the adapter portion of the instrument drive assembly embodiment of FIG. **26**.

FIGS. **32-34** illustrate one embodiment of the instrument mounting portion of FIGS. **24-25** showing components for translating motion of the driven elements into motion of the surgical instrument.

FIGS. **35-37** illustrate an alternate embodiment of the instrument mounting portion of FIGS. **24-25** 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 **538**.

FIGS. **38-42** illustrate an alternate embodiment of the instrument mounting portion FIGS. **24-25** showing another alternate example mechanism for translating rotation of the driven elements into rotational motion about the axis of the shaft.

FIGS. **43-46**A 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).

FIGS. **46**B-**46**C illustrate one embodiment of a tool mounting portion comprising internal power and energy sources.

FIG. **47** illustrates a schematic cross-sectional view of a portion of one example embodiment of an ultrasonic medical instrument comprising first, second and third waveguide portions, where the second waveguide portion is substantially ½ of a resonant-longitudinal-wavelength long.

FIG. **47**A illustrates cross sections for two example embodiments of the second waveguide portion of FIG. **47**.

FIG. **48** illustrates a schematic cross-sectional view of a portion of one example embodiment of an ultrasonic medical instrument comprising first and second waveguide portions, where the first waveguide portion spans multiple ½ resonant longitudinal wavelengths.

FIG. **49** illustrates a schematic cross-sectional view of one example embodiment of an ultrasonic waveguide for use with a medical instrument and comprising first and second waveguide portions, where a first waveguide portion is joined to a second waveguide portion by a dowel press fit.

FIG. **50** illustrates a schematic cross-sectional view of one example embodiment of an ultrasonic waveguide for use with a medical instrument and comprising first and second waveguide portions, where the first waveguide portion is joined to the second waveguide portion by a ball-and-socket type attachment.

FIG. **51** illustrates a schematic cross-sectional view of a portion of another embodiment of an ultrasonic medical instrument comprising a medical ultrasonic waveguide having a length and including a proximal waveguide portion and a distal waveguide portion.

FIG. **52** illustrates one embodiment of an instrument mounting portion for use with a robotic surgical system, such as the system of FIG. **19**, comprising a magnetic element-driven control mechanism.

FIGS. **53**A-G illustrate one embodiment of the rotatable body and magnetic elements of the instrument mounting portion of FIG. **52**, with the rotatable body at various angular positions to energize and/or de-energize combinations of the magnetic elements.

FIG. **54** illustrates another embodiment of an instrument mounting portion for use with a robotic surgical system, such as the system of FIG. **19**, comprising a magnetic element-driven control mechanism.

FIG. **55** illustrates another embodiment of an instrument mounting portion for use with a robotic surgical system, such as the system of FIG. **19**, comprising a magnetic element-driven control mechanism and a spool-driven control mechanism.

FIGS. **56-57** illustrate one embodiment of an instrument mounting portion for use with a robotic surgical system, such as the system of FIG. **19**, comprising a translatable cable driven by a pair of rotatable bodies.

FIG. **58** illustrates another embodiment of an instrument mounting portion for use with a robotic surgical system, such as the system of FIG. **19**, comprising a translatable cable driven by a pair of rotatable bodies.

FIGS. **59-62** illustrate one embodiment of an articulation mechanism that may be utilized by manual and/or robotic surgical instruments to articulate an end effector.

FIGS. **63**A-B illustrate one embodiment of an articulation mechanism that may be utilized with any suitable control mechanism, including those described above with respect to FIGS. **52-58**.

FIGS. **64-65** illustrate embodiments of the plate of the articulation mechanism of FIGS. **63**A-B configured for use with three and four cables, respectively.

FIGS. **66-67** illustrate one embodiment of a shaft portion of a surgical instrument utilizing an articulation mechanism similar to the mechanism of FIGS. **63**A-**63**B.

FIG. **68** illustrates one embodiment of a surgical instrument for use with a robotic surgical system, such as the system of FIG. **19**, comprising a translatable end effector.

FIG. **69**A illustrates one embodiment of an articulatable shaft portion that may be used in conjunction with a surgical instrument.

FIG. **69**B illustrates an additional view of one embodiment of the flexible articulation portion of the shaft portion of FIG. **69**A.

FIG. **70** illustrates one embodiment of a piece of flat stock with a pair of coil pipes welded thereto.

FIG. **71** illustrates one embodiment of the flat stock of FIG. **70** rolled into a tube shape.

FIG. **72** illustrates one embodiment of an instrument mounting portion that may be utilized to effect differential translation of the cables of FIG. **70**.

FIG. **73** illustrates one embodiment of an instrument mounting portion comprising a battery assembly for powering the at least one energy element.

FIG. **74** illustrates one embodiment of the instrument mounting portion of FIG. **73** further comprising a generator circuit.

FIG. **75** illustrates one embodiment of an instrument mounting portion with a cord-based generator circuit.

FIG. **76** illustrates one embodiment of an instrument mounting portion comprising a removable battery assembly.

FIG. **77** illustrates one embodiment of a surgical system with a wireless foot pedal for actuating an energy element.

FIGS. **78-83** illustrate one embodiment of a passive articulation mechanism for use with a robotic surgical system and/or manual surgical instrument.

DESCRIPTION

Various embodiments are directed to surgical instruments, including control mechanisms for handheld instruments and/or instruments for use with robotic surgical applications. The control mechanisms may be utilized to perform various actions with the surgical instruments including, for example, articulation of an end effector, actuation of various mechanical and/or energy elements of the surgical instruments, etc. In some embodiments, control mechanisms are positioned within an instrument mounting device for use with a robotic surgical system.

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.

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.

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 various embodiments, the generator **20** may be formed integrally within the handle assembly **12**. In such implementations, a battery would be co-located within the handle assembly **12** to act as the energy source. FIG. **18**A and accompanying disclosures provide one example of such implementations.

In some embodiments, the eletrosurgery/RF generator module **23** may be configured to generate a therapeutic and/or a sub-therapeutic energy level. 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.

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).

In one embodiment, the electrosurgical/RF generator module **23** may be configured to deliver a sub-therapeutic 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 on provided on a clamp member of the end effector assembly **26**. Accordingly, the electrosurgical/RF generator module **23** may be configured for sub-therapeutic 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 Instruments," the disclosure of which is herein incorporated by reference in its entirety.

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. 6,679,899 (Method for Detecting Transverse Vibrations in an Ultrasonic Hand Piece); 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).

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.

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 subtherapeutic 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 subtherapeutic 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**.

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).

When the generator **20** is activated via the triggering mechanism, in one embodiment 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 preselected 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.

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.

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**.

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 **33**A 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 **33**B when the user releases the squeezing force against the trigger **32**.

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 **32***a* molded over the trigger **32** substrate. The overmolded resilient portion **32***a* is formed to provide a more comfortable contact surface for control of the trigger **32** in outward direction **33**B. In one example embodiment, the overmolded resilient portion **32***a* 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.

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.

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 **30***a* and a second projecting knob **30***b* 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 **30***a* and the second projecting knob **30***b* are actuated. The one or more projecting knobs **30***a*, **30***b* 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 **30***a*, **30***b*. 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.

In one example embodiment, the first and second projecting knobs **30***a*, **30***b* 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 **30***a*, **30***b* 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.

In the illustrated embodiment, the first projecting knob **30***a* comprises a plurality of tactile elements **30***c*, e.g., textured projections or "bumps" in the illustrated embodiment, to allow the user to differentiate the first projecting knob **30***a* from the second projecting knob **30***b*. 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.

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

In other embodiments, the trigger **32** and/or the toggle switch **30** may be employed to actuate the electrosurgical/RF generator module **23** individually or in combination with activation of the ultrasonic generator module **21**.

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 **46***a* that is exposed at the distal end. The end cap portion **46***a* 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 **46***a* and the trocar. The

rotation knob **48** may comprise "scallops" or flutes formed of raised ribs **48***a* and concave portions **48***b* located between the ribs **48***a* 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**.

In one example embodiment, the handle assembly **12** is formed from two (2) housing portions or shrouds comprising a first portion **12***a* and a second portion **12***b*. From the perspective of a user viewing the handle assembly **12** from the distal end towards the proximal end, the first portion **12***a* is considered the right portion and the second portion **12***b* is considered the left portion. Each of the first and second portions **12***a*, **12***b* 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 **12***a* and **12***b* 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 **12***a* and **12***b* of the handle assembly **12** for ultrasonic welding purposes, e.g., energy direction/deflection points. The first and second portions **12***a* and **12***b* (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.

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 **60**A or **60**B 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 **62**A from an open position to a closed position about a pivot point **70** when the trigger **32** is squeezed in direction **33**A. The clamp arm assembly **64** is movable in direction **62**B from a closed position to an open position about the pivot point **70** when the trigger **32** is released or outwardly contacted in direction **33**B.

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 **33**A moves the clamp arm assembly **64** in direction **62**A 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 **33**B moves the clamp arm assembly **64** in direction **62**B 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.

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**.

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 **33**B 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 hook **36** 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 **33**A or when opening the trigger **32** in the outward opening motion in direction **33**B 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 **33**B. 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.

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**.

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

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.

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 **12***a*, **12***b* mate to form the handle assembly **12**. The first and second portions **12***a*, **12***b* 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 **72***a*, a tube collar cap **72***b*, a distal washer **72***c*, a proximal washer **72***d*, and a thread tube collar **72***e*. The reciprocating tubular actuating member **58** is located within a reciprocating yoke **84**, which is retained between the first and second portions **12***a*, **12***b* 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.

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 **86***a,b* to electrically energize the ultrasonic transducer **16** in accordance with the activation of the first or second projecting knobs **30***a*, **30***b*.

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.

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.

In one example embodiment, the trigger **32** is coupled to a linkage mechanism to translate the rotational motion of the trigger **32** in directions **33**A and **33**B to the linear motion of the reciprocating tubular actuating member **58** in corresponding directions **60**A and **60**B. The trigger **32** comprises a first set of flanges **98** with openings formed therein to receive a first yoke pin **92***a*. The first yoke pin **92***a* 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 **92***a* 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 **12***a*, **12***b* of the handle assembly **12** to form a trigger pivot point for the trigger **32**. A second end **92***b* 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 **94***b*. 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 **60**A,B.

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**.

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 20 Hz to 32 kHz and a well-suited vibrational frequency range may be about 30-10 kHz. A suitable operational vibrational frequency may be approximately 55.5 kHz, for example.

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**.

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 ($\lambda/4$).

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**.

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**.

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.

In one example embodiment, the blade **66** may have a length substantially equal to an integral multiple of one-half system wavelengths (nλ/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 55 kHz, for example.

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 (nλ/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.

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.

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**.

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 **12***a*, **12***b* 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**.

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.

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'**

FIGS. **11-18**C illustrate various embodiments of surgical instruments that utilize therapeutic and/or subtherapeutic electrical energy to treat and/or destroy tissue or provide feedback to the generators (e.g., electrosurgical instruments). The embodiments of FIGS. **11-18**C are adapted for use in a manual or hand-operated manner, although electrosurgical instruments may be utilized in robotic applications as well. FIG. **11** is a perspective view of one example embodiment of a surgical instrument system **300** comprising an electrical energy surgical instrument **310**. The electrosurgical instrument **310** may comprise a proximal handle **312**, a distal working end or end effector **326** and an introducer or elongated shaft **314** disposed in-between.

The electrosurgical system **300** can be configured to supply energy, such as electrical energy, ultrasonic energy, heat energy or any combination thereof, to the tissue of a patient either independently or simultaneously as described, for example, in connection with FIG. **1**, for example. In one example embodiment, the electrosurgical system **300** includes a generator **320** in electrical communication with the electrosurgical instrument **310**. The generator **320** is connected to electrosurgical instrument **310** via a suitable transmission medium such as a cable **322**. In one example embodiment, the generator **320** is coupled to a controller, such as a control unit **325**, for example. In various embodiments, the control unit **325** may be formed integrally with the generator **320** or may be provided as a separate circuit module or device electrically coupled to the generator **320** (shown in phantom to illustrate this option). Although in the presently disclosed embodiment, the generator **320** is shown separate from the electrosurgical instrument **310**, in one example embodiment, the generator **320** (and/or the control unit **325**) may be formed integrally with the electrosurgical instrument **310** to form a unitary electrosurgical system **300**, where a battery located within the electrosurgical instrument

310 is the energy source and a circuit coupled to the battery produces the suitable electrical energy, ultrasonic energy, or heat energy. One such example is described herein below in connection with FIGS. 17-18C.

