US012390259B2

(12) **United States Patent**
Dittrich et al.

(10) **Patent No.: US 12,390,259 B2**
(45) **Date of Patent: Aug. 19, 2025**

(54) **LINEAR ELECTRIC SURGICAL HAMMER IMPACT TOOL**

(71) Applicant: **Zimmer, Inc.**, Warsaw, IN (US)

(72) Inventors: **Joshua Dittrich**, Warsaw, IN (US); **Neil Singer**, Warsaw, IN (US); **Ken Pasch**, Warsaw, IN (US); **Alexander Slocum**, Bow, NH (US); **Nitin Goyal**, Mclean, VA (US)

(73) Assignee: **Zimmer, Inc.**, Warsaw, IN (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 218 days.

(21) Appl. No.: **18/222,830**

(22) Filed: **Jul. 17, 2023**

(65) **Prior Publication Data**

US 2024/0024012 A1 Jan. 25, 2024

Related U.S. Application Data

(60) Provisional application No. 63/450,316, filed on Mar. 6, 2023, provisional application No. 63/390,354, filed on Jul. 19, 2022.

(51) **Int. Cl.**
A61B 17/92 (2006.01)

(52) **U.S. Cl.**
CPC ***A61B 17/92*** (2013.01); *A61B 2017/924* (2013.01); *A61B 2017/928* (2013.01)

(58) **Field of Classification Search**
CPC A61B 17/92; A61B 2017/924
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,542,695 A * 2/1951 Neff A61B 17/92 D24/142
2,576,851 A 11/1951 Newman
2,655,921 A 10/1953 Haboush
3,450,215 A 6/1969 Emery
(Continued)

FOREIGN PATENT DOCUMENTS

AU 2019203142 A1 11/2019
AU 2020200771 A1 2/2020
(Continued)

OTHER PUBLICATIONS

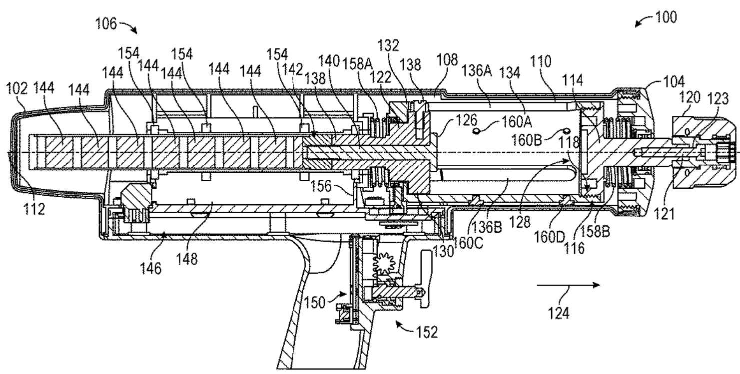
"U.S. Appl. No. 17/587,794, Response filed Aug. 28, 2023 to Restriction Requirement mailed Jun. 27, 2023", 7 pgs.
(Continued)

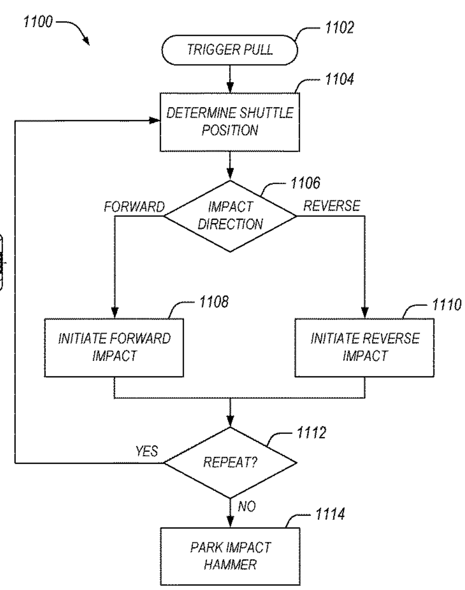
Primary Examiner — Christian A Sevilla
(74) *Attorney, Agent, or Firm* — SCHWEGMAN LUNDBERG & WOESSNER, P.A.

(57) **ABSTRACT**

Disclosed herein are linear electric surgical hammer impact tools and methods of use thereof. The linear electric surgical hammer impact tools can include a shuttle located inside a cavity of a housing. A wall of the shuttle defines a plurality of grooves extend from a first end of the shuttle to a second end of the shuttle. A piston can be located at least partially within the shuttle and arranged along the longitudinal axis of the housing. The piston includes protrusions and each of the protrusions can be arranged to travel within a respective one of the grooves of the shuttle. Motion of the piston in a first direction causes the piston to contact the first end of the shuttle and motion of the piston in a second direction causes the piston to contact the second end of the shuttle.

21 Claims, 14 Drawing Sheets





(56) **References Cited**

U.S. PATENT DOCUMENTS

3,472,323	A	10/1969	Hall	
3,626,935	A	12/1971	Pollock et al.	
3,752,161	A	8/1973	Bent	
3,829,974	A *	8/1974	McShirley	A61C 3/08 433/124
4,298,074	A *	11/1981	Mattchen	A61B 17/1624 606/104
4,466,429	A	8/1984	Loscher et al.	
4,651,833	A	3/1987	Karpf et al.	
4,834,092	A	5/1989	Alexson et al.	
5,057,112	A	10/1991	Sherman et al.	
5,108,400	A	4/1992	Appel et al.	
5,152,352	A	10/1992	Mandanis	
5,163,519	A	11/1992	Mead et al.	
5,210,918	A	5/1993	Wozniak et al.	
5,282,805	A	2/1994	Richelsoph et al.	
5,352,230	A	10/1994	Hood	
5,353,230	A	10/1994	Maejima et al.	
5,363,726	A	11/1994	Smith	
5,431,660	A	7/1995	Burke	
5,485,887	A	1/1996	Mandanis	
5,553,675	A	9/1996	Pitzen et al.	
5,868,756	A *	2/1999	Henry	G10K 9/10 606/128
6,126,694	A	10/2000	Gray, Jr.	
6,159,214	A	12/2000	Michelson	
6,264,660	B1	7/2001	Schmidt et al.	
6,264,661	B1	7/2001	Jerger et al.	
6,368,324	B1	4/2002	Dinger	
6,520,266	B2	2/2003	Bongers-ambrosius et al.	
6,626,913	B1	9/2003	Mckinnon et al.	
6,814,738	B2	11/2004	Naughton et al.	
6,868,918	B2	3/2005	Shinohara	
7,090,677	B2	8/2006	Fallin et al.	
7,189,241	B2	3/2007	Yoon et al.	
7,637,327	B2	12/2009	Gruenig	
7,874,839	B2 *	1/2011	Bouneff	A61C 1/148 433/121
8,002,776	B2	8/2011	Liu et al.	
8,393,409	B2	3/2013	Pedicini	
8,444,647	B2	5/2013	Walen et al.	
8,465,492	B2	6/2013	Estes	
8,556,901	B2	10/2013	Anthony et al.	
8,602,124	B2	12/2013	Pedicini	
8,695,726	B2	4/2014	Pedicini	
8,894,654	B2	11/2014	Anderson	
8,936,105	B2	1/2015	Pedicini	
8,936,106	B2	1/2015	Pedicini	
9,168,154	B2	10/2015	Behzadi	
9,186,158	B2	11/2015	Anthony et al.	
9,198,675	B2	12/2015	Nelson et al.	
9,220,612	B2	12/2015	Behzadi	
9,554,965	B2	1/2017	Foehrenbach	
9,629,641	B2	4/2017	Ferro et al.	
9,649,202	B2	5/2017	Behzadi et al.	
9,877,734	B2	1/2018	Anderson	
9,901,354	B2	2/2018	Pedicini	
9,931,151	B2	4/2018	Donald et al.	
9,943,318	B2	4/2018	Anthony et al.	
RE46,954	E	7/2018	Pedicini	
10,028,754	B2	7/2018	Johnson et al.	
RE46,979	E	8/2018	Pedicini	
10,159,500	B2	12/2018	Chavarria et al.	
10,172,722	B2	1/2019	Behzadi et al.	
10,245,160	B2	4/2019	Behzadi	
10,245,162	B2	4/2019	Behzadi et al.	
10,251,663	B2	4/2019	Behzadi	
10,299,930	B2	5/2019	Behzadi	
10,342,591	B2	7/2019	Pedicini	
10,368,882	B2	8/2019	Ferro et al.	
10,413,425	B2	9/2019	Behzadi et al.	
10,426,540	B2	10/2019	Behzadi	
10,441,244	B2	10/2019	Behzadi	
10,456,271	B2	10/2019	Behzadi	
10,463,505	B2	11/2019	Behzadi	
10,470,897	B2	11/2019	Behzadi	
10,478,318	B2	11/2019	Behzadi et al.	
10,568,643	B2	2/2020	Johnson et al.	
10,603,173	B2	3/2020	Carr et al.	
RE47,963	E	4/2020	Pedicini	
10,610,379	B2	4/2020	Behzadi	
RE47,997	E	5/2020	Pedicini	
10,653,533	B2	5/2020	Behzadi et al.	
10,660,767	B2	5/2020	Behzadi	
10,729,559	B2	8/2020	Behzadi et al.	
RE48,184	E	9/2020	Pedicini	
RE48,251	E	10/2020	Pedicini	
11,013,503	B2	5/2021	Pedicini	
11,490,943	B2	11/2022	Haiat et al.	
11,918,268	B2	3/2024	Doyle	
11,925,359	B2	3/2024	Slocum et al.	
12,004,793	B2	6/2024	Levy	
2004/0026097	A1	2/2004	Hecht	
2007/0282345	A1	12/2007	Yedlicka et al.	
2010/0137760	A1	6/2010	Schulz et al.	
2011/0255927	A1	10/2011	Boudreau et al.	
2011/0270256	A1	11/2011	Nelson et al.	
2012/0172939	A1	7/2012	Pedicini	
2012/0215267	A1	8/2012	Pedicini	
2012/0259339	A1	10/2012	Hood et al.	
2013/0161050	A1	6/2013	Pedicini	
2013/0261681	A1	10/2013	Bittenson	
2014/0318819	A1	10/2014	Pedicini	
2014/0318823	A1	10/2014	Pedicini	
2015/0196343	A1	7/2015	Donald et al.	
2016/0199199	A1	7/2016	Pedicini	
2017/0020536	A1	1/2017	Johnson et al.	
2017/0056205	A1	3/2017	Biegun et al.	
2018/0055518	A1	3/2018	Pedicini	
2018/0055552	A1	3/2018	Pedicini	
2018/0303496	A1	10/2018	Johnson et al.	
2018/0318089	A1	11/2018	Carr et al.	
2018/0360464	A1	12/2018	Irvine	
2019/0167434	A1	6/2019	Satterthwaite et al.	
2019/0183554	A1	6/2019	Pedicini	
2019/0216521	A1	7/2019	Chhatrala	
2019/0247057	A1	8/2019	Anderson	
2019/0282286	A1	9/2019	Pedicini	
2022/0142693	A1	5/2022	Slocum et al.	
2022/0226033	A1	7/2022	Slocum et al.	
2022/0240946	A1	8/2022	Slocum et al.	
2022/0240947	A1	8/2022	Marinkovich	
2022/0240998	A1	8/2022	Slocum	
2022/0273317	A1	9/2022	Levy	
2022/0361934	A1	11/2022	Pedicini	
2023/0240735	A1	8/2023	Doyle	

FOREIGN PATENT DOCUMENTS

AU	2021239844	A1	10/2022
AU	2017320580	B2	4/2023
AU	2021378282	A1	6/2023
AU	2022227599	A1	8/2023
CA	3063569	A1	11/2018
CA	3209081	A1	8/2022
CA	3211071	A1	9/2022
CH	701397	A2	1/2011
CN	2423872	Y	3/2001
CN	204863450	U	12/2015
CN	109070324	A	12/2018
CN	108602180	B	12/2022
CN	116801840	A	9/2023
CN	117414174	A	1/2024
DE	102010017726	A1	1/2011
EP	0290375	A1	11/1988
FR	2054809	A5	5/1971
JP	H06229427	A	8/1994
JP	H10174689	A	6/1998
JP	2002144255	A	5/2002
JP	2005506211	A	3/2005
JP	2010524577	A	7/2010
JP	2013036488	A	2/2013
JP	2015517341	A	6/2015
JP	2016202560	A	12/2016

(56) **References Cited**

FOREIGN PATENT DOCUMENTS

JP	2018502689	A	2/2018
JP	2019524165	A	9/2019
JP	2019177138	A	10/2019
JP	2019198645	A	11/2019
JP	2020530332	A	10/2020
JP	2020185421	A	11/2020
JP	7127068	B2	8/2022
JP	2022166207	A	11/2022
JP	7366968	B2	10/2023
JP	7375104	B2	10/2023
JP	7404463	B2	12/2023
JP	2023551117	A	12/2023
JP	2024013234	A	1/2024
JP	2024504977	A	2/2024
JP	2024505231	A	2/2024
JP	2024505239	A	2/2024
JP	2024505543	A	2/2024
JP	2024507954	A	2/2024
WO	WO-8802246	A2	4/1988
WO	WO-8906516	A1	7/1989
WO	WO-2008130904	A2	10/2008
WO	WO-2016112397	A1	7/2016
WO	WO-2018044348	A1	3/2018
WO	WO-2018217250	A1	11/2018
WO	WO-2022103835	A1	5/2022
WO	WO-2022159704	A1	7/2022
WO	WO-2022165215	A1	8/2022
WO	WO-2022165223	A1	8/2022
WO	WO-2022165357	A1	8/2022
WO	WO-2022182772	A1	9/2022

OTHER PUBLICATIONS

"International Application Serial No. PCT/US2022/013312, International Preliminary Report on Patentability mailed Aug. 3, 2023", 12 pgs.
"International Application Serial No. PCT/US2022/014368, International Preliminary Report on Patentability mailed Aug. 10, 2023", 10 pgs.
"International Application Serial No. PCT/US2022/014380, International Preliminary Report on Patentability mailed Aug. 10, 2023", 9 pgs.
"International Application Serial No. PCT/US2022/014596, International Preliminary Report on Patentability mailed Aug. 10, 2023", 7 pgs.
"International Application Serial No. PCT/US2022/017537, International Preliminary Report on Patentability mailed Sep. 7, 2023", 7 pgs.
"U.S. Appl. No. 17/587,794, Notice of Allowance mailed Nov. 15, 2023", 10 pgs.
"U.S. Appl. No. 17/587,866, Notice of Allowance mailed Apr. 11, 2024", 17 pgs.
"U.S. Appl. No. 17/678,807, Notice of Allowance mailed Feb. 14, 2024", 16 pgs.
"Australian Application Serial No. 2021378282, First Examination Report mailed Mar. 7, 2024", 3 pgs.
"European Application Serial No. 21820393.3, Response Filed Dec. 14, 2023 to Communication pursuant to Rules 161(1) and 162 EPC mailed Jul. 6, 2023", 10 pgs.
"European Application Serial No. 23186404.2, Extended European Search Report mailed Nov. 23, 2023", 8 pgs.
"U.S. Appl. No. 17/523,540, Notice of Allowance mailed Apr. 22, 2024", 10 pgs.
"Australian Application Serial No. 2021378282, Response filed May 22, 2024 to First Examination Report mailed Mar. 7, 2024", 8 pgs.
"Australian Application Serial No. 2022211325, First Examination Report mailed Apr. 29, 2024", 3 pgs.
"Australian Application Serial No. 2022211325, Response filed Jul. 19, 2024 to First Examination Report mailed Apr. 29, 2024", 17 pgs.
"Australian Application Serial No. 2022212126, First Examination Report mailed Apr. 26, 2024", 3 pgs.
"Australian Application Serial No. 2022212126, Response Filed Jul. 2, 2024 to First Examination Report mailed Apr. 26, 2024", 16 pgs.
"Australian Application Serial No. 2022212275, First Examination Report mailed May 15, 2024", 2 pgs.
"Australian Application Serial No. 2022212275, Response Filed Jun. 19, 2024 to First Examination Report mailed May 15, 2024", 14 pgs.
"Australian Application Serial No. 2022214931, First Examination Report mailed May 7, 2024", 3 pgs.
"Australian Application Serial No. 2022214931, Response filed Jul. 26, 2024 to First Examination Report mailed May 7, 2024", 9 pgs.
"Australian Application Serial No. 2022227599, First Examination Report mailed Apr. 18, 2024", 2 pgs.
"Australian Application Serial No. 2022227599, Response Filed Sep. 27, 2024 to First Examination Report mailed Apr. 18, 2024", 14 pgs.
"Australian Application Serial No. 2023206091, First Examination Report mailed Apr. 19, 2024", 4 pgs.
"Australian Application Serial No. 2023206091, Response filed Jul. 5, 2024 to First Examination Report mailed Apr. 19, 2024", 13 pgs.
"European Application Serial No. 22703776.9, Response Filed Mar. 11, 2024 to Communication pursuant to Rules 161(1) and 162 EPC mailed Aug. 30, 2023", 9 pgs.
"European Application Serial No. 22704684.4, Response filed Mar. 18, 2024 to Communication pursuant to Rules 161(1) and 162 EPC mailed Sep. 7, 2023", 17 pgs.
"European Application Serial No. 22705238.8, Response Filed Mar. 18, 2024 to Communication pursuant to Rules 161(1) and 162 EPC mailed Sep. 8, 2023", 172 pgs.
"European Application Serial No. 22705250.3, Response Filed Mar. 18, 2024 to Communication pursuant to Rules 161(1) and 162 EPC mailed Sep. 8, 2023", 15 pgs.
"European Application Serial No. 22713111.7, Response Filed Apr. 15, 2024 to Communication pursuant to Rules 161(1) and 162 EPC mailed Oct. 4, 2024", 8 pgs.
"European Application Serial No. 24161610.1, Extended European Search Report mailed Jul. 10, 2024", 6 pgs.
"Japanese Application Serial No. 2023-117628, Notification of Reasons for Refusal mailed May 28, 2024", w/ English translation, 7 pgs.
"Japanese Application Serial No. 2023-527766, Notification of Reasons for Refusal mailed Apr. 16, 2024", w/ English translation, 6 pgs.
"Japanese Application Serial No. 2023-544157, Notice of Reasons for Rejection mailed Apr. 23, 2024", w/ English translation, 5 pgs.
"Japanese Application Serial No. 2023-546065, Notification of Reasons for Refusal mailed Apr. 16, 2024", w/ English Translation, 15 pgs.
"Japanese Application Serial No. 2023-546135, Notification of Reasons for Refusal mailed Apr. 16, 2024", w/ English Translation, 9 pgs.
"Japanese Application Serial No. 2023-546333, Notification of Reasons for Refusal mailed Apr. 16, 2024", w/ English translation, 8 pgs.
"Japanese Application Serial No. 2023-552050, Notification of Reasons for Rejection mailed Jul. 2, 2024", W/English Translation, 5 pgs.
U.S. Appl. No. 17/523,540, filed Nov. 10, 2021, Bi-Spring Surgical Impact Tool.
U.S. Appl. No. 17/581,316, filed Jan. 21, 2022, Linear Electric Surgical Hammer Impact Tool.
U.S. Appl. No. 17/587,794, filed Jan. 28, 2022, Rotary Electric Surgical Hammer Impact Tool.
U.S. Appl. No. 17/587,866, filed Jan. 28, 2022, Orthopedic Impactor Tool.
U.S. Appl. No. 17/678,807, filed Feb. 23, 2022, Bi-Spring Surgical Hammer Impact Tools.
U.S. Appl. No. 17/589,456, filed Jan. 31, 2022, Tri-Roll Thread Electric Surgical Impacct Tool.
"U.S. Appl. No. 17/587,794, Restriction Requirement mailed Jun. 27, 2023", 7 pgs.

(56) **References Cited**

OTHER PUBLICATIONS

"International Application Serial No. PCT/US2021/058776, International Preliminary Report on Patentability mailed May 25, 2023", 10 pgs.
"International Application Serial No. PCT/US2021/058776, International Search Report mailed Feb. 9, 2022", 5 pgs.
"International Application Serial No. PCT/US2021/058776, Written Opinion mailed Feb. 9, 2022", 8 pgs.
"International Application Serial No. PCT/US2022/013312, International Search Report mailed Jun. 24, 2022", 6 pgs.
"International Application Serial No. PCT/US2022/013312, Invitation to Pay Additional Fees mailed May 3, 2022", 5 pgs.
"International Application Serial No. PCT/US2022/013312, Written Opinion mailed Jun. 24, 2022", 10 pgs.
"International Application Serial No. PCT/US2022/014368, International Search Report mailed May 30, 2022", 7 pgs.
"International Application Serial No. PCT/US2022/014368, Invitation to Pay Additional Fees mailed Apr. 5, 2022", 10 pgs.
"International Application Serial No. PCT/US2022/014368, Written Opinion mailed May 30, 2022", 8 pgs.
"International Application Serial No. PCT/US2022/014380, International Search Report mailed Jun. 24, 2022", 6 pgs.
"International Application Serial No. PCT/US2022/014380, Invitation to Pay Additional Fees mailed May 3, 2022", 5 pgs.
"International Application Serial No. PCT/US2022/014380, Written Opinion mailed Jun. 24, 2022", 7 pgs.
"International Application Serial No. PCT/US2022/014596, International Search Report mailed May 10, 2022", 4 pgs.
"International Application Serial No. PCT/US2022/014596, Written Opinion mailed May 10, 2022", 5 pgs.
"International Application Serial No. PCT/US2022/017537, International Search Report mailed Jun. 1, 2022", 4 pgs.
"International Application Serial No. PCT/US2022/017537, Written Opinion mailed Jun. 1, 2022", 5 pgs.
Budimir, Miles, "What is a rack and roller pinion?", [Online]. Retrieved from the Internet: <https://www.motioncontroltips.com/rack-roller-pinion/>, (Nov. 10, 2017), 13 pgs.
Nexen, "Rack and Roller Pinion System", [Online]. Retrieved from the Internet: <https://www.nexengroup.com/nxn/products/prod-nav/lp/Roller+Pinion+System>, (Accessed online Apr. 27, 2021), 10 pgs.

* cited by examiner

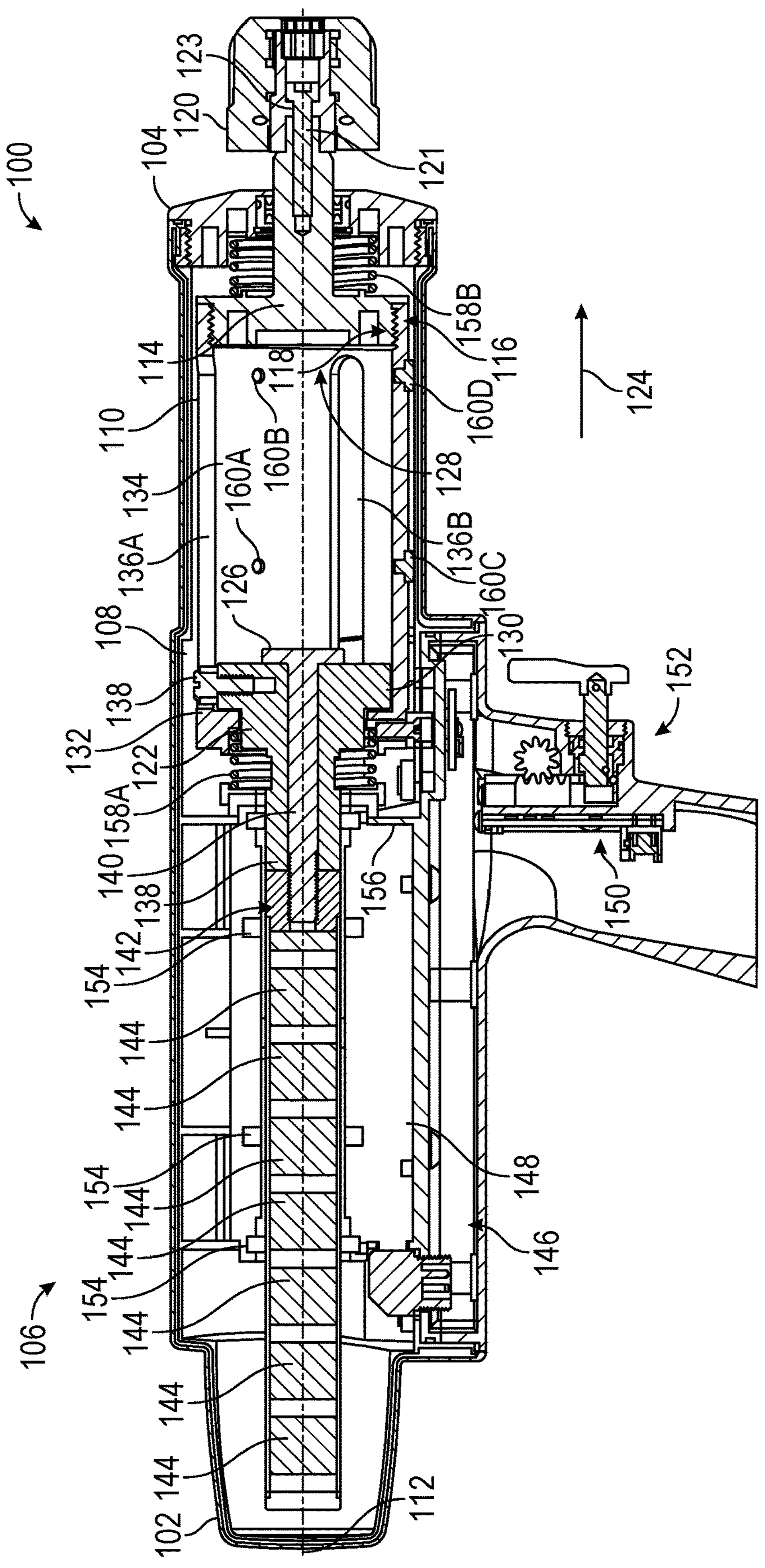

100
104
120
123
121
158B
116
114
118
110
160D
124
134
160A
160B
128
136A
136B
160C
126
108
130
152
138
132
122
158A
140
138
156
150
142
154
144
144
148
154
144
144
146
154
144
106
144
144
102
144
112

FIG. 1A

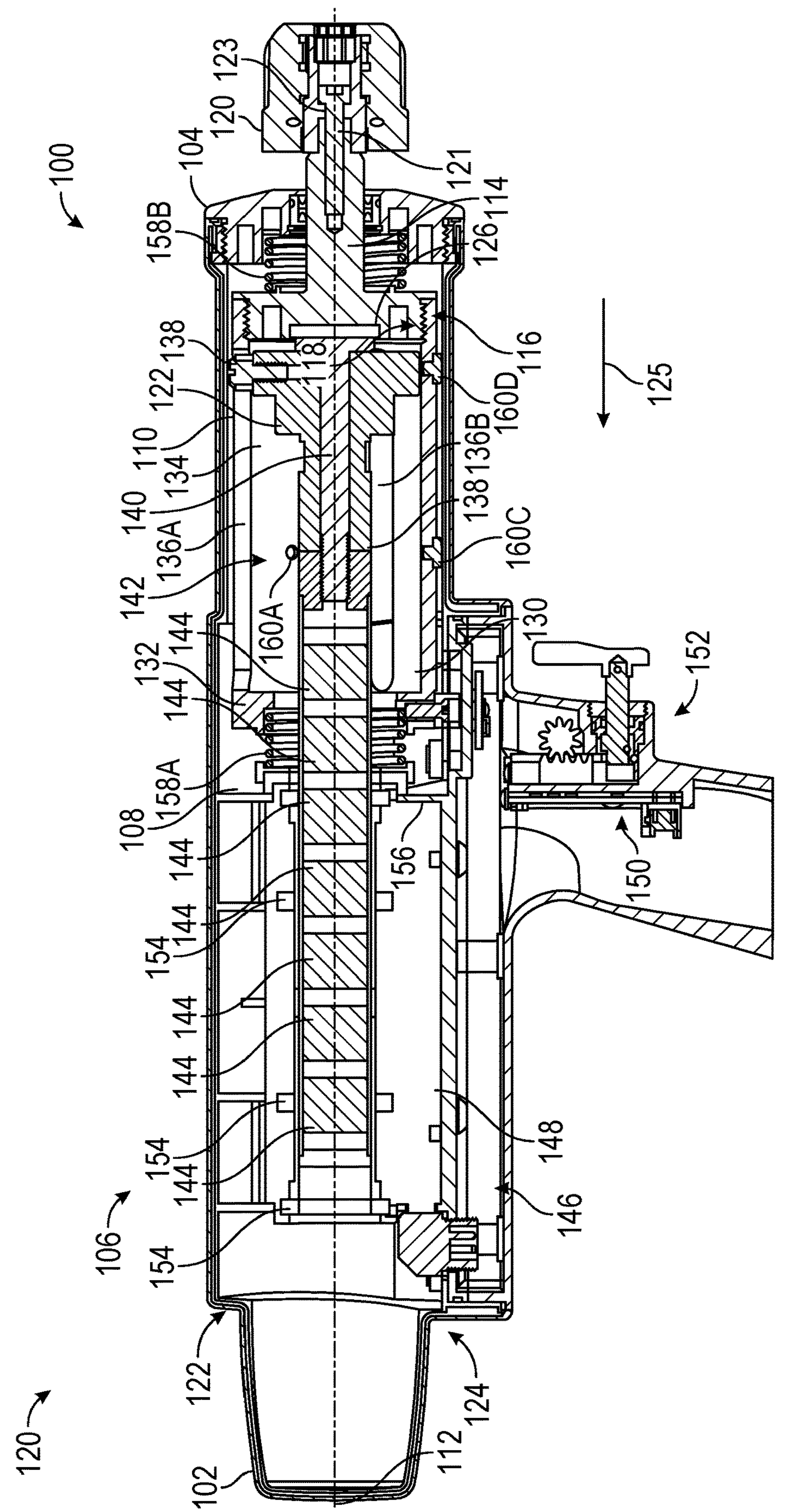

100
104
120
123
121
114
126
158B
116
118
138
122
110
134
140
136A
142
160D
136B
138
160C
160A
125
130
152
144
132
158A
108
156
150
154
148
146
106
124
112
102