The generator 320 may comprise an input device 335 located on a front panel of the generator 320 console. The input device 335 may comprise any suitable device that generates signals suitable for programming the operation of the generator 320, such as a keyboard, or input port, for example. In one example embodiment, various electrodes in the first jaw 364A and the second jaw 364B may be coupled to the generator 320. The cable 322 may comprise multiple electrical conductors for the application of electrical energy to positive (+) and negative (−) electrodes of the electrosurgical instrument 310. The control unit 325 may be used to activate the generator 320, which may serve as an electrical source. In various embodiments, the generator 320 may comprise an RF source, an ultrasonic source, a direct current source, and/or any other suitable type of electrical energy source, for example, which may be activated independently or simultaneously

In various embodiments, the electrosurgical system 300 may comprise at least one supply conductor 331 and at least one return conductor 333, wherein current can be supplied to electrosurgical instrument 300 via the supply conductor 331 and wherein the current can flow back to the generator 320 via the return conductor 333. In various embodiments, the supply conductor 331 and the return conductor 333 may comprise insulated wires and/or any other suitable type of conductor. In certain embodiments, as described below, the supply conductor 331 and the return conductor 333 may be contained within and/or may comprise the cable 322 extending between, or at least partially between, the generator 320 and the end effector 326 of the electrosurgical instrument 310. In any event, the generator 320 can be configured to apply a sufficient voltage differential between the supply conductor 331 and the return conductor 333 such that sufficient current can be supplied to the end effector 110.

FIG. 12 is a side view of one example embodiment of the handle 312 of the surgical instrument 310. In FIG. 12, the handle 312 is shown with half of a first handle body 312A (see FIG. 11) removed to illustrate various components within second handle body 312B. The handle 312 may comprise a lever arm 321 (e.g., a trigger) which may be pulled along a path 33. The lever arm 321 may be coupled to an axially moveable member 378 (FIGS. 13-16) disposed within elongated shaft 314 by a shuttle 384 operably engaged to an extension 398 of lever arm 321. The shuttle 384 may further be connected to a biasing device, such as a spring 388, which may also be connected to the second handle body 312B, to bias the shuttle 384 and thus the axially moveable member 378 in a proximal direction, thereby urging the jaws 364A and 364B to an open position as seen in FIG. 11. Also, referring to FIGS. 11-12, a locking member 190 (see FIG. 12) may be moved by a locking switch 328 (see FIG. 11) between a locked position, where the shuttle 384 is substantially prevented from moving distally as illustrated, and an unlocked position, where the shuttle 384 may be allowed to freely move in the distal direction, toward the elongated shaft 314. The handle 312 can be any type of pistol-grip or other type of handle known in the art that is configured to carry actuator levers, triggers or sliders for actuating the first jaw 364A and the second jaw 364B. The elongated shaft 314 may have a cylindrical or rectangular cross-section, for example, and can comprise a thin-wall tubular sleeve that extends from handle 312. The elongated shaft 314 may include a bore extending therethrough for carrying actuator mechanisms, for example, the axially moveable member 378, for actuating the jaws and for carrying electrical leads for delivery of electrical energy to electrosurgical components of the end effector 326.

The end effector 326 may be adapted for capturing and transecting tissue and for the contemporaneously welding the captured tissue with controlled application of energy (e.g., RF energy). The first jaw 364A and the second jaw 364B may close to thereby capture or engage tissue about a longitudinal axis "T" defined by the axially moveable member 378. The first jaw 364A and second jaw 364B may also apply compression to the tissue. In some embodiments, the elongated shaft 314, along with first jaw 364A and second jaw 364B, can be rotated a full 360° degrees, as shown by arrow 196 (see FIG. 11), relative to handle 312. For example, a rotation knob 348 may be rotatable about the longitudinal axis of the shaft 314 and may be coupled to the shaft 314 such that rotation of the knob 348 causes corresponding rotation of the shaft 314. The first jaw 364A and the second jaw 364B can remain openable and/or closeable while rotated.

FIG. 13 shows a perspective view of one example embodiment of the end effector 326 with the jaws 364A, 364B open, while FIG. 14 shows a perspective view of one example embodiment of the end effector 326 with the jaws 364A, 364B closed. As noted above, the end effector 326 may comprise the upper first jaw 364A and the lower second jaw 364B, which may be straight or curved. The first jaw 364A and the second jaw 364B may each comprise an elongated slot or channel 362A and 362B, respectively, disposed outwardly along their respective middle portions. Further, the first jaw 364A and second jaw 364B may each have tissue-gripping elements, such as teeth 363, disposed on the inner portions of first jaw 364A and second jaw 364B. The first jaw 364A may comprise an upper first jaw body 200A with an upper first outward-facing surface 202A and an upper first energy delivery surface 365A. The second jaw 364B may comprise a lower second jaw body 200B with a lower second outward-facing surface 202B and a lower second energy delivery surface 365B. The first energy delivery surface 365A and the second energy delivery surface 365B may both extend in a "U" shape about the distal end of the end effector 326.

The lever arm 321 of the handle 312 (FIG. 12) may be adapted to actuate the axially moveable member 378, which may also function as a jaw-closing mechanism. For example, the axially moveable member 378 may be urged distally as the lever arm 321 is pulled proximally along the path 33 via the shuttle 384, as shown in FIG. 12 and discussed above. FIG. 15 is a perspective view of one example embodiment of the axially moveable member 378 of the surgical instrument 310. The axially moveable member 378 may comprise one or several pieces, but in any event, may be movable or translatable with respect to the elongated shaft 314 and/or the jaws 364A, 364B. Also, in at least one example embodiment, the axially moveable member 378 may be made of 17-4 precipitation hardened stainless steel. The distal end of axially moveable member 378 may comprise a flanged "I"-beam configured to slide within the channels 362A and 362B in jaws 364A and 364B. The axially moveable member 378 may slide within the channels 362A, 362B to open and close the first jaw 364A and the second jaw 364B. The distal end of the axially moveable member 378 may also comprise an upper flange or "c"-shaped portion 378A and a lower flange or "c"-shaped portion 378B. The flanges 378A and 378B respectively define inner cam surfaces 367A and 367B for engaging

outward facing surfaces of the first jaw **364**A and the second jaw **364**B. The opening-closing of jaws **364**A and **364**B can apply very high compressive forces on tissue using cam mechanisms which may include movable "I-beam" axially moveable member **378** and the outward facing surfaces **369**A, **369**B of jaws **364**A, **364**B.

More specifically, referring now to FIGS. **13-15**, collectively, the inner cam surfaces **367**A and **367**B of the distal end of axially moveable member **378** may be adapted to slidably engage the first outward-facing surface **369**A and the second outward-facing surface **369**B of the first jaw **364**A and the second jaw **364**B, respectively. The channel **362**A within first jaw **364**A and the channel **362**B within the second jaw **364**B may be sized and configured to accommodate the movement of the axially moveable member **378**, which may comprise a tissue-cutting element **371**, for example, comprising a sharp distal edge. FIG. **14**, for example, shows the distal end of the axially moveable member **378** advanced at least partially through channels **362**A and **362**B (FIG. **13**). The advancement of the axially moveable member **378** may close the end effector **326** from the open configuration shown in FIG. **13**. In the closed position shown by FIG. **14**, the upper first jaw **364**A and lower second jaw **364**B define a gap or dimension D between the first energy delivery surface **365**A and second energy delivery surface **365**B of first jaw **364**A and second jaw **364**B, respectively. In various embodiments, dimension D can equal from about 0.0005" to about 0.040", for example, and in some embodiments, between about 0.001" to about 0.010", for example. Also, the edges of the first energy delivery surface **365**A and the second energy delivery surface **365**B may be rounded to prevent the dissection of tissue.

FIG. **16** is a section view of one example embodiment of the end effector **326** of the surgical instrument **310**. The engagement, or tissue-contacting, surface **365**B of the lower jaw **364**B is adapted to deliver energy to tissue, at least in part, through a conductive-resistive matrix, such as a variable resistive positive temperature coefficient (PTC) body, as discussed in more detail below. At least one of the upper and lower jaws **364**A, **364**B may carry at least one electrode **373** configured to deliver the energy from the generator **320** to the captured tissue. The engagement, or tissue-contacting, surface **365**A of upper jaw **364**A may carry a similar conductive-resistive matrix (i.e., a PTC material), or in some embodiments the surface may be a conductive electrode or an insulative layer, for example. Alternatively, the engagement surfaces of the jaws can carry any of the energy delivery components disclosed in U.S. Pat. No. 6,773,409, filed Oct. 22, 2001, entitled ELECTROSURGICAL JAW STRUCTURE FOR CONTROLLED ENERGY DELIVERY, the entire disclosure of which is incorporated herein by reference.

The first energy delivery surface **365**A and the second energy delivery surface **365**B may each be in electrical communication with the generator **320**. The first energy delivery surface **365**A and the second energy delivery surface **365**B may be configured to contact tissue and deliver electrosurgical energy to captured tissue which are adapted to seal or weld the tissue. The control unit **325** regulates the electrical energy delivered by electrical generator **320** which in turn delivers electrosurgical energy to the first energy delivery surface **365**A and the second energy delivery surface **365**B. The energy delivery may be initiated by an activation button **328** (FIG. **12**) operably engaged with the lever arm **321** and in electrical communication with the generator **320** via cable **322**. In one example embodiment, the electrosurgical instrument **310** may be energized by the generator **320** by way of a foot switch **329** (FIG. **11**). When actuated, the foot switch **329** triggers the generator **320** to deliver electrical energy to the end effector **326**, for example. The control unit **325** may regulate the power generated by the generator **320** during activation. Although the foot switch **329** may be suitable in many circumstances, other suitable types of switches can be used.

As mentioned above, the electrosurgical energy delivered by electrical generator **320** and regulated, or otherwise controlled, by the control unit **325** may comprise radio frequency (RF) energy, or other suitable forms of electrical energy. Further, the opposing first and second energy delivery surfaces **365**A and **365**B may carry variable resistive positive temperature coefficient (PTC) bodies that are in electrical communication with the generator **320** and the control unit **325**. Additional details regarding electrosurgical end effectors, jaw closing mechanisms, and electrosurgical energy-delivery surfaces are described in the following U.S. patents and published patent applications: U.S. Pat. Nos. 7,087,054; 7,083,619; 7,070,597; 7,041,102; 7,011,657; 6,929,644; 6,926,716; 6,913,579; 6,905,497; 6,802,843; 6,770,072; 6,656,177; 6,533,784; and 6,500,312; and U.S. Pat. App. Pub. Nos. 2010/0036370 and 2009/0076506, all of which are incorporated herein in their entirety by reference and made a part of this specification.

In one example embodiment, the generator **320** may be implemented as an electrosurgery unit (ESU) capable of supplying power sufficient to perform bipolar electrosurgery using radio frequency (RF) energy. In one example embodiment, the ESU can be a bipolar ERBE ICC 350 sold by ERBE USA, Inc. of Marietta, Ga. In some embodiments, such as for bipolar electrosurgery applications, 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, adjacent to and/or in electrical communication with, the tissue to be treated such that current can flow from the active electrode, through the positive temperature coefficient (PTC) bodies and to the return electrode through the tissue. Thus, in various embodiments, the electrosurgical system **300** may comprise a supply path and a return path, wherein the captured tissue being treated completes, or closes, the circuit. In one example embodiment, the generator **320** may be a monopolar RF ESU and the electrosurgical instrument **310** may comprise a monopolar end effector **326** in which one or more active electrodes are integrated. For such a system, the generator **320** may require a return pad in intimate contact with the patient at a location remote from the operative site and/or other suitable return path. The return pad may be connected via a cable to the generator **320**. In other embodiments, the operator **20** may provide subtherapeutic RF energy levels for purposes of evaluating tissue conditions and providing feedback in the electrosurgical system **300**. Such feedback may be employed to control the therapeutic RF energy output of the electrosurgical instrument **310**.

During operation of electrosurgical instrument **300**, the user generally grasps tissue, supplies energy to the captured tissue to form a weld or a seal (e.g., by actuating button **328** and/or pedal **216**), and then drives a tissue-cutting element **371** at the distal end of the axially moveable member **378** through the captured tissue. According to various embodiments, the translation of the axial movement of the axially moveable member **378** may be paced, or otherwise controlled, to aid in driving the axially moveable member **378** at a suitable rate of travel. By controlling the rate of the travel, the likelihood that the captured tissue has been

properly and functionally sealed prior to transection with the cutting element **371** is increased.

FIG. **17** is a perspective view of one example embodiment of a surgical instrument system comprising a cordless electrical energy surgical instrument **410**. The electrosurgical system is similar to the electrosurgical system **300**. The electrosurgical system can be configured to supply energy, such as electrical energy, ultrasonic energy, heat energy, or any combination thereof, to the tissue of a patient either independently or simultaneously as described in connection with FIGS. **1** and **11**, for example. The electrosurgical instrument may utilize the end effector **326** and elongated shaft **314** described herein in conjunction with a cordless proximal handle **412**. In one example embodiment, the handle **412** includes a generator circuit **420** (see FIG. **18**A). The generator circuit **420** performs a function substantially similar to that of generator **320**. In one example embodiment, the generator circuit **420** is coupled to a controller, such as a control circuit. In the illustrated embodiment, the control circuit is integrated into the generator circuit **420**. In other embodiments, the control circuit may be separate from the generator circuit **420**.

In one example embodiment, various electrodes in the end effector **326** (including jaws **364**A, **364**B thereof) may be coupled to the generator circuit **420**. The control circuit may be used to activate the generator **420**, which may serve as an electrical source. In various embodiments, the generator **420** may comprise an RF source, an ultrasonic source, a direct current source, and/or any other suitable type of electrical energy source, for example. In one example embodiment, a button **328** may be provided to activate the generator circuit **420** to provide energy to the end effectors **326**, **326**.

FIG. **18**A is a side view of one example embodiment of the handle **412** of the cordless surgical instrument **410**. In FIG. **18**A, the handle **412** is shown with half of a first handle body removed to illustrate various components within second handle body **434**. The handle **412** may comprise a lever arm **424** (e.g., a trigger) which may be pulled along a path **33** around a pivot point. The lever arm **424** may be coupled to an axially moveable member **478** disposed within elongated shaft **314** by a shuttle operably engaged to an extension of lever arm **424**. In one example embodiment, the lever arm **424** defines a shepherd's hook shape comprising a distal member **424***a* and a proximal member **424***b*.

In one example embodiment, the cordless electrosurgical instrument comprises a battery **437**. The battery **437** provides electrical energy to the generator circuit **420**. The battery **437** may be any battery suitable for driving the generator circuit **420** at the desired energy levels. In one example embodiment, the battery **437** is a 100 mAh, triple-cell Lithium Ion Polymer battery. The battery may be fully charged prior to use in a surgical procedure, and may hold a voltage of about 12.6V. The battery **437** may have two fuses fitted to the cordless electrosurgical instrument **410**, arranged in line with each battery terminal. In one example embodiment, a charging port **439** is provided to connect the battery **437** to a DC current source (not shown).

The generator circuit **420** may be configured in any suitable manner. In some embodiments, the generator circuit comprises an RF drive and control circuit **440** and a controller circuit **482**. FIG. **18**B illustrates an RF drive and control circuit **440**, according to one embodiment. FIG. **18**B is a part schematic part block diagram illustrating the RF drive and control circuitry **440** used in this embodiment to generate and control the RF electrical energy supplied to the end effector **326**. As will be explained in more detail below, in this embodiment, the drive circuitry **440** is a resonant mode RF amplifier comprising a parallel resonant network on the RF amplifier output and the control circuitry operates to control the operating frequency of the drive signal so that it is maintained at the resonant frequency of the drive circuit, which in turn controls the amount of power supplied to the end effector **326**. The way that this is achieved will become apparent from the following description.

As shown in FIG. **18**B, the RF drive and control circuit **440** comprises the above described battery **437** are arranged to supply, in this example, about 0V and about 12V rails. An input capacitor (C_{in}) **442** is connected between the 0V and the 12V for providing a low source impedance. A pair of FET switches **443-1** and **443-2** (both of which are N-channel in this embodiment to reduce power losses) is connected in series between the 0V rail and the 12V rail. FET gate drive circuitry **805** is provided that generates two drive signals—one for driving each of the two FETs **443**. The FET gate drive circuitry **445** generates drive signals that causes the upper FET (**443-1**) to be on when the lower FET (**443-2**) is off and vice versa. This causes the node **447** to be alternately connected to the 12V rail (when the FET **443-1** is switched on) and the 0V rail (when the FET **443-2** is switched on). FIG. **18**B also shows the internal parasitic diodes **448-1** and **448-2** of the corresponding FETs **443**, which conduct during any periods that the FETs **443** are open.

As shown in FIG. **18**B, the node **447** is connected to an inductor-inductor resonant circuit **450** formed by inductor L_s **452** and inductor L_m **454**. The FET gate driving circuitry **445** is arranged to generate drive signals at a drive frequency (f_d) that opens and crosses the FET switches **443** at the resonant frequency of the parallel resonant circuit **450**. As a result of the resonant characteristic of the resonant circuit **450**, the square wave voltage at node **447** will cause a substantially sinusoidal current at the drive frequency (f_d) to flow within the resonant circuit **450**. As illustrated in FIG. **18**B, the inductor L_m **454** is the primary of a transformer **455**, the secondary of which is formed by inductor L_{sec} **456**. The inductor L_{sec} **456** of the transformer **455** secondary is connected to an inductor-capacitor-capacitor parallel resonant circuit **457** formed by inductor L_2 **458**, capacitor C_4 **460**, and capacitor C_2 **462**. The transformer **455** up-converts the drive voltage (V_d) across the inductor L_m **454** to the voltage that is applied to the output parallel resonant circuit **457**. The load voltage (V_L) is output by the parallel resonant circuit **457** and is applied to the load (represented by the load resistance R_{load} **459** in FIG. **18**B) corresponding to the impedance of the forceps' jaws and any tissue or vessel gripped by the end effector **326**. As shown in FIG. **18**B, a pair of DC blocking capacitors C_{bI} **480-1** and **480-2** is provided to prevent any DC signal being applied to the load **459**.

In one embodiment, the transformer **455** may be implemented with a Core Diameter (mm), Wire Diameter (mm), and Gap between secondary windings in accordance with the following specifications:

Core Diameter, D (mm)
D=19.9×10-3
Wire diameter, W (mm) for 22 AWG wire
W=7.366×10-4
Gap between secondary windings, in gap=0.125
G=gap/25.4

In this embodiment, the amount of electrical power supplied to the end effector **326** is controlled by varying the frequency of the switching signals used to switch the FETs **443**. This works because the resonant circuit **450** acts as a frequency dependent (loss less) attenuator. The closer the drive signal is to the resonant frequency of the resonant

circuit **450**, the less the drive signal is attenuated. Similarly, as the frequency of the drive signal is moved away from the resonant frequency of the circuit **450**, the more the drive signal is attenuated and so the power supplied to the load reduces. In this embodiment, the frequency of the switching signals generated by the FET gate drive circuitry **445** is controlled by a controller **481** based on a desired power to be delivered to the load **459** and measurements of the load voltage (V_L) and of the load current (I_L) obtained by conventional voltage sensing circuitry **483** and current sensing circuitry **485**. The way that the controller **481** operates will be described in more detail below.

In one embodiment, the voltage sensing circuitry **483** and the current sensing circuitry **485** may be implemented with high bandwidth, high speed rail-to-rail amplifiers (e.g., LMH6643 by National Semiconductor). Such amplifiers, however, consume a relatively high current when they are operational. Accordingly, a power save circuit may be provided to reduce the supply voltage of the amplifiers when they are not being used in the voltage sensing circuitry **483** and the current sensing circuitry **485**. In one-embodiment, a step-down regulator (e.g., LT3502 by Linear Technologies) may be employed by the power save circuit to reduce the supply voltage of the rail-to-rail amplifiers and thus extend the life of the battery **437**.

FIG. **18**C illustrates the main components of the controller **481**, according to one embodiment. In the embodiment illustrated in FIG. **18**C, the controller **481** is a microprocessor based controller and so most of the components illustrated in FIG. **16** are software based components. Nevertheless, a hardware based controller **481** may be used instead. As shown, the controller **481** includes synchronous I,Q sampling circuitry **491** that receives the sensed voltage and current signals from the sensing circuitry **483** and **485** and obtains corresponding samples which are passed to a power, V_{rms} and I_{rms} calculation module **493**. The calculation module **493** uses the received samples to calculate the RMS voltage and RMS current applied to the load **459** (FIG. **18**B; end effector **326** and tissue/vessel gripped thereby) and from them the power that is presently being supplied to the load **459**. The determined values are then passed to a frequency control module **495** and a medical device control module **497**. The medical device control module **497** uses the values to determine the present impedance of the load **459** and based on this determined impedance and a pre-defined algorithm, determines what set point power (P_{set}) should be applied to the frequency control module **495**. The medical device control module **497** is in turn controlled by signals received from a user input module **499** that receives inputs from the user (for example pressing buttons or activating the control levers **114**, **110** on the handle **104**) and also controls output devices (lights, a display, speaker or the like) on the handle **104** via a user output module **461**.

The frequency control module **495** uses the values obtained from the calculation module **493** and the power set point (P_{set}) obtained from the medical device control module **497** and predefined system limits (to be explained below), to determine whether or not to increase or decrease the applied frequency. The result of this decision is then passed to a square wave generation module **463** which, in this embodiment, increments or decrements the frequency of a square wave signal that it generates by 1 kHz, depending on the received decision. As those skilled in the art will appreciate, in an alternative embodiment, the frequency control module **495** may determine not only whether to increase or decrease the frequency, but also the amount of frequency change required. In this case, the square wave generation module **463** would generate the corresponding square wave signal with the desired frequency shift. In this embodiment, the square wave signal generated by the square wave generation module **463** is output to the FET gate drive circuitry **445**, which amplifies the signal and then applies it to the FET **443-1**. The FET gate drive circuitry **445** also inverts the signal applied to the FET **443-1** and applies the inverted signal to the FET **443-2**.

The electrosurgical instrument **410** may comprise additional features as discussed with respect to electrosurgical system **300**. Those skilled in the art will recognize that electrosurgical instrument **410** may include a rotation knob **348**, an elongated shaft **314**, and an end effector **326**. These elements function in a substantially similar manner to that discussed above with respect to the electrosurgical system **300**. In one example embodiment, the cordless electrosurgical instrument **410** may include visual indicators **435**. The visual indicators **435** may provide a visual indication signal to an operator. In one example embodiment, the visual indication signal may alert an operator that the device is on, or that the device is applying energy to the end effector. Those skilled in the art will recognize that the visual indicators **435** may be configured to provide information on multiple states of the device.

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 or electrosurgical instruments, as described herein. Example robotic systems include those manufactured by Intuitive Surgical, Inc., of Sunnyvale, Calif., 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. Pat. No. 6,231,565, entitled "Robotic Arm DLUs For Performing Surgical Tasks", U.S. Pat. No. 6,783,524, entitled "Robotic Surgical Tool With Ultrasound Cauterizing and Cutting Instrument", U.S. Pat. No. 6,364,888, entitled "Alignment of Master and Slave In a Minimally Invasive Surgical Apparatus", U.S. Pat. No. 7,524,320, entitled "Mechanical Actuator Interface System For Robotic Surgical Tools", U.S. Pat. No. 7,691,098, entitled Platform Link Wrist Mechanism", U.S. Pat. No. 7,806,891, entitled "Repositioning and Reorientation of Master/Slave Relationship in Minimally Invasive Telesurgery", and U.S. Pat. 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.

FIGS. **19**-**46**C 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.

FIGS. **19-25** illustrate the structure and operation of several example robotic surgical systems and components thereof. FIG. **19** 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. Pat. 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.

FIG. **20** 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. Pat. 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.

FIG. **21** shows one example embodiment of the robotic manipulator **528** of the robotic arm cart **520**. In the example shown in FIG. **21**, 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 **534***a*, sometimes called the pitch axis. The links supporting the parallelogram linkage are pivotally mounted to set-up joints **526** (FIG. **20**) so that the surgical instrument **522** further rotates about an axis **534***b*, sometimes called the yaw axis. The pitch and yaw axes **534***a*, **534***b* 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 **534***c*), 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**.

FIG. **22** 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.

FIG. **23** 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. **20-22**. The controller **518** generally includes master controllers (generally represented as **519** in FIG. **23**) 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).

FIG. **24** 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. **24**, 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. **25** shows another example embodiment having an electrosurgical instrument **523** in place of the ultrasonic surgical instrument **522**. The surgical instrument **523** comprises a surgical end effector **548** that comprises closable jaws **551**A, **551**B having energy deliver surfaces **553**A, **553**B for engaging and providing electrical energy to tissue between the jaws **551**A, **551**B. A tissue cutting element or knife **555** may be positioned at the distal end of an axially movable member **557** that may extend through the elongated shaft assembly **554** to the instrument mounting portion **558**. FIG. **26** 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 instruments **522**, **523**. 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**, **523**. For example, actuation (e.g., opening and closing) of the clamp arm **552**, actuation (e.g., opening and closing) of the jaws **551**A, **551**B, actuation of the ultrasonic blade **550**, extension of the knife **555** and actuation of the energy delivery surfaces **553**A, **553**B, 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.

FIG. **27** shows another view of the instrument drive assembly of FIG. **26** including the ultrasonic surgical instrument **522**. FIG. **28** shows another view of the instrument drive assembly of FIG. **26** including the electrosurgical instrument **523**. The instrument mounting portion **558** includes an instrument mounting plate **562** that operably supports a plurality of (four are shown in FIG. **26**) 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**.

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.