FIG. 1B

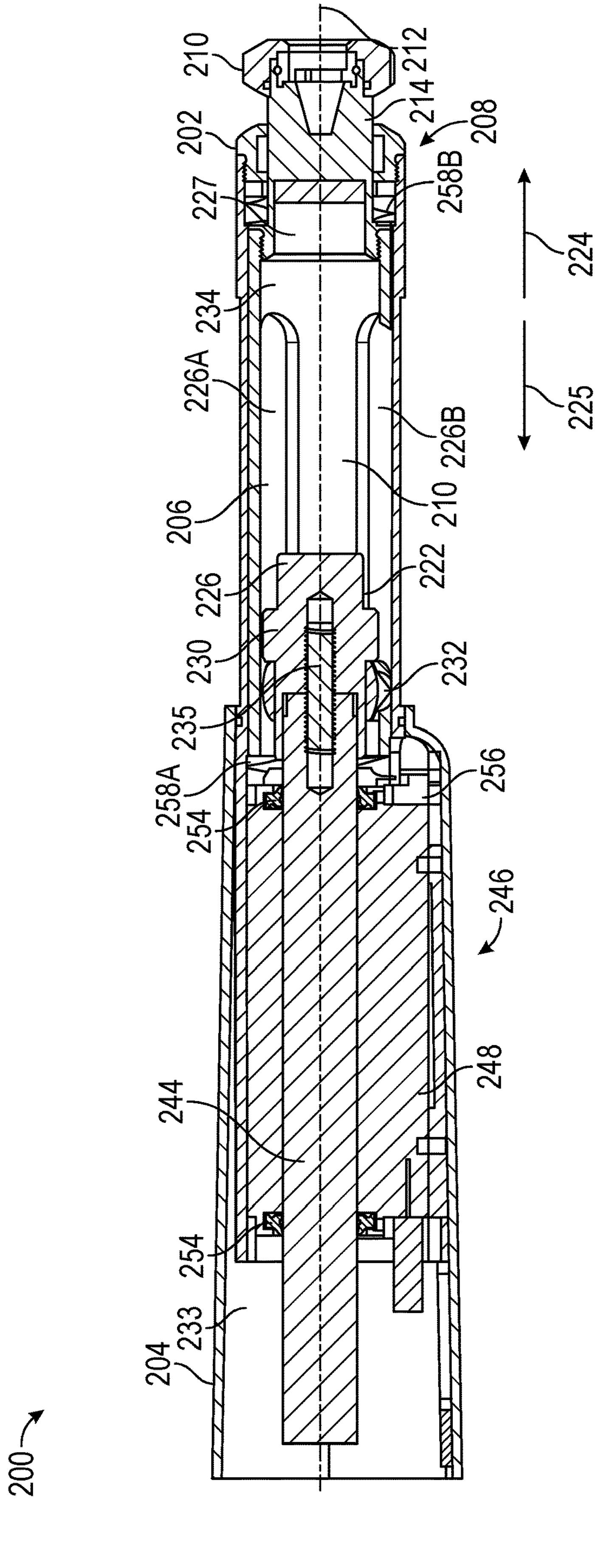

210
212
214
208
202
227
258B
224
234
226A
225
226B
210
206
222
226
230
232
235
258A
256
254
246
248
244
254
233
204
200

FIG. 2

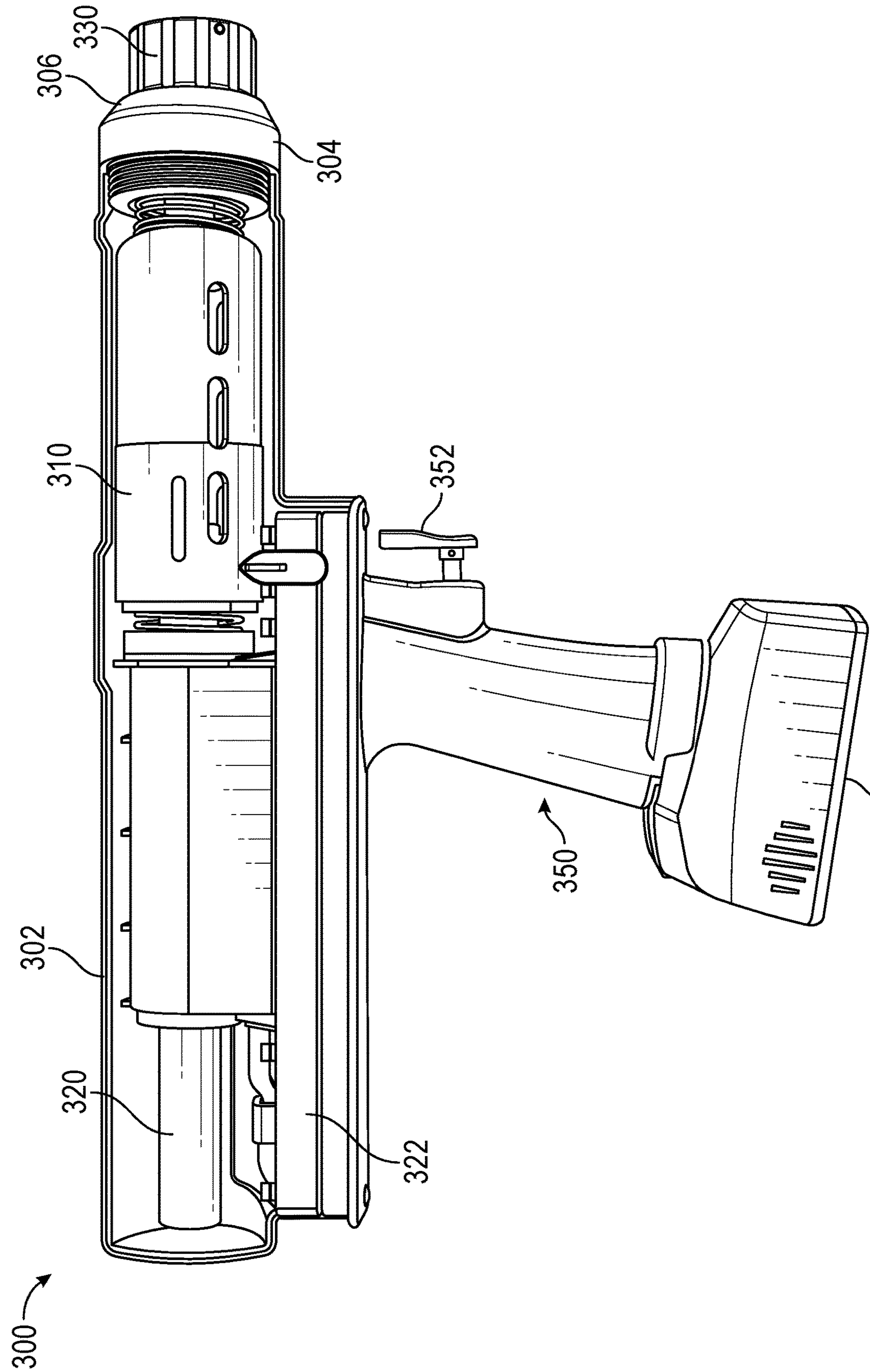


FIG. 3

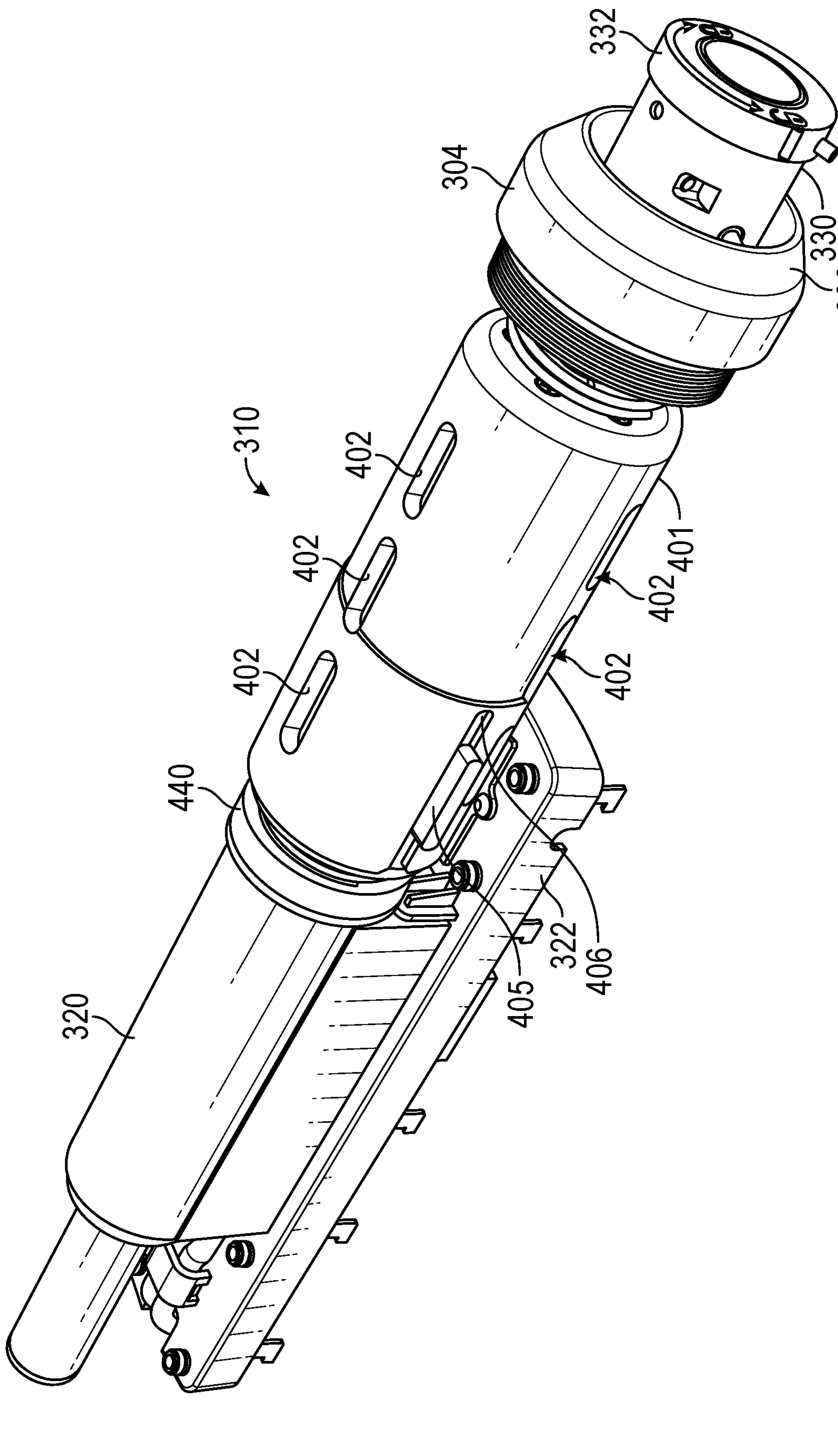
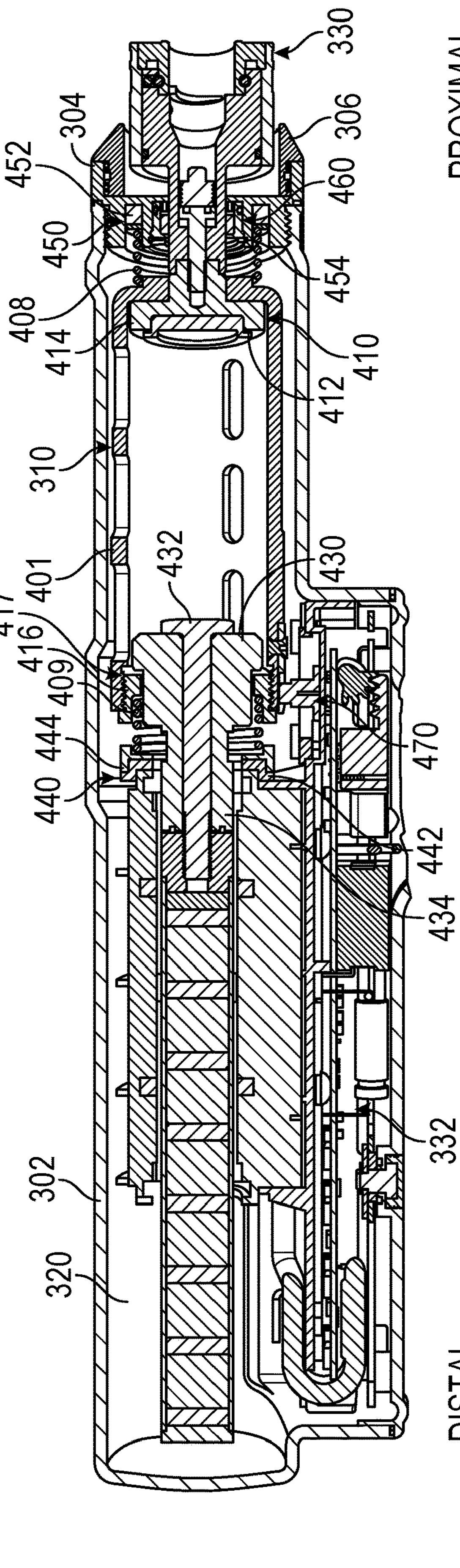
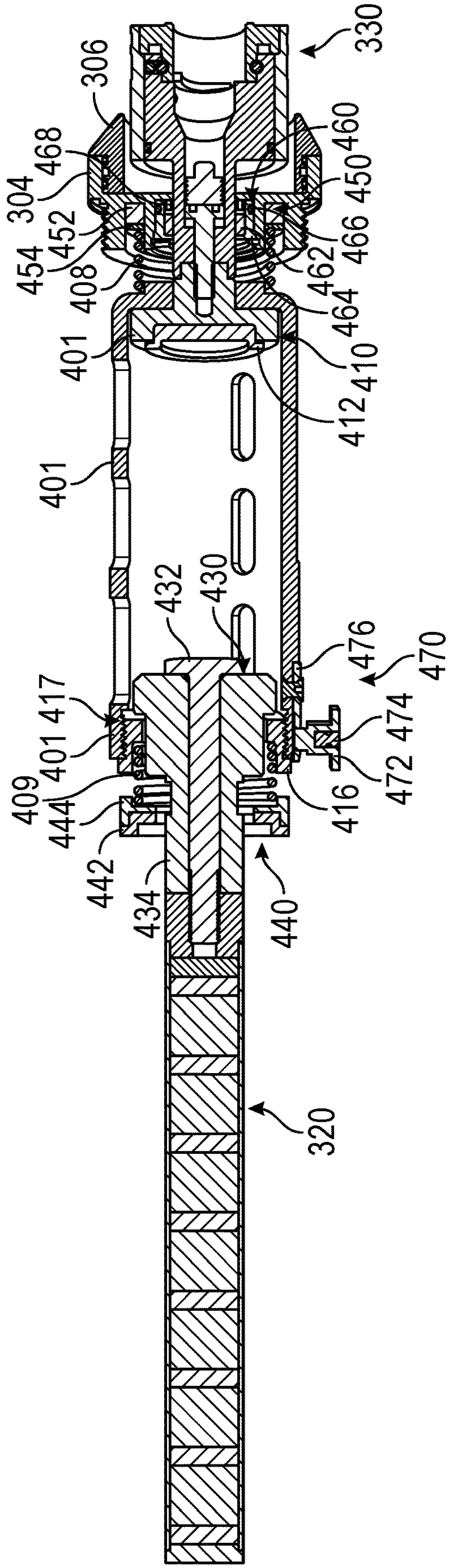