FIGS. **29-31** show additional views of the adapter portion **568** of the instrument drive assembly **546** of FIG. **26**. The adapter portion **568** generally includes an instrument side **572** and a holder side **574** (FIG. **29**). 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 FIGS. **24**, **25**) 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**.

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. **27**, **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**, **523** 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. **31**.

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. **31**) 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. **30**) by a circuit board of the adaptor **568**.

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. **26**. For example, as can be seen in FIG. **26**, 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. **30**. 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**.

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**.

FIGS. **32-34** 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**, **523**. FIGS. **32-34** 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 RF and/or 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**.

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.

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. **32-34**, 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 **620**L. The first rack gear **618** is attached to a first articulation band **622** (FIG. **32**) 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 **620**L. 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 **620**R. The second rack gear **628** is attached to a second articulation band **624** (FIG. **33**) 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 **620**R. 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.

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** (FIG. **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. **32-33**, 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 **634**CW. 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 **634**CCW. 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.

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 transla-

tion. 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**.

FIGS. **35-37** 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**, **523** 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. **36** and **37**, 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 **634**CW. 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 **634**CCW. 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.

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.

FIGS. **38-42** 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. **38-42**, 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. **38-39**, 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 **634**CW. A CCW rotation of the rotatable body **612** results in a CCW rotation of the shaft assembly **538** in the direction indicated by **634**CCW. 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.

FIGS. **43-46**A 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. **43-46**A, 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 **680**A, **680**B. 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 **680**A acts on the first follower arm **682** and the second cam portion **680**B 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 **680**A 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 **620**L. As the bottom cam portion **680**B acts of the second follower arm **684**, the shaft assembly **538** articulates in a right direction **620**R. 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. **46**A shows the bushings **688**, **690** and the dual cam assembly **680**, including the first and second cam portions **680**B, **680**B, with the first and second follower arms **682**, **684** removed to provide a more detailed and clearer view.

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. **46**B-**46**C illustrate one embodiment of a tool mounting portion **558'** comprising internal power and energy sources. For example, surgical instruments (e.g., instruments **522**, **523**) mounted utilizing the tool mounting portion **558'** need not be wired to an external generator or other power source. Instead, the functionality of the various generators **20**, **320** described herein may be implemented on board the mounting portion **558**.

As illustrated in FIGS. **46**B-**46**C, 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**, **523**, 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 generators **20**, **320**. For example, when an ultrasonic instrument **522** is utilized, the control circuit **704** may provide an ultrasonic drive signal in a manner similar to that described above with respect to generator **20**. Also, for example, when an RF instrument **523** or ultrasonic instrument **522** capable of providing a therapeutic or non-therapeutic RF signal is used, the control circuit **704** may provide an RF drive signal, for example, as described herein above with respect to the module **23** of generator **20** and/or the generator **300**. In some embodiments, the control circuit **704** may be configured in a manner similar to that of the control circuit **440** described herein above with respect to FIGS. **18**B-**18**C.

Various embodiments described herein comprise an articulatable shaft. When using an articulatable shaft, components running through the shaft from the end effector must be flexible, so as to flex when the shaft articulates. In various embodiments, this can be accomplished by utilizing waveguides that have flexible portions. For example, FIG. **47** illustrates a schematic cross-sectional view of a portion of one example embodiment of an ultrasonic medical instrument **1500** comprising first, second and third waveguide portions. In FIG. **47**, the hand piece and the sheath-articulation control knobs, etc. of the ultrasonic medical instrument **1500** are omitted for clarity. In the example embodiment shown in FIG. **47**, the ultrasonic medical instrument **1500** comprises a medical ultrasonic waveguide **1502** for transmitting ultrasonic energy from a transducer (not shown in FIG. **47**) to an ultrasonic blade **1544**. The medical ultrasonic waveguide **1502** has a length and includes first, second and third waveguide portions **1504**, **1506** and **1508**. The second waveguide portion **1506** is located lengthwise between the first and third waveguide portions **1504** and **1508**; the first waveguide portion **1504** is located proximal the second waveguide portion **1506**; and the third waveguide portion **1508** is located distal the second waveguide portion **1506**. The first and third waveguide portions **1504** and **1508** each have a larger transverse area and the second waveguide portion **1506** has a smaller transverse area. The second waveguide portion **1506** is more bendable than either of the first and third waveguide portions **1504** and **1508**. It is further noted that ultrasonic vibration can be any one, or any combination, of longitudinal, transverse, and torsional vibration. In some embodiments, the section **1506** may have a circular cross-section (e.g., a uniform cross-sectional radius).

In some embodiments the second bendable waveguide portion **1506** may not have a uniform cross-sectional radius. For example, FIG. **47**A illustrates cross sections for two example embodiments of the waveguide portion **1506**. The waveguide portion **1506'** is illustrated in relation to two axes **1509**, **1511**, also shown in FIG. **47**. In various embodiments, the waveguide portion **1506'** may have a cross sectional length along axis **1511** that is less than its cross sectional dimension along axis **1509**. In some embodiments, the cross sectional length along the axis **1509** may be equal to the cross sectional length of the other waveguide portions **1504**, **1506**. The waveguide portion **1506'** may be bendable along the axis **1509**. Referring now to waveguide portion **1506"**, its cross sectional lengths along the axis **1509**, **1511** may be the same, providing the waveguide portion **1506"** with a greater range of directions for bending.

In some example embodiments, the medical ultrasonic waveguide **1502** is a monolithic (e.g., the blade portion **1544** is integral to the waveguide **1502**). Also, in some example embodiments, the medical ultrasonic waveguide **1502** includes first and second longitudinal vibration antinodes **1510** and **1512**. The first waveguide portion **1504** may transition to the second waveguide portion **1506** proximate the first longitudinal vibration antinode **1510**; and the second waveguide portion **1506** may transition to the third waveguide portion **1508** proximate the second longitudinal vibration antinode **1512**. In some example embodiments, as illustrated by FIG. **47**, the second waveguide portion **1506** is substantially ½ of a resonant-longitudinal-wavelength long.

In one example application of the embodiment of FIG. **47**, the ultrasonic medical instrument **1500** also includes a user-actuated articulated sheath **1514** which surrounds the medical ultrasonic waveguide **1502**. In various example embodiments, the medical ultrasonic waveguide **1502** includes three (meaning at least three) longitudinal vibration nodes **1516** located, one each, on the first, second and third waveguide portions **1504**, **1506** and **1508**. It is noted that one or more additional longitudinal vibration nodes may, or may not, be present between any one or two of the three longitudinal vibration nodes **1516**. In one modification, the sheath **1514** contacts (e.g., directly contacts or indirectly contacts through at least one intervening member **1517** such as a silicone intervening member) the first, second and third waveguide portions **1504**, **1506** and **1508** at a corresponding one of the three longitudinal vibration nodes **1516**. In one example, the sheath **1514** includes a rigid first sheath portion

1518 contacting the first waveguide portion 1504 at the first longitudinal vibration node (the leftmost node 1516 of FIG. 47), a flexible second sheath portion 1520 contacting the second waveguide portion 1506 at the second longitudinal vibration node (the middle node 1516 of FIG. 47), and a rigid third sheath portion 1522 contacting the third waveguide portion 1508 at the third longitudinal vibration node (the rightmost node 1516 of FIG. 47). In some example embodiments, the sheath 1514 has only two articulation positions (e.g., straight and fully articulated). In other example embodiments, the sheath 1514 has a number of intermediate bent positions between a straight position and a fully articulated position depending on the number of energy efficient curves the waveguide 1502 can be formed to. In some example embodiments, such energy efficient curves minimize vibrational energy going into non-longitudinal vibrational modes.

FIG. 48 illustrates a schematic cross-sectional view of a portion of one example embodiment of an ultrasonic medical instrument 1524 comprising first and second waveguide portions 1530, 1532, where the first waveguide portion 1530 spans multiple ½ resonant longitudinal wavelengths. In the example embodiment show in FIG. 48, a medical ultrasonic waveguide 1526 includes at least two longitudinal vibration nodes 1528 located on the first waveguide portion 1530. In one variation, a sheath 1534 contacts (e.g., directly contacts or indirectly contacts through at least one intervening member 1536 such as a silicone intervening member) the first waveguide portion 1530 at the at-least-two longitudinal vibration nodes 1528. In some example embodiments, the sheath 1534 includes two rigid sheath portions 1538 and 1542 and one flexible sheath portion 1540, wherein the flexible sheath portion 1540 contacts the first waveguide portion 1530 at least one of the two longitudinal vibration nodes 1528, and wherein the flexible sheath portion 1540 is disposed between the two rigid sheath portions 1538 and 1542. In one example embodiment, the two rigid sheath portions 1538 and 1542 each contact the second waveguide portion 1532 at a corresponding one of the at-least-two longitudinal vibration nodes 1528.

Referring now to FIG. 47, the waveguide 1502 may comprise a blade portion 1544 adapted to contact and ultrasonically treat patient tissue. The blade portion 1544 may be disposed at a distal end of the waveguide 1502 (e.g., distal of the third blade portion 1508 of the blade 1502). In one example embodiment, the surgical instrument 1500 may also comprise a user-actuated clamp arm 1546 pivotally attached to the sheath 1514, 1534 proximate the blade portion 1544, wherein the clamp arm 1546 and the medical ultrasonic waveguide 1502 at least in part define an ultrasonic surgical shears 1548. The tissue pad and clamping arm control mechanism has been omitted from FIG. 47. Referring again to FIG. 48, the medical ultrasonic waveguide 1526 may also comprise a blade portion 1545, similar to the blade portion 1544, and disposed at a distal end of the first waveguide portion 1532. The blade portion 1545 may also be adapted to contact and ultrasonically treat patient tissue. The instrument 1524 of FIG. 48 may also comprise a clamp arm 1546, defining, with the blade portion 1545, an ultrasonic surgical shears 1548.

In various example embodiments, certain portions of the waveguides 1502, 1526 are substantially rigid. For example, first and third portions 1504 and 1508 of the waveguide 1502 may be substantially rigid. The first portion 1532 of the waveguide 1526 may be substantially rigid. Referring again to FIG. 47, the medical ultrasonic waveguide 1502 may include first and second neck portions 1550 and 1552 joining, respectively, the first and second waveguide portions 1504 and 1506 and the second and third waveguide portions 1506 and 1508. (A similar neck portion 1552 may join the first and second waveguide portions 1530, 1532 of the waveguide 1526.)

In one modification, the medical ultrasonic waveguide 1502 is substantially cylindrical from the first waveguide portion 1504 to the third waveguide portion 1508, wherein the first, second and third waveguide portions 1504, 1506 and 1508 each have a substantially constant diameter, and wherein the diameter of the second waveguide portion 1506 is smaller than the diameter of either of the first and third waveguide portions 1504 and 1508. In some example embodiments, the diameter of the second waveguide portion 1506 is between substantially one and two millimeters, and the diameter of the first and third waveguide portions is between substantially three and five millimeters. In one choice of materials, the medical ultrasonic waveguide 1502 consists essentially of a titanium alloy. In one modification, the medical ultrasonic waveguide 1502 includes first and second longitudinal vibration antinodes 1510 and 1512, and the first neck portion 1550 is disposed proximate the first longitudinal vibration antinode 1510 and the second neck portion 1552 is disposed proximate the second longitudinal vibration antinode 1512.

FIG. 49 illustrates a schematic cross-sectional view of one example embodiment of an ultrasonic waveguide 1554 for use with a medical instrument and comprising first and second waveguide portions, where a first waveguide portion 1556 is joined to a second waveguide portion 1558 by a dowel press fit. In the example illustrated in FIG. 49, the second waveguide portion 1558 is also coupled to a third waveguide portion 1560 by a dowel press fit. In various example embodiments, the second waveguide portion 1558 consists essentially of titanium or nitinol. In the same or a different illustration, the length of the second waveguide portion 1558 is less than ½ wavelength (a wavelength being the length of a resonant-longitudinal-wavelength of the medical ultrasonic waveguide which depends essentially on the material of the waveguide and the frequency at which it is run) and in one example is less than ⅛ wave.

FIG. 50 illustrates a schematic cross-sectional view of one example embodiment of an ultrasonic waveguide 1564 for use with a medical instrument. Like the waveguide 1554, the waveguide 1564 is not a monolithic waveguide. The waveguide 1564 may comprise first and second waveguide portions 1564, 1566, where the first waveguide portion 1564 is joined to the second waveguide 1566 portion by a ball-and-socket type attachment. The second waveguide portion 1566 may also be joined to a third waveguide portion 1568 in any suitable manner. In the example of FIG. 50, the second waveguide portion 1566 is joined to the third waveguide portion 1568 via a dowel press fit. Other attachments between waveguide portions are left to those skilled in the art.

FIG. 51 illustrates a schematic cross-sectional view of a portion of another embodiment of an ultrasonic medical instrument 1570 comprising a medical ultrasonic waveguide 1572 having a length and including a proximal waveguide portion 1574 and a distal waveguide portion 1576. The proximal waveguide portion 1574 has a larger transverse area and the distal waveguide portion 1576 has a smaller transverse area. The distal waveguide portion 1576 bends more easily than does the proximal waveguide portion 1574. The distal waveguide portion 1576 includes a distal end portion 1580 adapted to contact and ultrasonically treat patient tissue. In various example embodiments, the addi-

tional ½ wave needed to neck up and create the larger diameter end effector of the embodiment of FIG. **47** is eliminated making it possible to place the articulation joint closer to the distal end of the ultrasonic medical instrument **1570**. The embodiments, applications, etc. shown in FIGS. **47-50** are equally applicable (without the presence of the third waveguide portion) to the embodiment of FIG. **51**.

FIG. **52** illustrates one embodiment of an instrument mounting portion **1000** for use with a robotic surgical system, such as the system **300**, comprising a magnetic element-driven control mechanism. The instrument mounting portion **1000** may interface with a robotic surgical system, for example, in a manner similar to that described above with respect to the instrument mounting portion **558**. The instrument mounting portion **1000** may comprise a housing **1001**. A shaft **1003** may extend distally form the housing **1001**. A distal portion of the shaft **1003** may comprise an end effector for treating tissue. The end effector (not shown) may be similar to any of the end effectors described herein including, for example, the end effector assembly **26**, end effector **18**, end effector **278**, end effector **326**, end effector **110**, etc.

The housing **1001** may contain one or more magnetic elements **1002**, **1004**, **1006**, **1008**, **1010**, **1012**. The magnetic elements, for example, may be magnetic elements configured to generate linear motion such as, for example, solenoids, voice coil motors, etc. Each of the magnetic elements **1002**, **1004**, **1006**, **1008**, **1010**, **1012** may be fixedly secured to an inner wall or other portion of the housing **1001** or to another component within the housing **1001**. Each of the magnetic elements **1002**, **1004**, **1006**, **1008**, **1010**, **1012** may comprise a plunger or piston **1015** that may alternately extend from and be retracted within the respective magnetic elements based on whether the elements are energized.

As illustrated in FIG. **52**, the plungers **1015** of the various magnetic elements **1002**, **1004**, **1006**, **1008** are fixedly secured to an inner wall of the housing **1001**. Accordingly, upon energizing and de-energizing, the respective elements may be pulled towards the inner wall and pushed away from the inner wall. Compression springs **1014** may be positioned around the plungers **1015** to resist motion of the plungers **1015**. For example, upon energizing, the respective plungers **1015** may be forced out of the respective magnetic elements. The compression springs **1014** may resist this motion such that when the respective magnetic elements are de-energized, the plungers are pushed (by the springs **1014**) back into the respective magnetic elements. Also, in some embodiments, the positioning of the springs **1014** and operation of the plungers **1015** are reversed. For example, the plungers **1015** may be pulled within the respective elements on energizing. Springs **1014** may resist the motion of the plungers **1015** and pull the plungers back to an extended position upon de-energizing.

Opposite the compression spring **1014** and plunger **1015**, each magnetic element may be coupled to respective control cables **1016**, **1018**, **1020**, **1022**, **1024**, **1026**. In FIG. **52**, element **1002** is coupled to cable **1016**; element **1004** is coupled to cable **1018**; element **1006** is coupled to cable **1020**, element **1008** is coupled to cable **1022**; element **1010** is coupled to cable **1024** and element **1012** is coupled to cable **1026**. The control cables may extend distally through the shaft to the distal portion of the shaft **1003**, an end effector (not shown), etc. In some embodiments, the installation of the magnetic elements **1002**, **1004**, **1006**, **1008**, **1010**, **1012** may be reversed. For example, the respective elements may be fixedly coupled to the housing **1001** or other mechanism while the respective plungers **1015** are coupled to control cables **1016**, **1018**, **1020**, **1022**, **1024**, **1026**.

Distal and proximal translation of the respective cables may cause various mechanical motion in the instrument. For example, differential motion of two or more cables and/or distal and proximal translation of a single cable or cables may bring about articulation of an end effector, a distal cable portion, etc., as described herein above. For example, some or all of the control cables may operate in a manner similar to the articulation bands **622**, **624** described above. Also, for example, some or all of the control cables may be utilized to actuate a jaw or clamp arm member, as described herein above. Additional examples of articulation, end effector and other instrument portions that may be controlled by the control cables are provided in concurrently filed and commonly owned U.S. Patent Application Serial Nos. incorporated herein by reference at the section entitled CROSS-REFERENCE TO RELATED APPLICATIONS.

Each magnetic element **1002**, **1004**, **1006**, **1008**, **1010**, **1012** may be individually energizable. In some embodiments, when a magnetic element is energized, it is pulled towards the inner wall of the housing **1001**, compressing its corresponding compression spring **1014** and pulling its corresponding cable proximally through the shaft **1003**. For example, energizing the respective elements may pull the respective plungers **1015** into the elements. When the magnetic element is de-energized, the force pulling it towards the inner wall of the housing **1001** may be relaxed, allowing slack in the corresponding cable. Also, for example, respective compression springs **1014** may push the respective elements away from the inner wall of the housing **1001**.

The magnetic elements **1002**, **1004**, **1006**, **1008**, **1010**, **1012** may be actuated by rotable bodies **1005**, **1007**. The rotatable bodies **1005**, **1007** may operate in a manner similar to that described above with respect to the rotatable bodies **612**. For example, the rotatable bodies **1005**, **1007** may be driven, for example, by the drive pins under the control of the robotic surgical system, such as the drive pins **586** shown in FIG. **26** and described herein above. The respective rotatable bodies **1005**, **1007** may be coupled to a mounting member **1028**. Each mounting member **1028** may be coupled to one or more actuation members **1030**, **1032**, **1034**, **1036**, **1038**, **1040** extending from respective mounting members **1028** to switches **1042**, **1044**, **1046**, **1048**, **1050**, **1052** of the respective magnetic elements. Rotation of the rotatable bodies **1005**, **1007** may alternately place distal and proximal forces on the actuation members **1030**, **1032**, **1034**, **1036**, **1038**, **1040** causing the switches on the respective magnetic elements to transition between "on" (element is energized) and "off" (element is not energized) positions.

FIGS. **53**A-G illustrate one embodiment of the rotatable body **1005** and magnetic elements **1002**, **1004**, **1006** of the instrument mounting portion **1000**, with the rotatable body **1005** at various angular positions to energize and/or de-energize combinations of the magnetic elements **1002**, **1004**, **1006**. In FIG. **53**A, the rotatable body **1005** is shown rotated counter clockwise such that actuation members **1030**, **1032**, **1034** are all pulled proximally, pulling switches **1042**, **1044**, **1046** proximally, and de-energizing elements **1002**, **1004**, **1006**. In FIG. **53**B, the rotatable body **1005** is rotated slightly clockwise from the position shown in FIG. **53**A. Actuation member **1034** is pushed distally to transition switch **1042** and energize element **1002**. Elements **1004** and **1006** are still de-energized. In FIG. **53**C, the rotatable body **1005** is rotated further clockwise. Actuation member **1032** is not also pushed distally to transition switch **1042** and energy

element **1004**. Element **1006** is still de-energized. In FIG. **53**D, further clockwise rotation of the rotatable body **1005** pushes control member **1030** distally to transition switch **1046**. Accordingly, all of the elements **1002**, **1004**, **1006** are energized. In FIG. **53**E, further clockwise rotation of the rotatable body **1005** begins to pull the actuation member **1034** proximally, transitioning switch **1042** to de-energize the element **1002**. Elements **1004**, **1006** are still energized. In FIG. **53**F, further clockwise rotation of the rotatable body **1005** begins to pull the actuation member **1032** proximally, transitioning switch **1044** to de-energize element **1004**. Element **1006** is still energized. In FIG. **53**G, further clockwise rotation of the rotatable body **1005** pulls the control member **1030** distally to transition switch **1046** and de-energize the element **1006**. All elements **1002**, **1004**, **1006** are de-energized in FIG. **53**G.

It will be appreciated that the examples provided in FIGS. **53**A-G are merely examples of how the rotatable body **1005** may serve to energize and de-energize the various elements **1002**, **1004**, **1006**. In some embodiments, the rotatable body **1007** may operate in a similar manner to actuate the elements **1008**, **1010**, **1012**. Also, in some embodiments, the positions of the switches **1042**, **1044**, **1046** illustrated in FIGS. **53**A-G may be reversed, this reversing the described state of each element **1002**, **1004**, **1006** at each position.

FIG. **54** illustrates another embodiment of an instrument mounting portion **1060** for use with a robotic surgical system, such as the system **500**, comprising a magnetic element-driven control mechanism. In FIG. **53**, actuation of magnetic elements **1062**, **1064**, **1066**, **1068** may be initiated by an electronic signal provided to the respective magnetic elements **1062**, **1064**, **1066**, **1068**, for example, via a control line of the robotic surgical system **500**. In some embodiments, control signals may be provided to the magnetic elements via compression springs **1063**. Magnetic elements **1062**, **1064**, **1066**, **1068** may operate in a manner similar to the magnetic elements of the instrument mounting portion **1000** described above. For example, when energized, the magnetic elements **1062**, **1064**, **1066**, **1068** may retract respective plungers **1065** within the elements **1062**, **1064**, **1066**, **1068**, thus pulling the elements towards the interior wall of the housing **1001**, compressing compression springs **1063** and pulling respective cables **1070**, **1072**, **1074**, **1076** proximally. The elements **1062**, **1064**, **1066**, **1068**, however, may be configured and/or mounted in any suitable configuration, however.

In some embodiments, the magnetic elements **1062**, **1064**, **1066**, **1068** may utilize compression springs **1063** to exercise increased control over the positions of the respective cables **1070**, **1072**, **1074**, **1076**. For example, as described herein, the magnetic elements **1062**, **1064**, **1066**, **1068** may be driven by electric signals provided by the robotic surgical system **500**. The signal, for example, may provide an electric current to a coil or other electromagnetic element that may, in turn, exert an electromagnetic force on the respective plungers **1065**. The magnitude of the current may control the magnitude of the force exerted on the plungers **1065**. It will be appreciated that the compression (or displacement) of the springs **1063** may be proportional to the force provided by the respective magnetic elements. Accordingly, the displacement of the plungers **1063** and, therefore, the distal and/or proximal position of the control cables **1076**, **1074**, **1072**, **1070** may be controlled based on the magnitude of the current (or other control signal) provided to the respective magnetic elements.

In the configuration illustrated in FIG. **54**, cables **1070**, **1072**, **1074** extend distally through the shaft **1003**, for example, to control an articulation joint, end effector, etc. Control cable **1076** may be routed by a pulley **1078** and may be positioned around a proximal portion **1080** of the shaft. When the magnetic element **1068** is energized, the cable **1076** may be pulled proximally. When routed by the pulley, this may unwrap the cable **1076** from the proximal portion **1080** of the shaft, causing the shaft **1003** to rotate in the direction indicated by arrow **1082**.

FIG. **55** illustrates yet another embodiment of an instrument mounting portion **1084** for use with a robotic surgical system **500** comprising a magnetic element-driven control mechanism and a spool-driven control mechanism. In FIG. **55**, solenoids **1090**, **1092** may be coupled to control cables **1096** and **1098** and may operate in a manner similar to that described above with respect to elements **1062**, **1064**, **1066**. Additionally, rotatable bodies **1086**, **1088** may define spools for receiving cables **1094**, **1099** such that rotation of the rotatable bodies **1086**, **1088** causes winding and unwinding of the respective control cables **1096**, **1099**, resulting in proximal and distal translation of the same.

FIGS. **56-57** illustrate one embodiment of an instrument mounting portion **1100** for use with a robotic surgical system, such as the system **500**, comprising a translatable cable **1110** driven by a pair of rotatable bodies **1102**, **1104**. An elastic band **1112** may be coupled to fixed positions on each of the rotatable bodies **1102**, **1104**. For example, the elastic band **1112** may be coupled to respective pegs **1106**, **1108** mounted on the rotatable bodies **1104**, **1102**. The elastic band **1112** may be made from any suitable material including, for example rubber or any other suitable elastomer. The translatable cable **1110** may be coupled to the elastic band **1112**. As the rotatable bodies **1104** rotate, the pegs **1106**, **1108** may translate proximally and distally and also from top to bottom across the housing **1001** of the instrument mounting portion **1100**. The elastic nature of the band **1112** may cancel the up and down motion of the pegs **1106**, **1108** while the distal and proximal motion may be translated to the cable **1110**. Thus, the cable **1110** may also translate proximally and distally in the shaft **1003**.