FIG. 4A



330
PROXIMAL
304
306
452
460
450
454
408
414
410
412
310
432
430
401
417
416
409
444
470
440
442
434
332
302
320
DISTAL

FIG. 4B



330
306
468
304
452
454
408
460
450
466
462
464
401
410
412
401
432
430
476
470
401
417
409
444
442
434
474
472
416
440
320

FIG. 5A

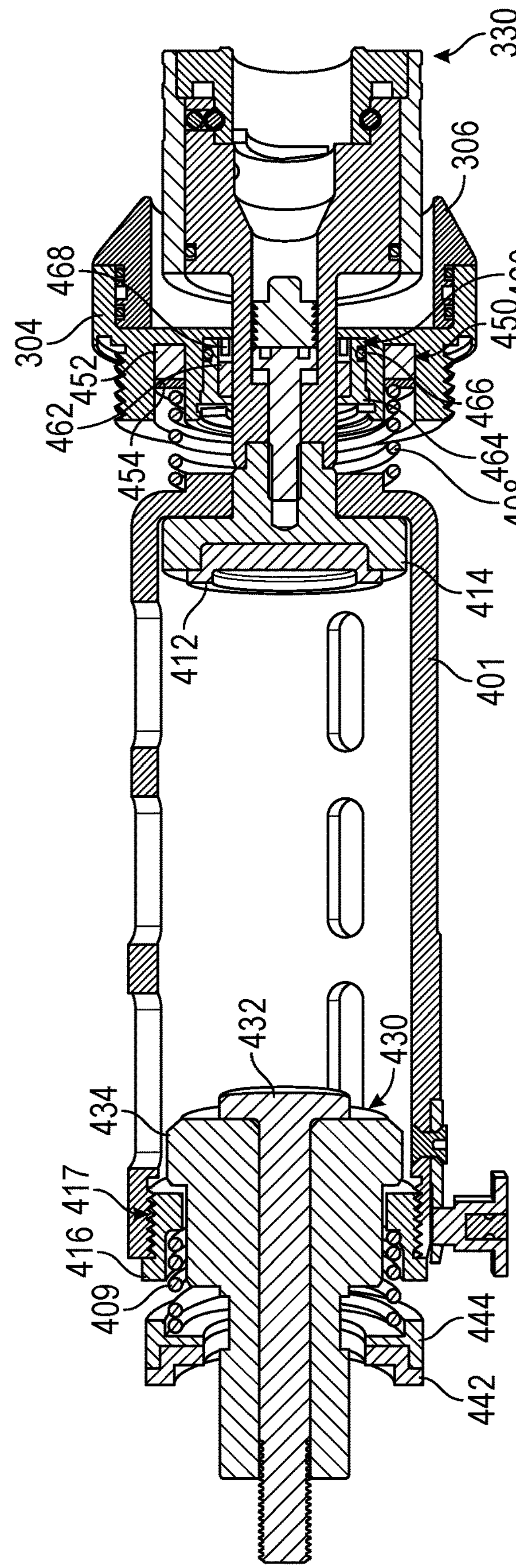

330
306
468
304
452
462
454
460
450
466
464
408
414
412
401
432
430
434
417
416
409
444
442