FIG. **58** illustrates another embodiment of an instrument mounting portion **1114** for use with a robotic surgical system, such as the system of **500**, comprising a translatable cable **1124** driven by a pair of rotatable bodies **1116**, **1118**. The cable **1124** is coupled to an interior wall of the housing **1001** at a mounting point **1124**. Posts or pulleys **1120**, **1122** are positioned on respective rotatable bodies **1116**, **1118**. The cable **1124** is routed around the pulleys **1120**, **1122** and extends distally through the shaft **1003**. As the rotatable bodies **1116**, **1118** rotate, the pulleys **1120**, **1122** translate distally and proximally as well as up and down as shown in FIG. **58**. This translation may cause the cable **1124** to translate proximally and distally within the shaft **1003**. For example, in the embodiment shown in FIG. **58**, up and down translation of the pulleys **1120**, **1122** may alternately create tension and slack in the cable **1124**, accentuating its distal and proximal translation.

FIGS. **59-62** illustrate one embodiment of an articulation mechanism **1130** that may be utilized by manual and/or robotic surgical instruments to articulate an end effector. In various embodiments, the mechanism **1130** may be utilized with an ultrasonic instrument, for example, as illustrated in FIG. **59**. In FIG. **59**, a proximal end (not shown) of a waveguide **1136** may be coupled to an ultrasonic transducer (not shown) as the waveguide **78** is coupled to the ultrasonic transducer **16** described above. The waveguide **1136** may also comprise a bendable portion **1138** similar to the bendable portions including **1506** described above with respect to

FIGS. **47-51**. The bendable portion **1138** may be positioned at an articulation joint within a shaft of the instrument, for example, similar to the articulation joint **556** described herein above.

The mechanism **1130** may comprise first and second helical cables **1132**, **1134**. The cables **1132**, **1134**, for example, may be constructed from a helically wound wire. The helical cables **1132**, **1134** may be coupled to a distal plate **1140**. The distal plate **1140** may be coupled to an end effector and/or distal shaft portion of the instrument. In some embodiments, the distal plate **1140** is coupled to the waveguide **1136**, as shown in FIG. **59**. For example, the distal plate **1140** may be coupled to a node of the waveguide **1136**. The helical cables **1132**, **1134** may extend proximally where they may engage with a gear **1141**. Respective plates **1142** may be positioned around the gear **1141** such that the cable **1132** passes between the gear **1141** and the plate **1142** and cable **1134** passes between the gear and the plate **1144**. Teeth of the gear **1141** may interface with the helical cables **1132**, **1134** such that clockwise rotation of the gear causes proximal translation of the cable **1134** and distal translation of the cable **1132**. This, in turn, may pull the plate **1140** proximally towards the cable **1134**, causing articulation. Similarly, counter-clockwise rotation of the gear **1141** may pull the cable **1132** proximally and push the cable **1134** distally. This may cause the plate **1140** to pivot towards the cable **1132** causing articulation opposite that when the gear **1141** rotates clockwise.

Rotation of the gear **1141** may be brought about in any suitable manner. For example, FIGS. **60** and **61** illustrate the mechanism **1130** for use in a hand held or manual instrument **1148**. Referring to FIG. **61**, a manual instrument **1148** may comprise an articulation lever **1152**. The articulation lever **1152** may be coupled to the gear **1141**, as illustrated in FIG. **60**, such that rotation of the articulation lever **1152** causes corresponding articulation of the gear **1151**. Rotation of the gear **1141**, and resulting differential translation of the helical cables **1132**, **1134** may cause articulation of the end effector **1154** about an articulation joint **1146**. FIG. **62** illustrates one embodiment of an instrument mounting portion **1156** comprising the mechanism **1130**. For example, the gear **1141** may be coupled to a rotatable body **612**. Cables **1132**, **1134** may be routed to extend distally through the shaft **1003**.

FIGS. **63**A-B illustrate one embodiment of an articulation mechanism **1150** that may be utilized with any suitable control mechanism, including those described above with respect to FIGS. **52-58**. The mechanism **1150** is shown in the context of an end effector **1152** and a shaft portion **1154** separated by a flexible articulation joint **1170**. The end effector **1152** may be any suitable type of ultrasonic, electrosurgical or combined end effector, as described herein. A plate **1156** may be positioned distally from the articulation joint **1170** and may be coupled to a plurality of control cables **1158**, **1160**, **1162**, **1164**, **1166**, **1168**. In some embodiments, the control cables **1158**, **1160**, **1162**, **1164**, **1166**, **1168** may be coupled to and/or the distal ends of control cables **1016**, **1018**, **1020**, **1022**, **1024**, **1026** described herein above. In some embodiments, the plate defines an opening **1172** for receiving wires, waveguides, etc. for operation of the end effector **1152**.

The end effector **1152** and shaft portion **1154** may be articulated relative to one another by differential translation of the control cables **1158**, **1160**, **1162**, **1164**, **1166**, **1168**. For example, proximal translation of a control cable may cause the portion of the plate **1156** coupled to the control cable to be pulled proximally. The number and position of control cables **1158**, **1160**, **1162**, **1164**, **1166**, **1168** that are pulled proximally may determine the direction in which the end effector **1152** is articulated. Although six cables are illustrated in FIGS. **63**A-B, it will be appreciated that any suitable number of cables may be used. For example, FIGS. **64-65** illustrate embodiments of the plate **1156** configured for use with three and four cables, respectively. For example, the plate **1156**, as illustrated in FIG. **64** comprises mounting points **1174** for three cables while the plate **1156**, as illustrated in FIG. **65**, comprises mounting points for four cables.

FIGS. **66-67** illustrate one embodiment of a shaft portion **1180** of a surgical instrument utilizing an articulation mechanism similar to the mechanism **1130** described herein above. The shaft portion **1180** may comprise four articulation control cables **1190**, **1192**, **1194**, **1196**. The articulation control cables **1190**, **1192**, **1194**, **1196** may be coupled to either an end effector **1182** or a distal shaft portion and may extend proximally to a handle and/or robotic instrument mounting portion. The cables **1190**, **1192**, **1194**, **1196** may be distally and proximally translated in any suitable manner including, for example, utilizing the mechanisms described herein above with respect to FIGS. **52-58** and **60-61**.

In various embodiments, the shaft portion **1180** may comprise an end effector **1182** comprising an ultrasonic blade **1197**. The ultrasonic blade **1197** may be coupled to a distally mounted ultrasonic transducer assembly **1184**. An articulation joint **1186** may coupled the end effector **1182** to the shaft **1188**. The articulation joint **1186** may be made from any type of flexible material and/or may comprise a hinge (not shown). The articulation control cables **1190**, **1192**, **1194**, **1196** may be coupled to any portion of the shaft portion **1180** distal of all or a part of the articulation joint **1186**. For example, a plate **1198** (similar to the plate **1156** of FIG. **65**) may be mounted as illustrated and may be coupled to the respective control cables **1190**, **1192**, **1194**, **1196**. A clamp arm control cable **1199** may be positioned to manipulate a clamp arm **1195** that may be actuated in a manner similar to that described above with respect to FIGS. **2-7**.

It will be appreciated that proximal translation of the respective cables **1190**, **1192**, **1194**, **1196** may articulate the end effector **1182** in different directions. For example, proximal translation of the cable **1194** may pull the end effector **1182** towards the cable **1194**, as illustrated in FIG. **67**. Likewise, proximal translation of any of the other cables **1190**, **1192**, **1196** may pull the end effector **1182** towards the proximally translated cable. FIG. **66** illustrates four example directions of articulation with the UP direction corresponding to proximal translation of the cable **1194**, the DOWN direction corresponding to proximal translation of the cable **1190**, the LEFT direction corresponding to proximal translation of the cable **1196** and the RIGHT direction corresponding to proximal translation of the cable **1192**. In various embodiments, the end effector **1182** of FIGS. **66-67** may be articulated in directions other than the four indicated by the UP, DOWN, LEFT and RIGHT arrows, for example, by proximally translating more than one of the cables **1190**, **1192**, **1194**, **1196**. Also, the degree of proximal translation of any given cable **1190**, **1192**, **1194**, **1196** may affect the degree of articulation toward the cable, with more proximal translation corresponding to more sever bending at the articulation joint **1186**.

FIG. **68** illustrates one embodiment of a surgical instrument **1200** for use with a robotic surgical system, such as the system **500**, comprising a translatable end effector **1202**. The instrument may comprise an instrument mounting portion **1204** comprising a housing **1001**. A shaft **1003** may extend from the instrument mounting portion **1204**. The instrument mounting portion **1204** is shown coupled to a robotic arm

1214 comprising a trocar 1216. The trocar 1216 is illustrated deployed within a patient 1218. The shaft 1003 and end effector 1202 extend through the trocar 1216 to access tissue of the patient 1218.

The instrument 1200 illustrated in FIG. 68 may be an ultrasonic instrument. For example, the end effector 1202 may comprise an ultrasonic blade 1220 and optional clamp arm 1222, for example, in the manner described herein above. The ultrasonic blade 1220 may be coupled to a waveguide 1212 that may extend proximally to be acoustically coupled to an ultrasonic transducer 1208. In one embodiment, the transducer 1208, waveguide 1212, shaft 1003 and end effector 1202 are coupled to one another and are translatable relative to the instrument mounting portion 1204 along the direction of a longitudinal axis. For example, a proximal shaft portion 1211 may comprise an exterior rack gear 1210. The rack gear 1210 may be coupled to a gear 1206. The gear 1206 may be coupled to a rotatable body 612 of the instrument mounting portion 1204 to rotate the gear. When the gear 1206 rotates, it may interface with the rack gear 1210 to alternately translate the shaft 1003, transducer 1208, end effector 1202 and waveguide 1212 distally and proximally, for example, as indicated by arrow 1224.

FIG. 69A illustrates one embodiment of an articulatable shaft portion 1230 that may be used in conjunction with a surgical instrument. The shaft portion 1230 comprises a proximal tube 1232, a distal tube 1234 and a flexible portion 1233. FIG. 69B illustrates an additional view of one embodiment of the flexible articulation joint section 1233 of the shaft portion 1230. An end effector 1236 may be coupled to a distal portion of the distal tube 1234. The end effector 1236 may be any suitable type of ultrasonic, electrosurgical or combined end effector, as described herein. In various embodiments, wires, waveguides, actuation members such as axially movable member 378, etc. may pass to the end effector 1236 within the tubes 1232, 1234 and flexible portion 1233.

Articulation cables 1254 and 1256 may extend through the proximal tube 1232, distal tube 1234 and articulation portion 1233. The cables 1254, 1256 may be made of any suitable material and, in some embodiments, may comprise braided steel or other metal. The proximal tube 1232 may define first and second channels 1238, 1240 for receiving the articulation cables 1254, 1256. The articulation portion 1233 may define corresponding channels 1242, 1242. Likewise the distal tube 1234 may define corresponding channels 1246, 1248. The articulation cables 1254, 1256 may extend through the respective channels. For example, cable 1254 may extend through channels 1238, 1242 and 1246. Cable 1256 may extend through channels 1240, 1244 and 1248. In various embodiments, cables 1254, 1256 may be coupled to the distal tube 1234 and/or end effector 1236 in any suitable manner. For example, the cables 1254, 1256 may be welded to the distal tube 1234 and/or end effector 1236. Also, in some embodiments, channels 1246, 1248 extend completely through the distal tube 1234 such that cables 1254, 1256 extend beyond the distal tube 1234. The cables 1254, 1256 may terminate with crimp balls 1250, 1252 or other features having a diameter larger than the diameter of the channels 1246, 1248.

The components of the shaft portion 1230 may be constructed in any suitable manner. In some embodiments, the components of the shaft portion 1230 may be formed from rolled flat stock with the respective channels comprising coil pipes or other tubes welded to the flat stock. For example, FIG. 70 illustrates one embodiment of a piece of flat stock 1260 with a pair of coil pipes 1262, 1264 welded thereto. The flat stock 1260 may be any suitable flexible material that can ultimately be used to construct the proximal tube 1232 or distal tube 1234 of the shaft portion 1230. For example, the flat stock 1260 may be made of steel. The coil pipes 1262, 1262 may be welded to the flat stock, as shown. In various embodiments, any suitable tubular structure may be used in place of coil pipes. FIG. 71 illustrates one embodiment of the flat stock 1260 rolled into a tube shape. A seam 1266 may be fastened using any suitable method including, for example a weld. The rolled stock 1260, as illustrated in FIG. 71, may form all or a part of the proximal tube 1232, the distal tube 1234 and/or the flexible articulation portion 1233 of FIG. 69A.

Referring now to FIG. 69B, the flexible articulation section 1233 may also be constructed in any suitable manner. For example, the flexible articulation section 1233 may be constructed from a elastomeric material, such as rubber, allowing it to flex as described. Also, in some embodiments, the flexible articulation section 1233 may be made from a metal formed into an accordion-like shape, as illustrated in FIG. 69B, so as to allow flexibility.

Referring again to FIG. 69A, articulation of the end effector 1236 and distal tube 1234 may be brought about by differential translation of the articulation cables 1254, 1256. For example, proximal translation of the cable 1254 may cause articulation at the flexible articulation portion 1233, pulling the end effector 1236 and distal tube 1234 proximally toward the cable 1254. Similarly, proximal translation of the cable 1256 may cause articulation at the flexible articulation portion 1233, pulling the end effector 1236 and distal tube 1234 proximally toward the cable 1256. In some embodiments, when one of the cables 1254, 1256 is pulled proximally, the other cable may be extended distally. The presence of the channels 1238, 1240, 1242, 1244, 1246, 1248 may, in some embodiments, prevent the cables 1254, 1256 from binding as the cables are pushed distally.

The cables 1254, 1256 may be differentially translated in any suitable manner. For example, FIG. 72 illustrates one embodiment of an instrument mounting portion 1266 that may be utilized to effect differential translation of the cables 1254, 1256. Cables 1256, 1254 may be routed by pulleys 1270, 1272 to a spool 1268 mounting on a rotatable body 612 of the instrument mounting portion 1266. In some embodiments, cables 1254, 1256 may be ends of a common cable wound around the spool 1268. Rotation of the spool 1268 may alternately cause distal and proximal translation of the cables 1254, 1256. Differential translation of the cables 1254, 1256 may also be effected, for example, as described above with respect to FIGS. 25-46B. In some embodiments, the shaft portion 1230 may be utilized in conjunction with a hand held or manual instrument. In such embodiments, a spool, such as spool 1268 may be actuated by a lever, such as the lever 1152 shown in FIGS. 60-61.

FIG. 73 illustrates one embodiment of an instrument mounting portion 1270 comprising a battery assembly 1272 for powering the at least one energy element (e.g., ultrasonic and/or electrosurgical). In the configuration shown in FIG. 73, the instrument mounting portion 1270 is coupled to an ultrasonic transducer 1274 for use with an ultrasonic blade (not shown). Some robotic surgical systems provide instrument mounting portions, such as 1270 with limited power (e.g., 12 volts). Often the power provided is not sufficient to power energy elements such as ultrasonic transducers/blades, electrosurgical elements, etc., that may be utilized with instrument end effectors to treat tissues. Accordingly, instrument mounting portions for instruments utilizing energy elements often require exterior power sources, such

as exterior cables. The instrument mounting portion **1270** comprises the battery assembly **1272** for powering at least one energy element. The battery assembly **1272** may comprise any suitable type of battery cell or cells including, for example, a lithium-ion cell.

In some embodiments, the battery assembly **1272** may be charged utilizing an inductive coil **1276**. The inductive coil **1276** is shown wrapped around the transducer **1274** but may be placed in any suitable location. The coil **1276** may be coupled to the battery assembly by leads **1273**, **1275**. A second inductive coil **1278** is displayed installed on the transducer **1274** next to the first coil **1276**. The second coil **1276** may be electrically coupled to a power source, such as a wall outlet, and may provide a power signal for inductively charging the battery assembly **1272** via the first coil **1276**. In some embodiments, the power source may be located within the robotic surgical system such as, for example, in an arm of the robot. Also, in some embodiments, the power source within the robot may be electrically connected to charge the battery when the robotic surgical system is not in use and connected to charge the battery when the robotic surgical system is in use.

FIG. **74** illustrates one embodiment of the instrument mounting portion **1270** further comprising a generator circuit **1271**. The generator circuit **1271** may operate in a manner similar to that described above with respect to generators **20**, **320** to drive an energy element, for example, with power from the battery assembly **1272**. For example, when an ultrasonic instrument **522** is utilized, the generator circuit **1271** may provide an ultrasonic drive signal in a manner similar to that described above with respect to generator **20**. Also, for example, when an RF instrument **523** or ultrasonic instrument **522** capable of providing a therapeutic or non-therapeutic RF signal is used, the generator circuit **1271** may provide an RF drive signal, for example, as described herein above with respect to the module **23** of generator **20** and/or the generator **320**. In some embodiments, the generator circuit **1271** may be configured in a manner similar to that of the control circuit **440** described herein above with respect to FIGS. **18**B-**18**C. In some embodiments, the generator circuit **1271** and/or battery assembly **1272** may comprise a sensor for sensing a charge of the battery assembly **1272**. The sensor may be any suitable type of sensor. In some embodiments, the sensor comprises a resistor configured such that a voltage drop across the resistor indicates a voltage provided by the battery assembly **1272**. The sensor may be in communication with a communications bus (not shown) of the robotic surgical system **500** such that a state of the battery assembly **1272** may be derived by the robotic surgical system and displayed to the clinician (e.g., via display **521**).

FIG. **75** illustrates one embodiment of an instrument mounting portion **1280** with a cord-based generator circuit **1284**. The cord **1282** may be electrically coupled to the instrument mounting portion **1280**, for example, to provide suitable power to power an energy element for treating tissue. The generator circuit **1284** may operate in a manner similar to that of the generator circuit **1271** described herein above. Instead of being within the instrument mounting portion **1280**, however, the generator circuit **1284** may be positioned in series with the cord **1282**.

FIG. **76** illustrates one embodiment of an instrument mounting portion **1286** comprising a removable battery assembly **1290**. The battery assembly **1290** may power one or more energy elements positioned at an end effector **1288**. The battery assembly **1290** may comprise any suitable battery cell or cells, for example, as described above with respect to the battery assembly **1272**. The assembly **1290** may be received within an exterior socket **1292** in the housing **1001** of the instrument mounting portion **1286**. When the battery assembly **1290** requires re-charging, it may be removed from the exterior socket **1292** and charged. In some embodiments, the battery assembly **1290** and/or the housing **1001** may further comprise a generator circuit, such as the generator circuit **1271**.

FIG. **77** illustrates one embodiment of a surgical system **1294** with a wireless foot pedal **1296** for actuating an energy element. The system **1294** may also comprise an instrument mounting portion **1293** coupled to a shaft comprising an end effector **1295**. The end effector **1295** may comprise at least one energy element for treating tissue. The foot pedal **1296** may be coupled to a transmitter **1298**. The transmitter **1298** may be external to the pedal **1296** as shown, or may be embodied as a circuit and/or antenna within the foot pedal **1296** itself. When the pedal **1296** is actuated (e.g., by clinician's foot **1291**) the transmitter **1298** may emit a signal that may be received by a receiver **1297** positioned in or in communication with the instrument mounting portion **1293** or other component of the robotic surgical system (e.g., **500**). Upon receipt of the signal, the instrument mounting portion **1293** or other component of the robotic surgical system may energize an energy element of the end effector **1295**.

FIGS. **78**-**83** illustrate one embodiment of a passive articulation mechanism for use with a robotic surgical system and/or manual surgical instrument. FIG. **78** illustrates one embodiment of a shaft portion **1300**. The shaft portion **1300** comprises a distal end **1301** that may be directly or indirectly coupled to an end effector for treating tissue (not shown) such as one of the end effectors described herein. A proximal shaft portion **1314** may extend proximally and may be coupled to an instrument mounting portion or handle (not shown). Member **1310** represents various connections that may be made between the end effector and handle or instrument mounting portion. Such connections may include, for example, a waveguide for acoustically coupling a transducer and an ultrasonic blade, wires for providing drive signals to one or more electrosurgical electrodes, etc.

An articulation joint **1302** may comprise a plurality of interfacing joint members **1304**. The joint members **1304** may be configured to slide over one another to change the orientation of the articulation joint **1302**. FIG. **79** shows an example of a flexible boot **1305** that may be positioned over the articulation joint **1302**. The boot **1305** may flex with the articulation joint **1302**. In various embodiments, the boot **1305** may prevent individual joint members **1304** from sliding too far relative to one another. Also, in some embodiments, the boot **1305** may contain oil or another lubricant for allowing the joint members **1304** to slide relative to one another.

In some embodiments, as shown in FIG. **80**, some or all of the joint members **1304** define distally-facing concave faces and proximally-facing convex faces. Accordingly, adjacent joint members may slide over one another to articulate the joint **1302**, as shown in FIG. **80**. Articulation cables **1306**, **1308** may extend through the proximal shaft portion **1314** and joint members **1302**. For example, each joint member may define channels **1312** for receiving the cables **1306**, **1308**. In various embodiments, the articulation joint **1302** is a passive articulation joint. For example, when the cables **1306**, **1308** are loosened or have slack, the clinician may articulate the joint **1302**, either with his or her hand or by pushing the end effector (not shown) or distal shaft portion **1307** against tissue at a surgical site. This may

cause the joint members **1304** to slide over one another as shown in FIG. **80**. When the cables **1306**, **1308** are tightened, the joint members **1304** may not be free to slide over one another, thus locking the joint **1302** in place. For example, the joint **1302** may be locked in an articulated position, as shown in FIG. **78**, or in a straight position, as shown in FIG. **80**.

FIGS. **81-82** illustrate one embodiment of a mechanism **1329** for alternately loosening and tightening the cables **1306**, **1308** so as to alternately allow and prevent articulation at the joint **1302**. The mechanism **1329** may be positioned, for example, at a handle and/or instrument mounting portion. For example, the cables **1306**, **1308** may extend proximally through the proximal shaft portion **1314** and between a rotor **1320** and a pair of posts **1322**, **1324**. The rotor **1320** may comprise convex faces **1330** and concave faces **1332**. When the rotor **1320** is rotated such that its concave faces **1332** face the posts **1322**, **1324**, the cables **1306**, **1308** may be free to slide freely between the rotor **1320** and the respective posts **1322**, **1324**. The rotor **1320** may also be rotated to the position shown in FIG. **82**, however, where a portion of the rotor **1320** (e.g., the convex portion **1330** and/or an edge of the concave portion **1332**) pinches the respective cables **1306**, **1308** between the rotor **1320** and respective posts **1322**, **1322**. In this position, no slack in the cables **1306**, **1308** may be available, thus locking the position of the articulation joint **1302**.

FIG. **83** illustrates one embodiment of an instrument mounting portion **1340** that may contain the mechanism **1329**. For example, the rotor **1320** may be mounted on a rotatable body **612** to be controlled by the robotic surgical system, as described herein. Cables **1306**, **1308** may terminate, for example, against the housing **1001** at termination points **1342**, **1344** as shown. The termination points **1342**, **1344** may be positioned at any suitable location. For example, the termination points **1342**, **1344** may be positioned against the housing **1001**, as shown, or against any other mechanism or component of the instrument mounting portion **1340**. In some embodiments, the cables **1306**, **1308** and/or distal portions thereof may comprise respective springs or elastic portions **1346**, **1348**. The elastic portions **1346**, **1348** may allow the cables **1306**, **1308** to extend distally, for example, when the articulation joint **1302** is in an articulated position.

Non-Limiting Embodiments

Various embodiments are directed to surgical instruments for use in handheld applications or with robotic surgical systems. The surgical instruments may comprise an end effector to treat tissue and a shaft extending proximally from the end effector along a longitudinal axis. In various embodiments, a surgical instrument may further comprise a waveguide extending proximally from an ultrasonic blade through the shaft. The waveguide may define a bendable portion at about the flexible articulation joint. A first plate may be positioned distally from the flexible articulation joint at a node of at least one of the waveguide and the ultrasonic blade. First and second helical cables may be coupled to the first plate at points offset from the longitudinal axis and may extend proximally. A gear may be positioned proximally from the flexible articulation joint and may have a first side that interlocks with the first helical cable and a second side that interlocks with a second helical cable such that rotation of the gear causes differential translation of the first and second helical cables.

In other embodiments, the shaft of the surgical instrument comprises a proximal tube and a distal tube. An end effector may be coupled to a distal portion of the distal tube and a flexible articulation portion may be positioned between the proximal tube and the distal tube. In various embodiments, the proximal tube defines a first channel positioned near an interior wall of the proximal tube. The surgical instrument may also comprise a first articulation cable coupled to at least one of the end effector and the distal tube and extending proximally through the first channel of the proximal tube such that proximal translation of the first articulation cable pulls the distal tube and the end effector away from the longitudinal axis towards the first articulation cable.

In another embodiment, the flexible articulation portion comprises a plurality of interfacing joint members. Each of the joint members may define first and second channels. A first articulation cable may be coupled to at least one of the end effector and the distal tube and may extend through the first channels of the plurality of joint members. A second articulation cable may be coupled to at least one of the end effector and the distal tube and may extend through the second channels of the plurality of joint members. The first and second articulation cables may be transitionable between an unlocked position where the first and second cables are free to translate distally and proximally and the plurality of joint members are slidable relative to one another to pivot the distal tube and end effector away from the longitudinal axis, and a locked position where translation of the first and second cables is locked, causing the position of the end effector and distal tube relative to the longitudinal axis to also be locked.