FIG. 5B

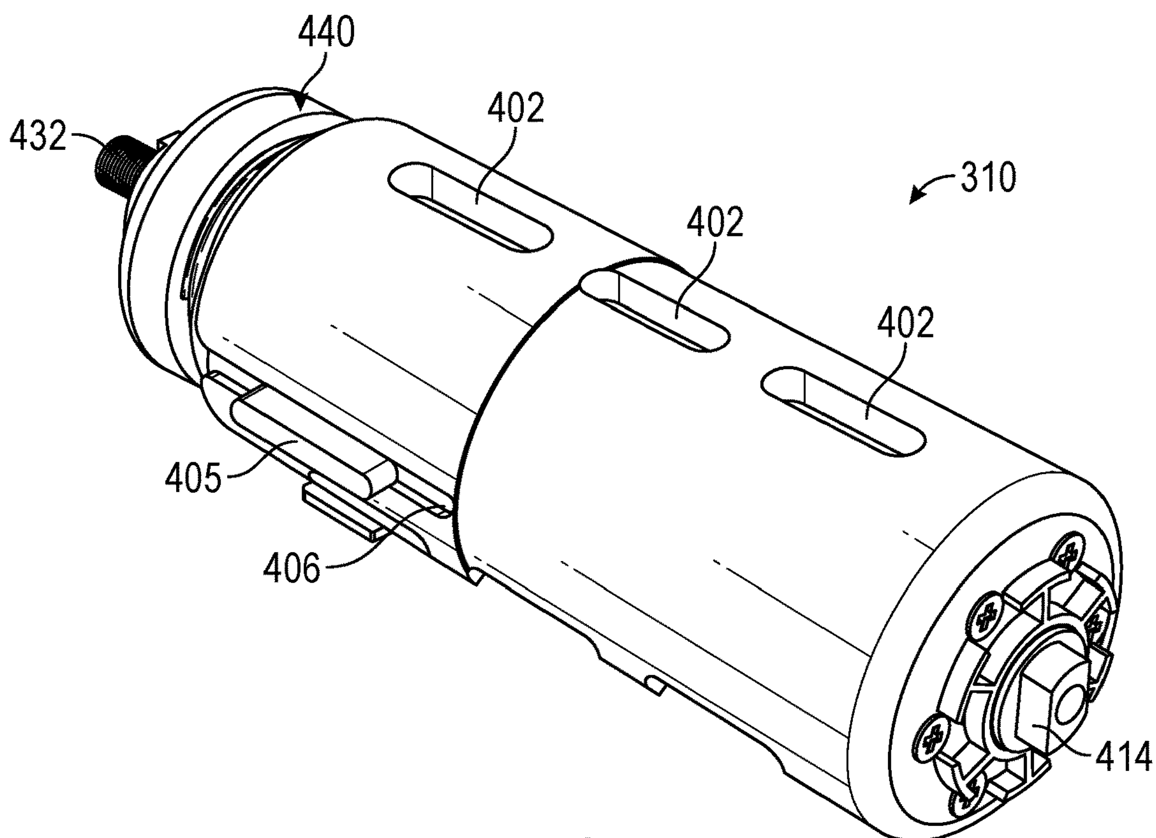

440
432
402
310
402
402
405
406
414

FIG. 6A

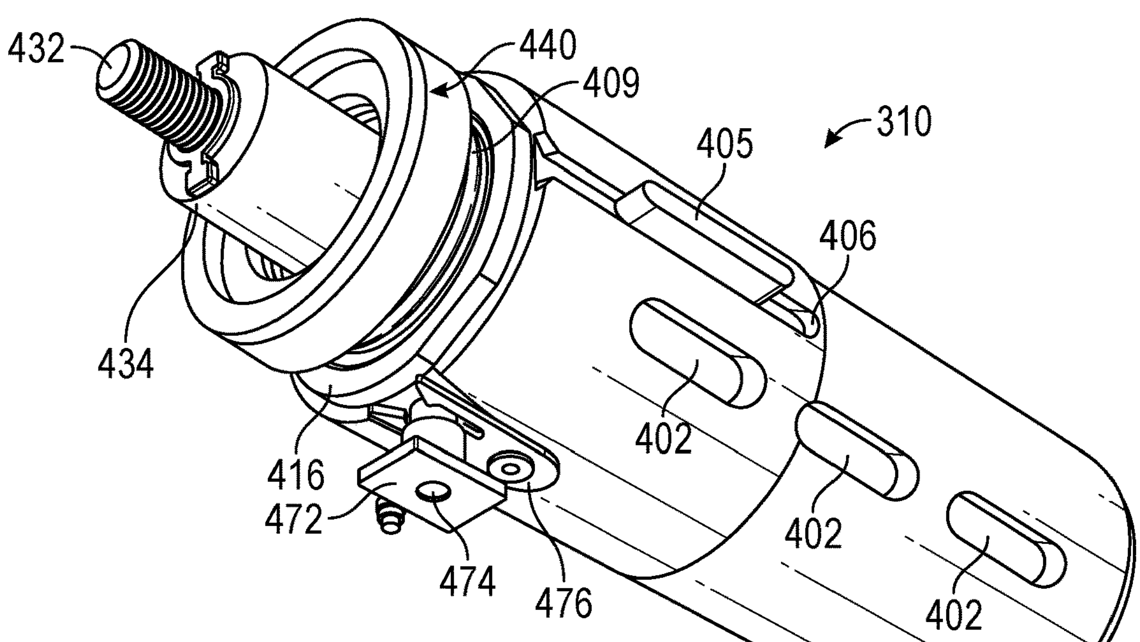

432
440
409
310
405
406
434
402
416
472
402
474
476
402

FIG. 6B

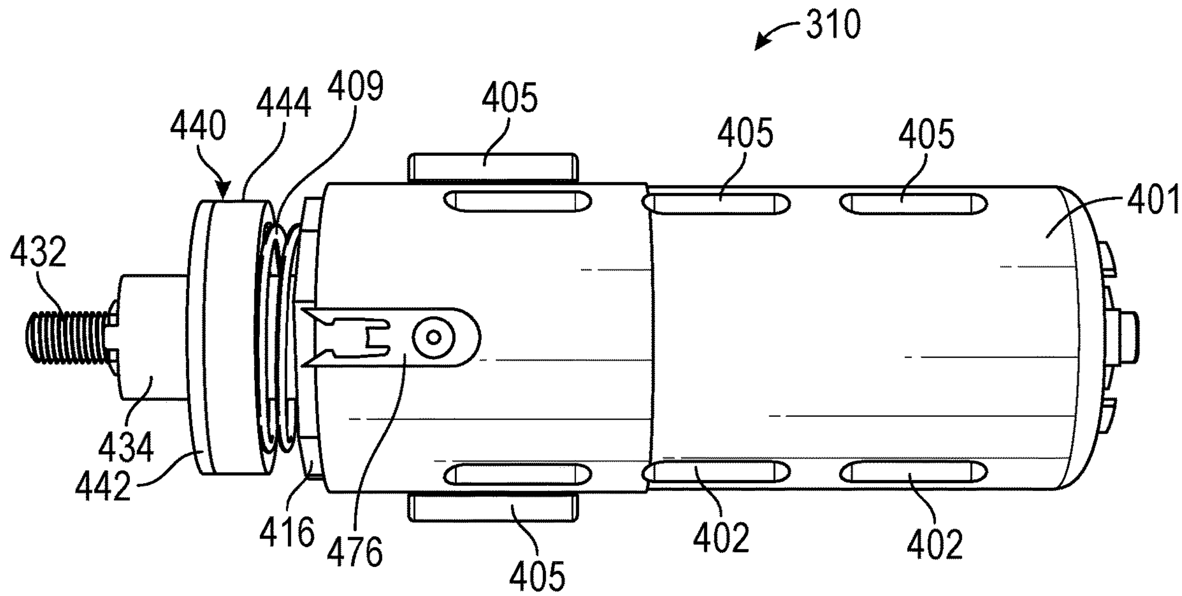

310
440
444
409
405
405
405
401
432
434
442
416
476
405
402
402

FIG. 6C

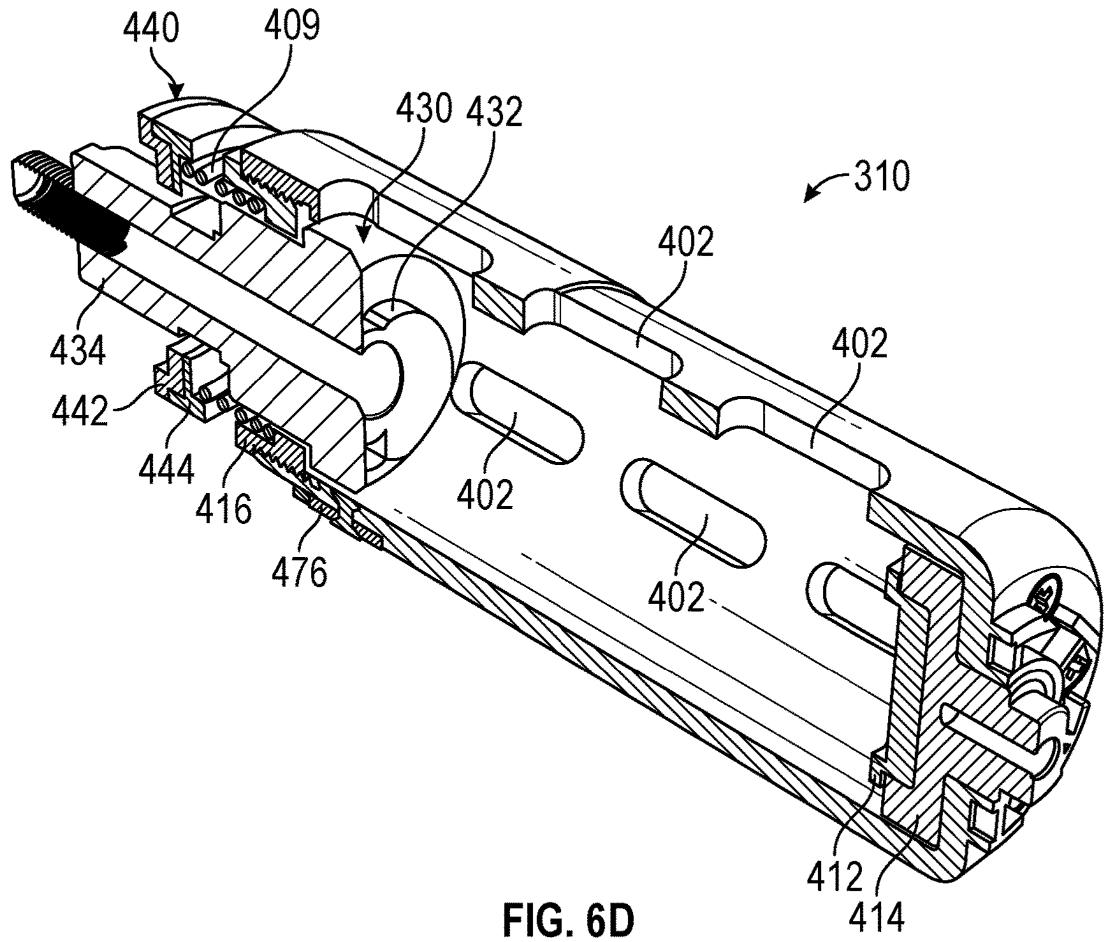

440
409
430
432
310
402
402
434
442
444
416
402
476
402
412
414

FIG. 6D

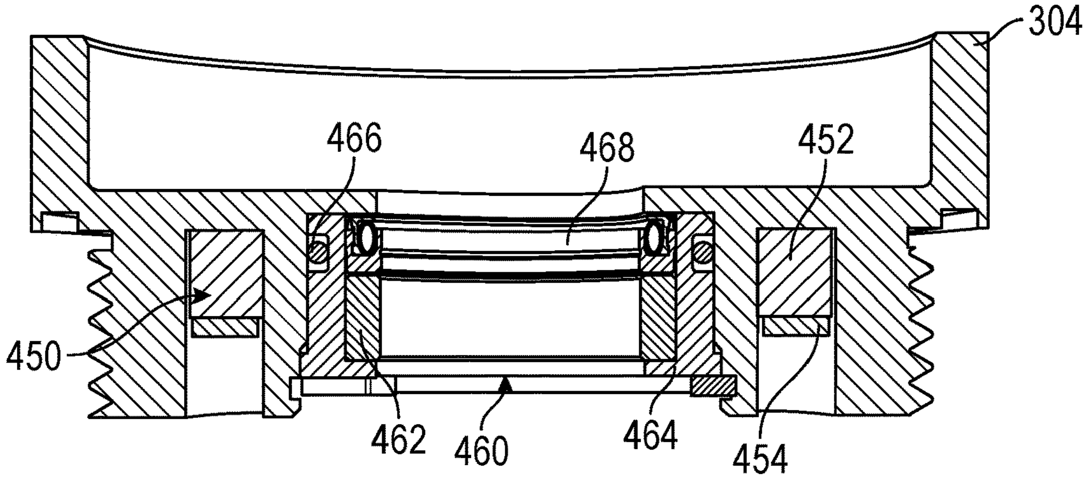


FIG. 7

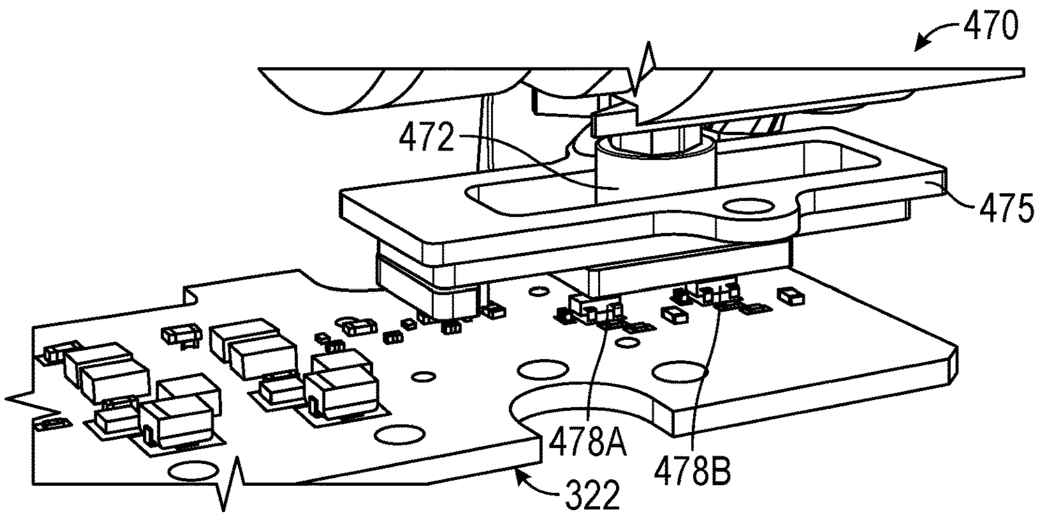


FIG. 8A

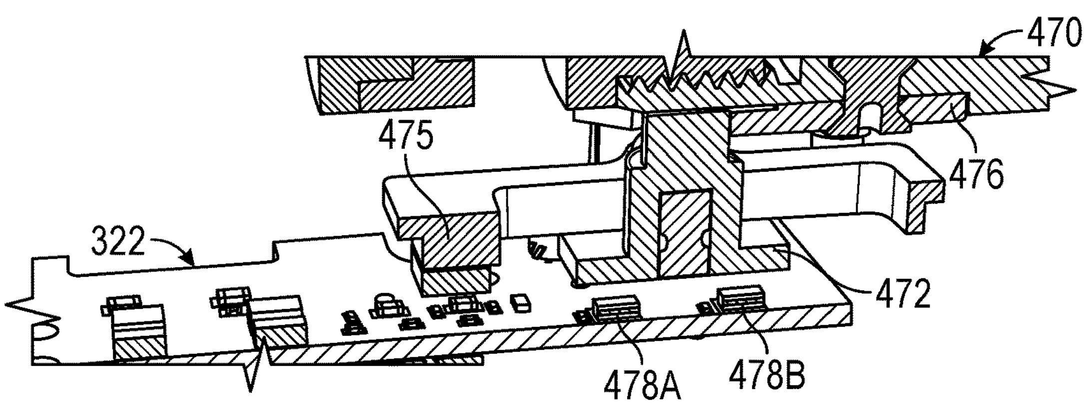


FIG. 8B

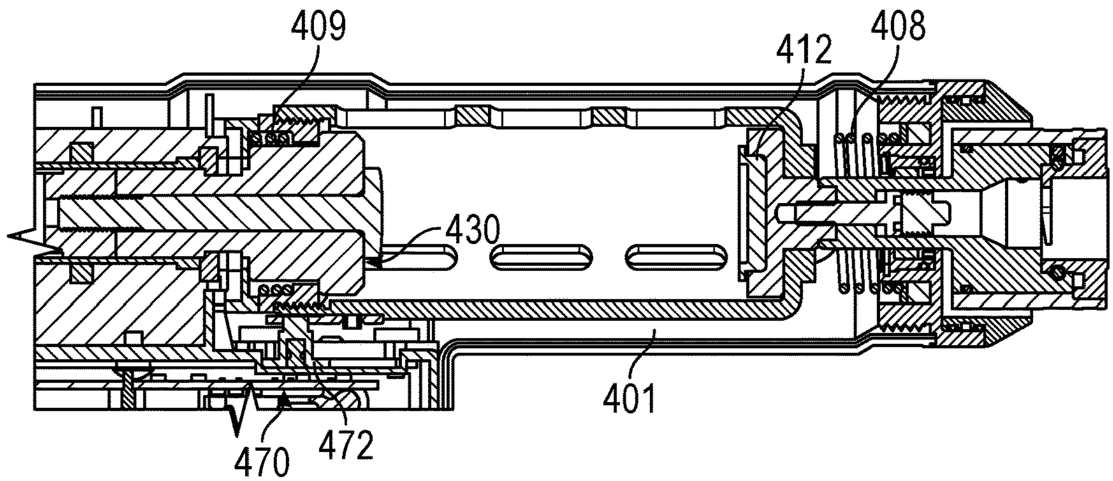


FIG. 9A

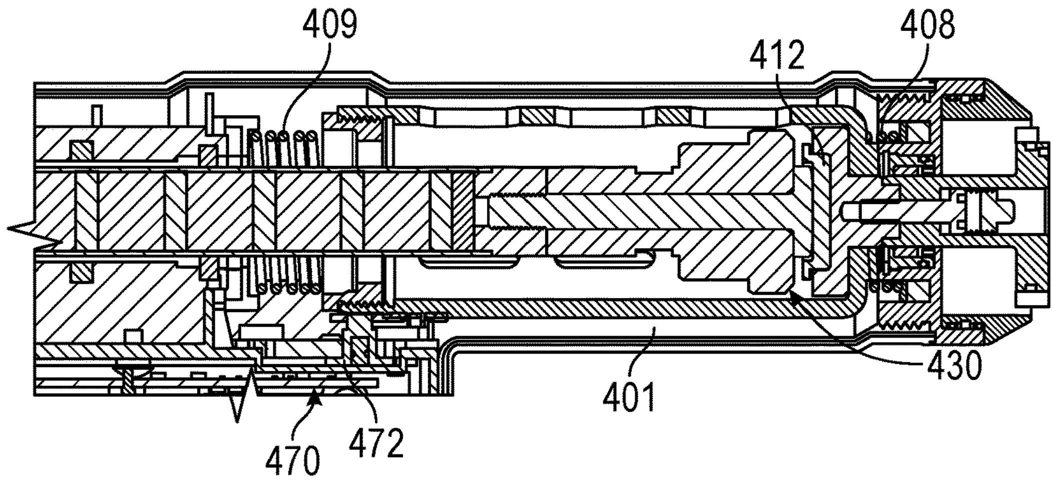


FIG. 9B

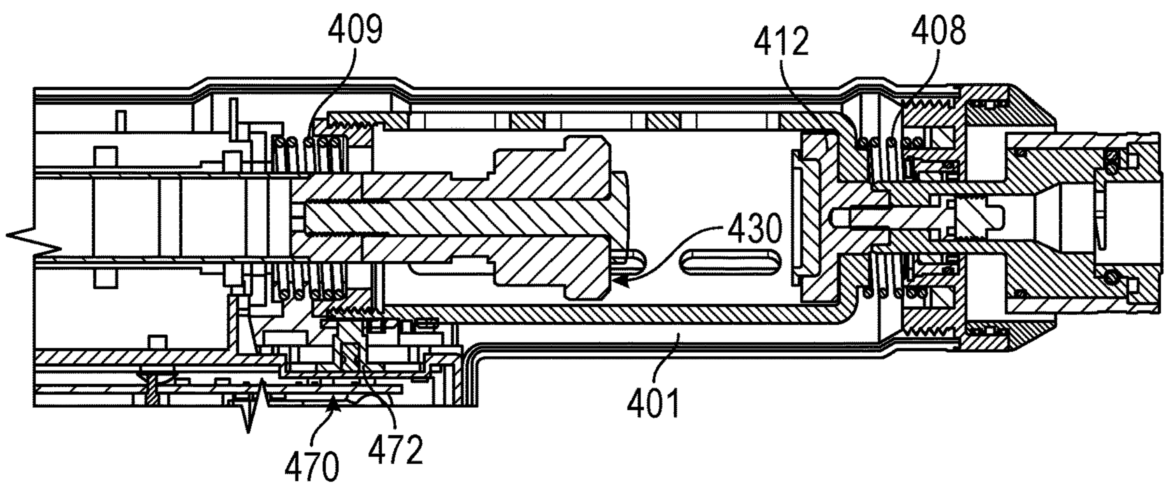


FIG. 9C

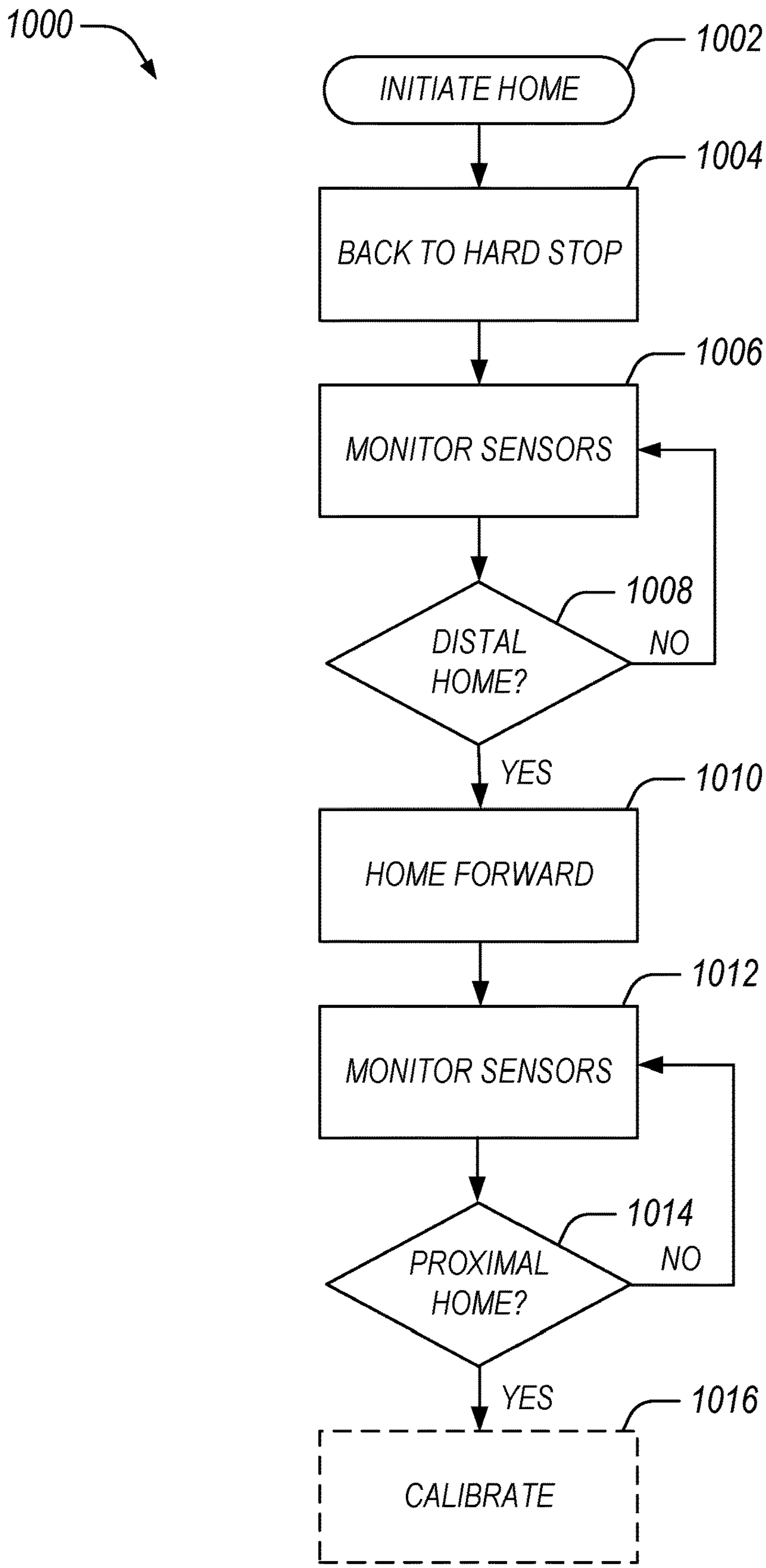

1000
1002
INITIATE HOME
1004
BACK TO HARD STOP
1006
MONITOR SENSORS
1008
DISTAL HOME?
NO
YES
1010
HOME FORWARD
1012
MONITOR SENSORS
1014
PROXIMAL HOME?
NO
YES
1016
CALIBRATE

FIG. 10

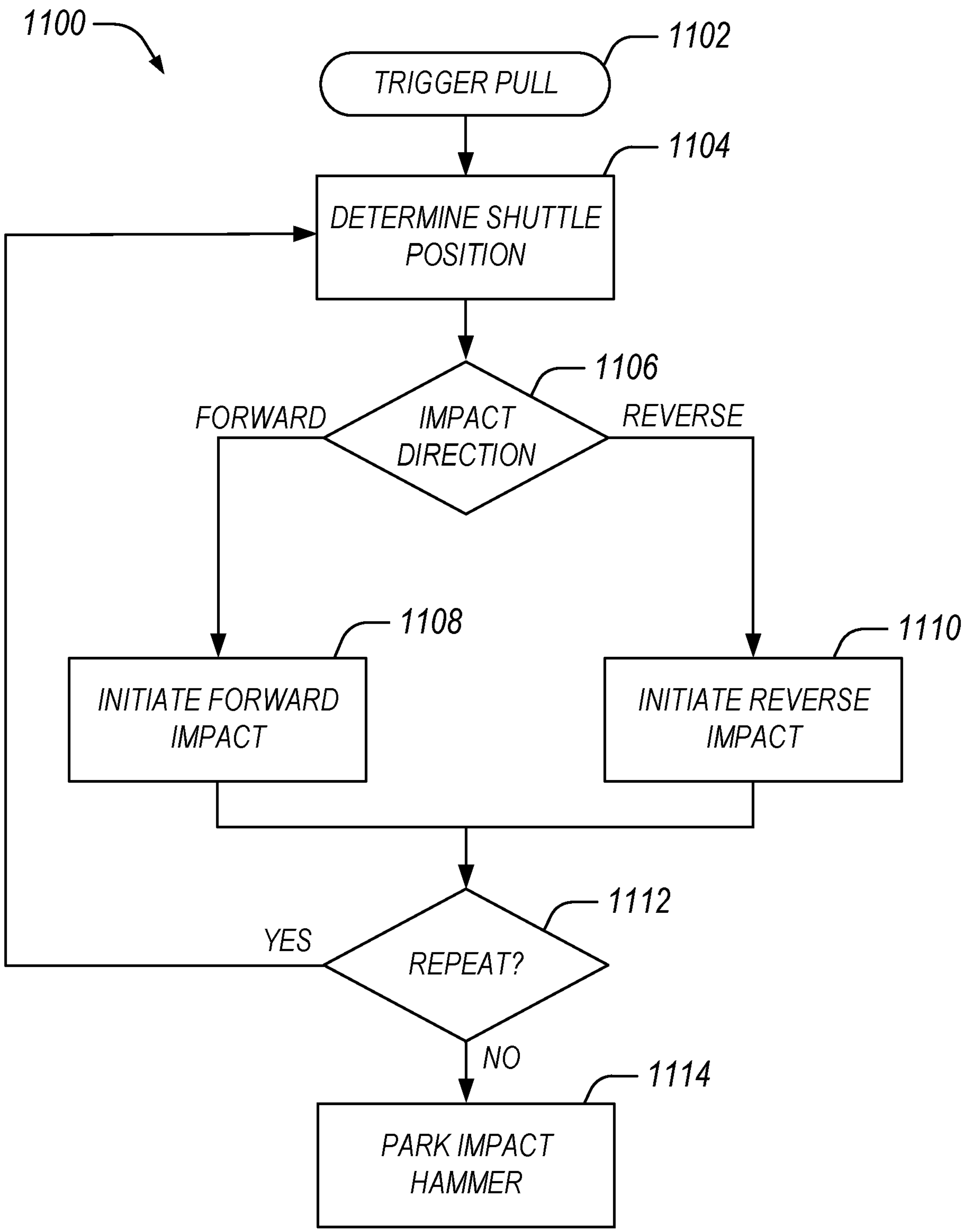

1100
1102
TRIGGER PULL
1104
DETERMINE SHUTTLE POSITION
1106
FORWARD
IMPACT DIRECTION
REVERSE
1108
INITIATE FORWARD IMPACT
1110
INITIATE REVERSE IMPACT
1112
YES
REPEAT?
NO
1114
PARK IMPACT HAMMER

FIG. 11

LINEAR ELECTRIC SURGICAL HAMMER IMPACT TOOL

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application Ser. No. 63/390,354, filed on Jul. 19, 2022, and also claims the benefit of U.S. Provisional Patent Application Ser. No. 63/450,316, filed on Mar. 6, 2023, the benefit of priority of each of which is claimed hereby, and each of which is incorporated by reference herein in its entirety.

The present application is related to U.S. Provisional Application No. 63/140,071, entitled "Linear Electric Hammer Impact Tool," filed on Jan. 21, 2021, and U.S. Non-Provisional application Ser. No. 17/581,316, entitled Linear Electric Surgical Hammer Impact Tool," filed on Jan. 21, 2022; the contents of which are hereby incorporated by reference in their entirety.

FIELD OF THE DISCLOSURE

The present disclosure relates generally to surgical instruments and use thereof. More specifically, the present disclosure relates to an electric surgical impact tool and methods of use thereof.

BACKGROUND

Orthopedic surgeons commonly utilize tools for cutting or carving bone that require a hammer or mallet to transmit an impaction force to the tool. An example is a broach tool used to prepare the proximal end of a femur to receive the stem of a hip implant. Such broaches can be used with a hammer wielded by the physician or with a pneumatic "jackhammer" like tool. However, striking a broach tool with a hammer can be tiresome and can cause high stresses on the physician's own joints, such as the shoulder joint. Furthermore, pneumatic impact tools require connection to an air hose, which can be inconvenient and can potentially limit the physician's ability to orient the tool in the desired manner.

SUMMARY

The following, non-limiting examples, detail certain aspects of the present subject matter to solve the challenges and provide the benefits discussed herein, among others.

Example 1 is a linear electric surgical hammer impact tool comprising: a housing defining a cavity extending along a longitudinal axis of the housing; a shuttle located inside the cavity and arranged along the longitudinal axis of the housing, the shuttle comprising a first end, a second end, and a wall extending from the first end to the second end, the wall defining a plurality of grooves extend from a first end of the shuttle to a second end of the shuttle; a piston located at least partially within the shuttle and arranged along the longitudinal axis of the housing, the piston comprising a plurality of protrusions, each of the plurality of protrusion arranged to travel within a respective one of the plurality of grooves of the shuttle; a motor configured to drive the piston along the longitudinal axis in a first direction and a second direction; and a tool holder connected to the shuttle, wherein motion of the piston in a first direction causes the piston to contact the first end of the shuttle and motion of the piston in a second direction causes the piston to contact the second end of the shuttle.

In Example 2, the subject matter of Example 1 optionally includes a cap connected to a proximal end of the housing; and a first biasing member located in between the first end of the shuttle and the cap.

In Example 3, the subject matter of any one or more of Examples 1-2 optionally include a partition located within the housing; and a second biasing member located in between the second end of the shuttle and the partition.

In Example 4, the subject matter of any one or more of Examples 2-3 optionally include wherein at least one of the first biasing member and the second biasing member comprise a spring.

In Example 5, the subject matter of any one or more of Examples 1-4 optionally include wherein each of the plurality of protrusions comprises a polymer.

In Example 6, the subject matter of Example 5 optionally includes wherein the polymer is impregnated with a lubricant.

In Example 7, the subject matter of any one or more of Examples 1-6 optionally include wherein the plurality of protrusions are straight.

In Example 8, the subject matter of any one or more of Examples 1-7 optionally include a sensor arrange to detect a position of the shuttle within the cavity.

In Example 9, the subject matter of any one or more of Examples 1-8 optionally include wherein the tool holder comprises a quick connect/disconnect chuck.

In Example 10, the subject matter of any one or more of Examples 1-9 optionally include a handle that defines a cavity sized to receive electronics and a trigger.

In Example 11, the subject matter of any one or more of Examples 1-10 optionally include wherein the tool holder threadably connects to the shuttle.

In Example 12, the subject matter of any one or more of Examples 1-11 optionally include wherein a distal surface of the tool holder forms an impact surface.

Example 13 is a linear electric surgical hammer impact tool comprising: a housing defining a cavity extending along a longitudinal axis of the housing; a shuttle located inside the cavity and arranged along the longitudinal axis of the housing, the shuttle comprising a first end, a second end, and a wall extending from the first end to the second end, the wall defining a plurality of grooves extend from a first end of the shuttle to a second end of the shuttle; a piston located at least partially within the shuttle and arranged along the longitudinal axis of the housing, the piston comprising a plurality of protrusions and a flange, each of the plurality of protrusion arranged to travel within a respective one of the plurality of grooves of the shuttle; a motor configured to drive the piston along the longitudinal axis in a first direction and a second direction; and a tool holder threadably connected to the shuttle, the tool holder comprising a distal surface that forms an impact surface, wherein motion of the piston in a first direction causes the piston to contact the impact surface of the tool holder and motion of the piston in a second direction causes the flange of the piston to contact the second end of the shuttle.

In Example 14, the subject matter of Example 13 optionally includes a cap connected to a proximal end of the housing; and a first biasing member located in between the first end of the shuttle and the cap.

In Example 15, the subject matter of any one or more of Examples 13-14 optionally include a partition located within the housing; and a second biasing member located in between the second end of the shuttle and the partition.

In Example 16, the subject matter of any one or more of Examples 13-15 optionally include wherein at least one of the first biasing member and the second biasing member comprise a spring.

In Example 17, the subject matter of any one or more of Examples 13-16 optionally include wherein each of the plurality of protrusions comprises a polymer impregnated with a lubricant.

In Example 18, the subject matter of any one or more of Examples 13-17 optionally include wherein the plurality of protrusions are straight.

In Example 19, the subject matter of any one or more of Examples 13-18 optionally include a sensor arrange to detect a position of the shuttle within the cavity.

In Example 20, the subject matter of any one or more of Examples 13-19 optionally include wherein the tool holder comprises a quick connect/disconnect chuck.

In Example 21, the subject matter of any one or more of Examples 13-20 optionally include a handle that defines a cavity sized to receive electronics and a trigger.

In Example 21, the surgical impact tools, systems, and/or methods of any one or any combination of Examples 1-20 can optionally be configured such that all elements or options recited are available to use or select from.

Example 22 is a linear electric surgical hammer impact tool comprising: a housing defining a cavity extending along a longitudinal axis of the housing; a shuttle located inside the cavity and arranged along the longitudinal axis of the housing, the shuttle comprising a first end, a second end, and a wall extending from the first end to the second end, the wall including opposing exterior key grooves extending a length of an exterior portion of the wall; a hammer assembly located at least partially within a proximal end of the shuttle and arranged along the longitudinal axis of the housing; a linear electric motor configured to drive the piston along the longitudinal axis in a first direction and a second direction; and an impact assembly located at least partially within a distal end of the shuttle. The linear electric impact tool operates by motion of the hammer assembly in a first direction causing the hammer assembly to contact the first end of the shuttle to generate a forward impact and motion of the hammer assembly in a second direction causing the hammer assembly to contact the second end of the shuttle to generate a reverse impact.

In Example 23, the subject matter of Example 22 can optionally include the hammer assembly having an impact piston surrounding an impact hammer.

In Example 24, the subject matter of any one of Examples 22 or 23 can optionally include the impact hammer having a curved proximal contact surface.

In Example 25, the subject matter of any one of Examples 22 to 24 can optionally include the curved proximal contact surface having a radius of 100 mm.

In Example 26, the subject matter of any one of Examples 22 to 25 can optionally include the impact piston having a distal circumferential ridge to engage a reverse impact cap to generate reserve impacts.

In Example 27, the subject matter of any one of Examples 22 to 26 can optionally include the impact assembly having an impact button adapted to receive impacts from the impact hammer.

In Example 28, the subject matter of Example 27 can optionally include the impact assembly having an impact interface adapted to transfer impacts received on the impact button to an impact tool held in a chuck adjacent a distal end of the impact tool.

In Example 29, the subject matter of any one of Examples 27 or 28 can optionally include the impact button being a polymer material and the impact hammer is a dense metal.

In Example 30, the subject matter of any one of Examples 27 to 29 can optionally include the impact button having a pocket formed to receive a radiused proximal surface of the impact hammer.

In Example 31, the subject matter of any one of Examples 22 to 30 can optionally include a proximal bias spring and a distal bias spring that operate to center the shuttle within the house and absorb excess impact energy.

In Example 32, the subject matter of any one of Examples 22 to 32 can optionally include a proximal energy absorption assembly and a distal energy absorption assembly.

In Example 33, the subject matter of Example 32 can optionally include the proximal energy absorption assembly having a forward absorption ring and a proximal bias ring.

In Example 34, the subject matter of Example 33 can optionally include the forward absorption ring being an energy absorbing rubber and the proximal bias ring being a metallic ring structure adapted to receive the proximal bias spring.

In Example 35, the subject matter of any one of Examples 22 to 34 can optionally include an impact shaft transmits impact from the impact assembly and extends distally through an impact shaft bearing assembly, the impact shaft bearing assembly operating as a self-aligning shaft bearing on the impact shaft.

In Example 36, the subject matter of any one of Examples 22 to 35 can optionally include a position sensor assembly including a slider clip to removably couple a position slider to the shuttle.

Example 37 is a method for homing any one of the impact tools of Examples 1 to 36. The homing method can include: operating a linear electric motor to reverse a shuttle mechanism to a distal hard stop; monitoring a position sensor assembly during operation of the linear electric motor; determining, based on feedback from the position sensor assembly and the linear electric motor, that a distal home position has been reached; upon determining that the distal home position was reached, operating the linear electric motor to move the shuttle mechanism to a proximal home position; and determining, based on feedback from the position sensor and the linear electric motor, that the proximal home position has been reached.

In Example 38, the subject matter of Example 37 can optionally include the determining the distal home position has been reached by monitoring voltages on a distal position sensor and a proximal position sensor.

In Example 39, the subject matter of any one of Examples 37 and 38 can optionally include calibrating the sensor assembly based on voltage readings at the distal home and proximal home positions.

Example 40 is a method of operating any one of the impact tools of Examples 1 to 36. The operating method can include: detecting activation of a trigger mechanism to initiate an impact from the impact tool; determining a position of a shuttle assembly within a housing of the impact tool, the shuttle including components adapted to generate an impact; determining, from the position of the shuttle assembly, an intended impact direction; and delivering an impact in the intended impact direction by operating a linear electric impact mechanism.

In Example 41, the subject matter of Example 40 can optionally include after delivering the impact, determining, based on a position of the trigger mechanism, whether to repeat delivery of the impact.

In Example 42, the subject matter of Example 41 can optionally include upon determining not to repeat delivery of the impact, parking the linear electric impact mechanism.