Various embodiments are directed to surgical instruments for use with robotic surgical systems. The surgical instruments may comprise an end effector to treat tissue, a shaft extending proximally from the end effector along a longitudinal axis and a housing. The shaft may be coupled to a distal end of the housing. In various embodiments, a surgical instrument comprises a first magnetic element positioned within the housing. A first cable may be coupled to the first magnetic element and may extend distally from the first magnetic element and distally through the shaft such that actuation of the magnetic element causes the first cable to translate along the longitudinal axis. The first magnetic element may be actuated by a rotatable body positioned within the housing. An actuation member may extend from the rotatable body to a switch of the first magnetic element such that rotation of the rotatable body alternately transitions the switch from a first position where the first magnetic element is actuated to a second position where the first magnetic element is not actuated.

In various embodiments, a surgical instrument comprises a first rotatable body positioned within the housing and comprising a first peg offset from a center of rotation of the first rotatable body. A second rotatable body may also be positioned within the housing and may comprise a second peg offset from a center of rotation of the second rotatable body. An elastic band may be coupled to the first peg and the second peg. Further, a cable may be coupled to the elastic band and extend distally through the shaft. Rotation of the first and second rotatable bodies that moves the first and second pegs proximally also pulls the elastic band and cable proximally.

In various embodiments, a surgical instrument comprises a first rotatable body positioned within the housing and comprising a first peg offset from a center of rotation of the first rotatable body. A second rotatable body may also be positioned within the housing and may comprise a second

peg offset from a center of rotation of the second rotatable body. A rotational axis of the first rotatable body may be positioned distally from a rotational axis of the second rotatable body. A cable may be fixedly secured to an interior portion of the housing, routed by the first and second pegs, and extend distally through the shaft such that rotation of the first and second rotatable bodies causes the cable to translate along the longitudinal axis.

In various embodiments, the end effector comprises an ultrasonic blade. The instrument may further comprise an ultrasonic transducer coupled to a proximal end of the shaft, a waveguide acoustically coupled to the ultrasonic transducer and the ultrasonic blade and extending through the shaft. The shaft may extend through the housing. The shaft, ultrasonic transducer, waveguide, and end effector may be translatable distally and proximally along the longitudinal axis.

In various embodiments, the end effector comprises at least one energy element for providing energy to tissue. The instrument may further comprise a battery assembly for powering the at least one energy element. The battery assembly may comprise a rechargeable battery positioned within the housing. The rechargeable battery may be electrically coupled to the at least one energy element. The battery assembly may also comprise an inductive coil coupled to the rechargeable battery. The inductive coil may be positioned to be placed in proximity with a second inductive coil providing electrical energy for recharging the battery.

In various embodiments where the end effector comprises at least one energy element, the instrument further comprises a power cord electrically coupled to the at least one energy element and extending from the housing. The power cord may comprise therein a generator for providing a drive signal to the at least one energy element. Also, in various embodiments where the end effector comprises at least one energy element, the instrument further comprises a removable battery assembly for powering the at least one energy element. The removable battery assembly may be receivable into the exterior socket of the housing to be in electrical communication with the at least one energy element.

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

U.S. patent application Ser. No. 13/536,271, filed on Jun. 28, 2012 and entitled "Flexible Drive Member," now U.S. Patent Application Publication No. 2014/0005708;

U.S. patent application Ser. No. 13/536,288, filed on Jun. 28, 2012 and entitled "Multi-Functional Powered Surgical Device with External Dissection Features," now U.S. Patent Application Publication No. 2014/005718;

U.S. patent application Ser. No. 13/536,295, filed on Jun. 28, 2012 and entitled "Rotary Actuatable Closure Arrangement for Surgical End Effector," now U.S. Pat. No. 9,119,657;

U.S. patent application Ser. No. 13/536,326, filed on Jun. 28, 2012 and entitled "Surgical End Effectors Having Angled Tissue-Contacting Surfaces," now U.S. Patent Application Publication No. 2014/0005653;

U.S. patent application Ser. No. 13/536,303, filed on Jun. 28, 2012 and entitled "Interchangeable End Effector Coupling Arrangement," now U.S. Pat. No. 9,028,494;

U.S. patent application Ser. No. 13/536,393, filed on Jun. 28, 2012 and entitled "Surgical End Effector Jaw and Electrode Configurations," now U.S. Patent Application Publication No. 2014/0005640;

U.S. patent application Ser. No. 13/536,362, filed on Jun. 28, 2012 and entitled "Multi-Axis Articulating and Rotating Surgical Tools," now U.S. Pat. No. 9,125,662; and

U.S. patent application Ser. No. 13/536,417, filed on Jun. 28, 2012 and entitled "Electrode Connections for Rotary Driven Surgical Tools," now U.S. Pat. No. 9,101,385.

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.

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.

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.

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.

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.

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, accord-

ing 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.

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.

What is claimed is:

1. A surgical instrument for use with a robotic surgical system, the surgical instrument comprising:

an end effector to treat tissue;

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

a housing, wherein the shaft is coupled to a distal end of the housing;

a first magnetic element positioned within the housing, wherein the first magnetic element comprises a switch;

a first cable coupled to the first magnetic element and extending distally from the first magnetic element and distally through the shaft such that actuation of the first magnetic element causes the first cable to translate along the longitudinal axis;

a rotatable body positioned within the housing and rotatable between a first angular position and a second angular position;

a first actuation member extending from the rotatable body to the switch of the first magnetic element such that, at the first angular position of the rotatable body, the first actuation member causes the switch of the first magnetic element to assume a first position where the first magnetic element is actuated, and, at the second angular position of the rotatable body, the first actuation member causes the switch of the first magnetic element to assume a second position where the first magnetic element is not actuated;

a second magnetic element positioned within the housing, wherein the second magnetic element comprises a switch;

a second cable coupled to the second magnetic element and extending distally from the second magnetic element and distally through the shaft such that actuation of the second magnetic element causes the second cable to translate along the longitudinal axis; and

a second actuation member extending from the rotatable body to the switch of the second magnetic element such that, at the first angular position of the rotatable body, the second actuation member causes the switch of the second magnetic element to assume a first position where the second magnetic element is actuated, and, at the second angular position of the rotatable body, the second actuation member causes the switch of the second magnetic element to assume a second position where the second magnetic element is not actuated.

2. The surgical instrument of claim **1**, wherein the rotatable body is also rotatable to a third angular position at which the first actuation member causes the switch of the first magnetic element to assume the second position where the first magnetic element is not actuated and the second actuation member causes the switch of the second magnetic element to assume the first position where the second magnetic element is actuated.

3. The surgical instrument of claim **1**, further comprising:

a third magnetic element positioned within the housing, wherein the third magnetic element comprises a switch;

a third cable coupled to the third magnetic element and extending distally from the third magnetic element and distally through the shaft such that actuation of the third magnetic element causes the third cable to translate along the longitudinal axis; and

a third actuation member extending from the rotatable body to the switch of the third magnetic element.

4. The surgical instrument of claim **3**, wherein, at the first angular position, the first and second magnetic elements are actuated and the third magnetic element is not actuated, and wherein the rotatable body is rotatable:

to a third angular position where the first magnetic element is actuated and the second and third magnetic elements are not actuated; and

to a fourth angular position where the first, second, and third magnetic elements are not actuated.

5. The surgical instrument of claim **4**, wherein the rotatable body is rotatable:

to a fifth angular position where the first and second magnetic elements are not actuated and the third magnetic element is actuated; and

to a sixth angular position where the first magnetic element is not actuated and the second and third magnetic elements are actuated.

6. A surgical instrument for use with a robotic surgical system, the surgical instrument comprising:

an end effector to treat tissue;

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

a housing, wherein the shaft is coupled to a distal end of the housing;

a first magnetic element positioned within the housing, wherein the first magnetic element comprises a switch;

a first cable coupled to the first magnetic element and extending distally from the first magnetic element and distally through the shaft such that actuation of the first magnetic element causes the first cable to translate along the longitudinal axis;

a rotatable body positioned within the housing and rotatable between a first angular position and a second angular position;

a first actuation member extending from the rotatable body to the switch of the first magnetic element such that, at the first angular position of the rotatable body, the first actuation member causes the switch of the first magnetic element to assume a first position where the first magnetic element is actuated, and, at the second angular position of the rotatable body, the first actuation member causes the switch of the first magnetic element to assume a second position where the first magnetic element is not actuated;

a second magnetic element positioned within the housing, wherein the second magnetic element comprises a switch;

a second cable coupled to the second magnetic element and extending distally from the second magnetic ele-

ment and distally through the shaft such that actuation of the second magnetic element causes the second cable to translate along the longitudinal axis;

a second rotatable body positioned within the housing; and

a second actuation member extending from the second rotatable body to a the switch of the second magnetic element such that rotation of the second rotatable body alternately transitions the switch of the second magnetic element from a first position where the second magnetic element is actuated to a second position where the second magnetic element is not actuated.

7. A surgical instrument for use with a robotic surgical system, the surgical instrument comprising:

an end effector to treat tissue;

a shaft extending proximally from the end effector along a longitudinal axis, wherein the shaft comprises a flexible articulation joint;

a housing, wherein the shaft is coupled to a distal end of the housing;

a first magnetic element positioned within the housing, wherein the first magnetic element comprises a switch;

a first cable coupled to the first magnetic element and extending distally from the first magnetic element and distally through the shaft such that actuation of the first magnetic element causes the first cable to translate along the longitudinal axis;

a rotatable body positioned within the housing and rotatable between a first angular position and a second angular position; and

a first actuation member extending from the rotatable body to the switch of the first magnetic element such that, at the first angular position of the rotatable body, the first actuation member causes the switch of the first magnetic element to assume a first position where the first magnetic element is actuated, and, at the second angular position of the rotatable body, the first actuation member causes the switch of the first magnetic element to assume a second position where the first magnetic element is not actuated;

wherein the first cable is coupled to the shaft distally from the flexible articulation joint and offset from the longitudinal axis such that proximal translation of the first cable causes pivoting of the end effector away from the longitudinal axis towards the first cable.

8. The surgical instrument of claim **7**, wherein the end effector comprises an ultrasonic blade, further comprising a transducer assembly positioned distally from the flexible articulation joint and acoustically coupled to the ultrasonic blade.

9. A surgical instrument for use with a robotic surgical system, the surgical instrument comprising:

an end effector to treat tissue;

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

a housing, wherein the shaft is coupled to a distal end of the housing;

a first magnetic element positioned within the housing, wherein the first magnetic element comprises a switch;

a first cable coupled to the first magnetic element and extending distally from the first magnetic element and distally through the shaft such that actuation of the first magnetic element causes the first cable to translate along the longitudinal axis;

a rotatable body positioned within the housing and rotatable between a first angular position and a second angular position;

a first actuation member extending from the rotatable body to the switch of the first magnetic element such that, at the first angular position of the rotatable body, the first actuation member causes the switch of the first magnetic element to assume a first position where the first magnetic element is actuated, and, at the second angular position of the rotatable body, the first actuation member causes the switch of the first magnetic element to assume a second position where the first magnetic element is not actuated

a second rotatable body; and

a second cable coupled to the second rotatable body and extending distally from the rotatable body through the shaft such that rotation of the second rotatable body causes the second cable to translate along the longitudinal axis.

10. A surgical instrument for use with a robotic surgical system, the surgical instrument comprising:

a plate;

a shaft extending distally from the plate along a longitudinal axis;

an end effector to treat tissue positioned distally from the shaft;

a first magnetic element comprising a body, a plunger, and a switch, wherein the switch comprises a first position that energizes the first magnetic element to at least partially retract the plunger into the body and a second position that de-energizes the first magnetic element to release the plunger;

a first cable coupled to the first magnetic element and extending distally through the shaft;

a rotatable body coupled to the plate, wherein the rotatable body is rotatable between a first angular position and a second angular position;

an actuation member extending from the rotatable body to the switch, wherein when the rotatable body is at the first angular position, the actuation member transitions the switch to the first position, and wherein when the rotatable body is at the second angular position, the actuation member transitions the switch to the second position.

11. The surgical instrument of claim **10**, further comprising:

a second magnetic element comprising a second body, a second plunger, and a second switch, the second switch comprising a first position that energizes the second magnetic element to at least partially retract the second plunger into the second body and a second position that de-energizes the second magnetic element to release the second plunger;

a second cable coupled to the second magnetic element and extending distally through the shaft; and

a second actuation member extending from the rotatable body to the second switch, wherein when the rotatable body is at a third angular position, the second actuation member transitions the second switch to the first position, and wherein when the rotatable body is at a fourth angular position, the second actuation member transitions the second switch to the second position.

12. The surgical instrument of claim **11**, wherein when the rotatable body is in the first angular position, the second actuation member transitions the second switch to the second position.

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