BRIEF DESCRIPTION OF THE FIGURES

In the drawings, which are not necessarily drawn to scale, like numerals can describe similar components in different views. Like numerals having different letter suffixes can represent different instances of similar components. The drawings illustrate generally, by way of example, but not by way of limitation, various embodiments discussed in the present document.

FIGS. **1**A and **1**B each shows section view of a linear electric surgical hammer impact tool consistent with at least one example of this disclosure; and

FIG. **2** shows section view of a linear electric surgical hammer impact tool consistent with at least one example of this disclosure.

FIG. **3** is a cut away view of a linear electric impact tool consistent with at least one example of this disclosure.

FIG. **4**A is a perspective view illustrating multiple sub-assemblies of a linear electric impact tool consistent with at least one example of this disclosure.

FIG. **4**B is a cross section view of multiple sub-assemblies of a linear electric impact tool consistent with at least one example of this disclosure.

FIG. **5**A is a cross section view of multiple sub-assemblies of a linear electric impact tool consistent with at least one example of this disclosure.

FIG. **5**B is a cross section view of an impactor sub-assembly of a linear electric impact tool consistent with at least one example of this disclosure.

FIGS. **6**A-**6**C are various views of a shuttle sub-assembly of a linear electric impact tool consistent with at least one example of this disclosure.

FIG. **6**D is a cross section view of a shuttle sub-assembly of a linear electric impact tool consistent with at least one example of this disclosure.

FIG. **7** is a cross section view of a self-aligning impact shaft bearing structure for a linear electric impact tool consistent with at least one example of this disclosure.

FIGS. **8**A-**8**B are various views of a position sensor sub-assembly for a linear electric impact tool consistent with at least one example of this disclosure.

FIGS. **9**A-**9**C are cross section views illustrating various impactor positions within a linear electric impact tool consistent with at least one example of this disclosure.

FIG. **10** is a flowchart illustrating a homing and calibration technique for a linear electric impact tool consistent with at least one example of this disclosure.

FIG. **11** is a flowchart illustrating a surgeon intent detection technique consistent with at least one example of this disclosure.

Corresponding reference characters indicate corresponding parts throughout the several views. The exemplifications set out herein illustrate exemplary embodiments of the disclosure, and such exemplifications are not to be construed as limiting the scope of the disclosure in any manner. Reference characters used in FIGS. **3**-**9**C do not necessarily have any correspondence to reference characters used in previous figures.

DETAILED DESCRIPTION

As an alternative to a pneumatic piston driven system, disclosed herein are electrically driven systems. Specifically, the linear electric surgical hammer impact tools disclosed herein can include impact elements, sometimes called sliders that can impact shuttles, tool holding elements, etc. to generate impact forces.

An electric motor can be configured to drive the impact elements to create the impact forces. For example, motion of a piston in a first direction can cause the piston to contact a first end of a housing and motion of the piston in a second direction can cause the piston to contact a second end of the housing. The contact between the piston and the housing can generate the impact forces to drive a rasp and/or broach into a canal of a bone and extract the rasp and/or broach from the canal.

The above discussion is intended to provide an overview of subject matter of the present patent application. It is not intended to provide an exclusive or exhaustive explanation of the invention. The description below is included to provide further information about the present patent application.

Turning now to the figures, FIGS. **1**A and **1**B each shows an example of a linear electric surgical hammer impact tool **100** consistent with at least one example of this disclosure. As disclosed herein, linear electric surgical hammer impact tool **100** can provide a simple, efficient, and robust battery powered handheld linear electric surgical hammer impact tool for use in surgical procedures. Linear electric surgical hammer impact tool **100** can include a distal end cap **102** and a proximal end cap **104** on opposite ends of a housing **106**. Housing **106** can sometimes be referred to as a tool body and can define a cavity **108**.

A shuttle **110** can be located within cavity **108** and arranged along a longitudinal axis **112** of housing **106**. A tool holder **114** can be connected to shuttle **110**. For example, and as shown in FIGS. **1**A and **1**B, shuttle **110** can include first threads **116** and shuttle **110** can have second threads **118** that allow tool holder **114** to be threadably connected to shuttle **110**. Other forms of attaching tool holder **114** to shuttle **110** can include adhesives, press fit, welding, screws, etc.

Tools, such as a rasp, broach, etc., can be attached directed to tool holder **114**. For example, a broach can be secured to tool holder **114** via a pin, threads, etc. Consistent with embodiments disclosed herein, a chuck **120** can be attached to tool holder **114**. Chuck **120** can be a quick connect/disconnect chuck that allows for a surgeon or other operating room staff to quickly connect and disconnect tools from linear electric surgical hammer impact tool **100**. For example, chuck **120** can allow a surgeon to quickly disconnect a first rasp from linear electric surgical hammer impact tool **100** and quickly connect a second rasp, which can be a different size and/or shape than the first rasp, to linear electric surgical hammer impact tool **100**.

Chuck **120** can be attached to tool holder **114** via a bolt **121**. For example, chuck **120** can define a through hole **123**. Bolt **121** can pass through through hold 123 to secure chuck **120** to tool holder **114**. The us of bolt **121** can allow a surgeon or other staff to change chucks depending on a surgeon's preference. For instance, a first surgeon can prefer a first type of chuck and a second surgeon can prefer a second type of chuck. Use of bolt **121** can allow staff to change chucks in between surgery performed by the first and second surgeons.

Linear electric surgical hammer impact tool **100** can further include a piston **122** located at least partially within housing **106**. During operation, piston **122** can move in a first direction as indicated by arrow **124** (FIG. 1A). Motion in the first direction can cause a surface **126** of piston **122** to contact a surface **128** of shuttle **110** to generate an impact force to drive a tool into bone. Surface **128** of shuttle **110** can be a surface, sometimes called an impact surface, of tool holder **114**.

Motion of piston **122** in a second direction as indicated by arrow **125** (FIG. **1**B) can cause a flange **130** of piston **122** to impact a distal portion **132** of shuttle **110**. The impact of flange **130** with distal portion **132** can generate an extraction force that can allow for tools, such as broaches, rasps, etc. to be removed from bone.

Piston **122** can be constructed from dense materials to increase the impact forces generated. For example, piston **122** can be constructed of a metal, such a tungsten, that includes more mass for a given volume of material. The result is that for a given velocity, piston **122** can have a greater kinetic energy that can be transferred to tool holder **114** and/or shuttle **110** via piston **122** impacting tool holder **114** and/or shuttle **110** as disclosed herein.

Shuttle **114** can include a wall **134**. Wall **134** can define grooves **136** (labeled individually as grooves **136**A and **136**B). Piston **122** can include one or more protrusions **138** that fit within a respect one of grooves **136**. Protrusions **138** can act as bearings that secure piston **122** in a particular orientation as well as provide clearance between wall **134** and piston **122** to minimize friction.

Protrusions **138** can be constructed of a polymer. Polymer protrusions can be impregnated with a lubricant to further reduce friction and wear. Protrusions **138** can be secured to piston **122** via threads, adhesives, press fit, etc. The threaded interface between tool holder **114** and shuttle **110** can allow piston **122** to be placed within shuttle **110**. Once inside shuttle **110**, protrusions **138** can be passed through grooves **136** and attached to piston **122** thereby securing piston **122** in a desired orientation.

Piston **122** can comprise two components. For example, piston **122** can include a body portion **138** and a weight **140**. Both body portion **138** and weight **140** can be mad of metals, polymers, ceramics, or any combination thereof. For example, weight **140** can be made of a dense metal, such as tungsten, and body portion **138** can be made of a polymer. Weight **140** can be press into body portion **138**. Weight **140** can include a threaded portion **142** that can be used to secure piston to a moveable portion, such as magnets **144** of a motor **146**.

Motor **146** can be a linear electric motor and can include magnets **144** and a stator **148**. Electronics **150** can be electrically couple motor **146** to a trigger **152**. During operations, a user can depress trigger **152** to cause linear electric surgical hammer impact tool **100** to generate impact forces to drive a tool into bone and/or retract a tool from bone as disclosed herein.

Sensors **154** can be used to determine a position of piston **122** within shuttle **110**. For example, sensors **154** can be Hall effect sensors that can determine magnet flux generated by magnets **144**. Based on the magnetic flux, or changes in the magnetic flux, a position of piston **122** can be determined. Based on the position of piston **122**, electronics **150** can apply a current to stator **148** to drive piston **122** to generation impaction and retraction forces. For example, motor **146** can be a tubular electromagnetic linear motor with a coil structure, e.g., stator **148**, fixed inside the housing **106**. The coil structure actuates a magnetic or ferromagnetic mechanical impact motion element, e.g., magnets **144**, which are connected to piston **122**, to cause motion base on the position of the magnets as determined by the sensors **154**.

Housing **106** can include a partition **156**. As disclosed herein, shuttle **110** can oscillate in the first direction as indicated by arrow **124** and the second direction as indicated by arrow **125**. When piston **122** is not in contact with surface **128** or distal portion **132**, shuttle **110** can be biased toward a neutral position by biasing elements **158** (labeled individually as biasing elements **158**A and **158**B). Biasing elements **158** can be springs (tensions and/or compression), rubber structures, airbags, etc.

During operation, piston **122** can travel in the first direction and strike surface **128**. After striking surface **128**, biasing element **158**B can push tool holder **114** and shuttle **110** in the second direction to reset shuttle for additional impacts as piston **122** repeatedly strikes surface **128**. Shuttle **110** can also be biased in the second direction by the user pressing linear electric surgical hammer impact tool **100** against a bone. In this instance biasing element **158**A can act as a shock absorber to mitigate shuttle impacting partition **156** after piston **122** strikes surface **128**.

Also, during operation piston **122** can travel in the second direction and strike distal portion **132**. After striking distal portion **132**, biasing element **158**A can push shuttle **110** in the first direction to reset shuttle for additional impacts as piston **122** repeatedly strikes distal portion **132**. Shuttle **110** can also be biased in the first direction by the user pulling linear electric surgical hammer impact tool **100** away from a bone. In this instance biasing element **158**B can act as a shock absorber to mitigate shuttle **110** impacting cap **104** after piston **122** strikes distal portion **132**.

Wall **134** can also define holes **160** (labeled individually as holes **160**A, **160**B, **160**C, and **160**D. Plug **162** (labeled individually as plugs **162**A, **162**B, **162**C, and **162**D) can be inserted into holes **160**. Plugs **162** can be polymer plugs that are impregnated with a lubricant. Thus, plugs **162** can provide friction reduction while supporting shuttle **110**. Supporting shuttle **110** can act to keep protrusions **138** aligned within grooves **136** to minimize friction and/or binding that could reduce impact forces.

FIG. **2** shows an example of a linear electric surgical hammer impact tool **200** consistent with at least one example of this disclosure. As disclosed herein, linear electric surgical hammer impact tool **200** can provide a simple, efficient, and robust battery powered handheld linear electric surgical hammer impact tool for use in surgical procedures. Linear electric surgical hammer impact tool **200** can include a distal end cap and a proximal end cap **202** on opposite ends of a housing **204**. Housing **204** can sometimes be referred to as a tool body and can define a cavity **206**.

A shuttle **210** can be located within cavity **206** and arranged along a longitudinal axis **212** of housing **204**. A tool holder **214** can be connected to shuttle **210**. For example, and as shown in FIG. **2**, a threadable connection **208** can allow tool holder **214** to be threadably connected to shuttle **210**. Other forms of attaching tool holder **214** to shuttle **210** can include adhesives, press fit, welding, screws, etc.

Tools, such as a rasp, broach, etc., can be attached directed to tool holder **214**. For example, a broach can be secured to tool holder **214** via a pin, threads, etc. Consistent with embodiments disclosed herein, a chuck **220** can be attached to tool holder **214**. Chuck **220** can be a quick connect/disconnect chuck that allows for a surgeon or other operating room staff to quickly connect and disconnect tools from linear electric surgical hammer impact tool **200**. For example, chuck **220** can allow a surgeon to quickly disconnect a first rasp from linear electric surgical hammer impact tool **200** and quickly connect a second rasp, which can be a different size and/or shape than the first rasp, to linear electric surgical hammer impact tool **200**. Chuck **220** can be attached to tool holder **214** via a bolt or other mechanism as disclosed herein with respect to chuck **120**.

Linear electric surgical hammer impact tool **200** can further include a piston **222** located at least partially within housing **204**. During operation, piston **222** can move in a first direction as indicated by arrow **224**. Motion in the first direction can cause a first end **226** of piston **222** to seat within a recess **227** defined by tool holder **214** to generate an impact force to drive a tool into bone.

Motion of piston **222** in a second direction as indicated by arrow **225** can cause a flange **230** of piston **222** to impact a distal portion **232** of shuttle **210**. The impact of flange **230** with distal portion **232** can generate an extraction force that can allow for tools, such as broaches, rasps, etc. to be removed from bone.

Piston **222** can be constructed from dense materials to increase the impact forces generated. For example, piston **222** can be constructed of a metal, such a tungsten, that includes more mass for a given volume of material. The result is that for a given velocity, piston **222** can have a greater kinetic energy that can be transferred to tool holder **214** and/or shuttle **210** via piston **222** impacting tool holder **214** and/or shuttle **210** as disclosed herein.

Shuttle **214** can include a wall **234**. Wall **234** can define grooves **236** (labeled individually as grooves **236**A and **236**B). Piston **222** can include one or more protrusions as disclosed herein with respect to protrusions **138** that fit within a respect one of grooves **236** and act as bearings that secure piston **222** in a particular orientation as well as provide clearance between wall **234** and piston **222** to minimize friction. The protrusions can be constructed of polymers that are impregnated with lubricants and connected to piston **222** as disclosed herein.

Piston **222** can be connected to a slider element **233** via a connecting member **235**. Connecting member **235** can be a threaded rod, a rod press fitted into both slider element **233** and piston **222**, welded to slider element **233**, and/or via adhesives. Piston **222** can include weights and can be multiple components as disclosed with respect to piston **122**.

Slider element **233** can be a portion of a motor **246**, which can be a linear electric motor and can include magnets **244** and a stator **248**. As disclosed herein, electronics can be electrically couple motor **246** to a trigger. During operations, a user can depress the trigger to cause linear electric surgical hammer impact tool **200** to generate impact forces to drive a tool into bone and/or retract a tool from bone as disclosed herein.

Sensors **254** can be used to determine a position of piston **222** within shuttle **210**. For example, sensors **254** can be Hall effect sensors that can determine magnet flux generated by magnets **244**. Based on the magnetic flux, or changes in the magnetic flux, a position of piston **222** can be determined. Based on the position of piston **222**, the electronics can apply a current to stator **248** to drive piston **222** to generation impaction and retraction forces. For example, motor **246** can be a tubular electromagnetic linear motor with a coil structure, e.g., stator **248**, fixed inside the housing **204**. The coil structure actuates a magnetic or ferromagnetic mechanical impact motion element, e.g., magnets **244**, which are connected to piston **222**, to cause motion base on the position of the magnets as determined by the sensors **254**.

Housing **204** can include a partition **256**. As disclosed herein, shuttle **210** can oscillate in the first direction as indicated by arrow **224** and the second direction as indicated by arrow **225**. When piston **222** is not in contact with tool holder **214** or distal portion **232**, shuttle **210** can be biased toward a neutral position by biasing elements **258** (labeled individually as biasing elements **258**A and **258**B). Biasing elements **258** can be springs (tensions and/or compression), rubber structures, airbags, etc.

During operation, piston **222** can travel in the first direction and strike tool holder **214**. After striking tool holder **214**, biasing element **258**B can push tool holder **214** and shuttle **210** in the second direction to reset shuttle for additional impacts as piston **222** repeatedly strikes tool holder **214**. Shuttle **210** can also be biased in the second direction by the user pressing linear electric surgical hammer impact tool **200** against a bone. In this instance biasing element **258**A can act as a shock absorber to mitigate shuttle **210** impacting partition **256** after piston **222** strikes tool holder **214**.

Also, during operation piston **222** can travel in the second direction and strike distal portion **232**. After striking distal portion **232**, biasing element **258**A can push shuttle **210** in the first direction to reset shuttle for additional impacts as piston **222** repeatedly strikes distal portion **232**. Shuttle **210** can also be biased in the first direction by the user pulling linear electric surgical hammer impact tool **200** away from a bone. In this instance biasing element **258**B can act as a shock absorber to mitigate shuttle impacting cap **202** after piston **222** strikes distal portion **232**.

The following describes an additional embodiment of an impact instrument designed for using in orthopedic joint replacement procedures, among other surgical procedures. The impact instrument described below is another instrument that utilizes a linear electric motor to drive a hammer assembly within a shuttle structure to produce forward and/or reverse impacts on an attached instrument, such as a broach or rasp. As with the tool described above, an electric motor can be configured to drive the impact elements to create the impact forces. The following description focused on areas where this example impact instrument differs from the device described above. The basic operational characteristics are similar between the two examples, as they both utilize a similar linear electric motor to drive the hammer assembly to create impact forces at an attached impact instrument, such as a broach or rasp.

FIG. **3** is a cut away view of a linear electric impact tool **300** consistent with at least one example of this disclosure. In this example, the impact tool **300** is illustrated in a partial cut away view with a portion of the housing **302** removed to allow visualization of certain sub-assemblies within the tool. The cut away portion of the housing **302** reveal the shuttle assembly **310** and the linear electric motor assembly **320**. The shuttle assembly **310** is the structure that produces the impact forces transferred to an instrument coupled to the chuck **330**. The shuttle can include a cylindrical body that contains impact receiving structures on both the distal and proximal ends. The shuttle also retains the impact hammer assembly that is the portion of the impact tool **300** that moves to generate impact forces. The impact hammer assembly is linearly translated by the linear electric motor assembly **320**. Details on these sub-assemblies are discussed below in reference to FIGS. **4**A-**8**B.

The impact tool **300** also includes a battery assembly **340** and a handle **350**. In this example, the handle **350** includes a trigger **352** for activation of the impact tool **300**. The housing **302** also includes a proximal end cap **304** that threads into a proximal end of the housing **302**. Adjacent the proximal end cap **304** is a proximal cap seal **306** that seals the proximal end of the impact tool **300**.

In this example, the housing **302** of the impact tool **300** is an injection molded plastic or polymer that is laser welded together during the assembly process. The housing **302** is specifically designed to minimize impacts on the motor dynamics of the linear electric motor assembly **320**. The use of injection molded plastic was favored over a metal housing, such as aluminum, to avoid eddy current braking effects on the linear electric motor. Another housing material choice that can be used to similarly avoid eddy current impacts would be laminating non-conductive or low conductivity metals to form the housing **302**.

FIG. **4**A is a perspective view illustrating multiple sub-assemblies of a linear electric impact tool **300** consistent with at least one example of this disclosure. In this example, FIG. **4**A illustrates the shuttle assembly **310** and the linear electric motor assembly **320** extracted from the impact tool **300**. In this example, the shuttle assembly **310** includes a cylindrical shuttle housing **401** with multiple shuttle vents **402** and at least two opposing key grooves to receive shuttle keys **405**. The shuttle vents **402** operate to vent the interior portion of the shuttle housing **401**, which reduces air compression induced drag on the hammer assembly **430**. The shuttle keys **405** restriction rotation of the shuttle housing **401** relative to the housing **302** of the impact tool **300**. The shuttle assembly **310** also includes a distal energy absorption assembly **440** discussed in detail below. The linear electric motor assembly **320** can include control circuit assembly **322** that includes a circuit board containing control electronics for controlling the linear electric motor and providing position feedback regarding the hammer assembly within the shuttle housing **401**. The figure also includes illustration of the chuck **330** and chuck lock **332**. The chuck lock **332** rotates to lock an impact instrument into the impact tool **300**.

FIG. **4**B is a cross section view of multiple sub-assemblies of a linear electric impact tool **300** consistent with at least one example of this disclosure. In this example, the sub-assemblies discussed above are illustrated in cross section to detail additional components within each sub-assembly. In this example, the linear electric motor assembly **320** can include the linear electric motor, the control circuit assembly **322** and a position sensor assembly **470**. The position sensor assembly **470** includes a structure that clips into the shuttle housing **401** to monitor position of the shuttle assembly **310** during operation. The linear electric motor (discussed in detail above) includes internal sensors to provide feedback on the position of the hammer assembly **430**.

In this example, the shuttle assembly **310** includes the shuttle housing **401**, an impact assembly **410**, the hammer assembly **430**, the distal energy absorption assembly **440**, the proximal energy absorption assembly **450**, and the impact shaft bearing assembly **460**. The impact assembly **410** can include an impact button **412** and an impact interface **414**. The impact button **412** is for receiving forward impacts from the impact hammer **432**. In order to minimize energy loss due to vibrations, the impact button **412** can be made of a low-loss polymer material, such as Acetal® or Delrin®. The low-loss polymers have low wear characteristics allowing the impact assembly **410** to provide a long service life. In this example, the impact hammer **432** is part of the hammer assembly **430** that also includes a reverse impact piston **434**. The impact button **412** also includes a pocket formed to receive the radiused proximal surface of the impact hammer **432**, which further enhances energy transfer between the impact hammer **432** and the impact button **412**. The radius of the proximal surface allows the edge of the impact zone of the impact hammer **432** to avoid contact with the surface of the impact button **412**. The radius of the proximal surface can be in the range of 10% to 25% of the diameter of the impact button **412** and accomplish the goal of avoiding edge contact. In this example, the impact button **414** is held in a recess within the impact interface **414**. The impact interface **414** transfers energy received by the impact button **412** to an impact tool held in the chuck **330**. The impact interface **414** includes a proximal shaft extending outside the shuttle housing **401** that interfaces with a distal end of an impact shaft extending distally from the chuck **330**. The impact shaft is held in position by an impact shaft bearing assembly **460**.

In this example, the impact hammer **432** is a dense metal material to enhance the impact energy transfer to the impact button **412**. The combination of the dense metal impact hammer **432** and the stiff polymer impact button **412** operates like a dead blow hammer to efficiently transmit impact forces to an impact instrument coupled to the chuck **330**. The other component of the hammer assembly **430** is the reverse impact piston **434**, which can also be a dense metal material and is designed to impart reverse (or distal) impacts on the reverse impact cap **416** that is threaded into the distal end of the shuttle housing **401**. Similar to the impact button **412**, the reverse impact cap **416** can be made from a stiff polymer material to efficiently transmit reverse impact forces to the shuttle housing **401**. In certain examples, the reverse impact cap **416** can be made from a metallic material to enhance wear characteristics, while the system relies on the long force path created by the shuttle housing **401** to dampen any vibrations generated during reverse impacts.

In this example, the shuttle assembly **310** also includes a proximal bias spring **408** and a distal bias spring **409** (discussed here collectively as "bias springs"). The bias springs operate to keep the shuttle housing **401** centered within the housing **302** during operation. The bias springs also operate to dissipate excess impact energy not transferred into the impact instrument. In an example, energy dissipation is enhanced by the proximal energy absorption assembly **450** and the distal energy absorption assembly **440** (discussed here collectively as "energy absorption assemblies"). The energy absorption assemblies include additional energy absorbing components to dissipate impact forces in case of a dry fire or a situation where the impact instrument is not fully engaged or otherwise able to absorb the impact energy produced by the tool. The energy absorption assemblies operate to minimize negative force transmission to the housing **302** and ultimately to the user of the impact tool **300**. In this example, the distal energy absorption assembly **440** includes a reverse absorption ring **442** and a distal bias ring **444**. The reverse adsorption ring **442** can be made from energy absorbing rubber, such as Sorbothane®. The distal bias ring **444** can be a metallic ring that receives bias forces from the distal bias spring **409**. The proximal energy absorption assembly **450** can include a forward absorption ring **452** and a proximal bias ring **454**. Like the reverse absorption ring **442**, the proximal absorption ring **452** can be made from an energy absorbing rubber compound such as Sorbothane®. The proximal bias ring **454** is a metallic ring structure designed to receive the proximal bias spring **408** and protect the proximal absorption ring **452**. The distal bias ring **444** and the proximal bias ring **454** also operate to distribute forces from the bias springs as they are compressed by forward or reverse impacts.

The impact shaft bearing assembly **460** operates as a self-aligning shaft bearing on the impact shaft that transmits impacts from the shuttle assembly **310** to the chuck **330**. In an example, the impact shaft bearing assembly **460** can include a shaft bearing **462**, a bearing housing **464**, a housing O-ring **466**, a shaft seal **468**, and a snap ring **469**. The shaft bearing **462** guides the impact shaft and allows linear transverse movements of the impact shaft. The bearing housing **464** and housing O-ring **466** cooperate to create a self-aligning bearing assembly by allowing for minute angular movements of the impact shaft within the impact shaft bearing assembly **460**. The shaft seal **468** ensures no contaminates enter into the impact tool **300** via the impact shaft. Finally, the snap ring **469** holds the impact shaft bearing assembly **460** into the proximal end cap **304**.

FIG. **5**A is a cross section view of multiple sub-assemblies of a linear electric impact tool **300** consistent with at least one example of this disclosure. This figure strips away additional housing components of the impact tool **300** to provide for additional detailed views of the shuttle assembly **310** and linear electric motor assembly **320** (note, only the linear electric motor is shown in this figure). The illustrated example includes the impact assembly **410**, the hammer assembly **430**, the distal energy absorption assembly **440**, the proximal energy absorption assembly **450**, and the impact shaft bearing assembly **460** as part of the shuttle assembly **310**. Components of each of the illustrated assemblies are discussed above. FIG. **5**A also includes the position slider **472** and position magnet **474**, which are components of the position sensor assembly **470**.

FIG. **5**B is a cross section view of an impactor sub-assembly of a linear electric impact tool **300** consistent with at least one example of this disclosure. In this example, the impactor sub-assembly corresponds to the shuttle assembly **310** discussed above in reference to FIGS. **4**A-**5**A. In this example, only the shuttle assembly **310** is illustrated with the chuck **330** connected to the impact shaft extending from the impact interface **414**. FIG. **5**B enables additional detail to be visualized, such as the curvature on the proximal face of the impact hammer **432**. In an example, the proximal face of the impact hammer **432** includes a radius of 100 mm. The impact hammer **432** can be milled or cast from metallic materials, such as stainless steel or tungsten.

FIGS. **6**A-**6**C are various views of the shuttle sub-assembly **310** of a linear electric impact tool **300** consistent with at least one example of this disclosure. In this example, the shuttle assembly **310** is illustrated extracted from the remainder of the impact tool **300**. The shuttle assembly **310** can include a shuttle housing **401**, multiple shuttle vents **402**, opposing key groove **406** to receive shuttle keys **405**. The figures also include components such as distal energy absorption assembly **440** and distal bias spring **409**. A threaded end of the impact hammer **432** is shown extending distally from the reverse impact piston **434**. In an example, the linear electric motor threads onto the impact hammer **432**. On the proximal end of the shuttle housing **401** the proximal end of the impact interface **414** is illustrated. The proximal end of the impact interface **414** receives the impact shaft that couples to the chuck **330**.

FIGS. **6**B and **6**C include illustrations of parts of the position sensor assembly **470** such as the position slider **472**, the position magnet **474**, and the slider clip **476**. The slider clip **476** is the component that couples the position sensor assembly **470** to the shuttle housing **401**. More specifically, the slide clip **476** couples to a superior end of the position slider **472** that includes a narrowed cross section to be received into the slide clip **476**. The slide clip **476** allows for the shuttle assembly **310** and parts of the linear electric motor assembly **320** to be easily inserted into the tool housing **302** after the electronics and battery are assembled into the housing **302**. The slide clip **476** is designed to require a low coupling force due to the angled arms and a high uncoupling force due to the abrupt extensions on the arms. Accordingly, the shuttle and motor assemblies can be easily inserted, while also being possible (but difficult) to remove. The slide clip **476** is designed to release the shuttle assembly **310** if sufficient force is exerted allowing for maintenance or repair of these key components.

FIG. **6**D is a cross section view of the shuttle sub-assembly **310** of a linear electric impact tool **300** consistent with at least one example of this disclosure. This figure is included to provide additional perspective on orientation of different illustrated components. The details of each of the illustrated components is included above.

FIG. **7** is a cross section view of a self-aligning impact shaft bearing structure for a linear electric impact tool **300** consistent with at least one example of this disclosure. In this example, the impact shaft bearing assembly **460** is illustrated positioned within the proximal end cap **304** of the housing **302**. Also included in this illustration is the proximal energy absorption assembly **450** that includes the forward absorption ring **452** and the proximal bias ring **454**. The proximal energy absorption assembly **450** is positioned within a deep cylindrical groove in the distal side of the proximal end cap **304**. The proximal end cap **304** also includes a central cylindrical bore with a snap ring groove to retain the impact shaft bearing assembly **460**. As discussed above, the impact shaft bearing assembly includes the shaft bearing **462**, the bearing housing **464**, the housing O-ring **466**, and the shaft seal **468**. In this example, the housing O-ring **466** is depicted within an O-ring groove in the outer surface of the bearing housing **464**. The housing O-ring **466** is biased towards the proximal end of the bearing housing **464** in this example. In another example, the housing O-ring **466** can be positioned within an groove centered between the proximal and distal ends of the bearing housing **464**. A centered O-ring groove provide different angular self-alignment characteristics. Similarly, the groove could be positioned near the distal end of the bearing housing **464**, but this position may have limited angular self-alignment due to the proximity of the snap ring retaining the impact shaft bearing assembly **460**.

FIGS. **8**A-**8**B are various views of the position sensor sub-assembly **470** for a linear electric impact tool **300** consistent with at least one example of this disclosure. In this example, the position sensor assembly **470** includes the position slider **472**, the position magnet **474**, the track **475**, the slider clip **476** and position sensors **478**A, **478**B (collectively referenced as position sensors **478**). The position slider **472** clips into the slider clip **476** to couple the position slider **472** to the shuttle housing **401**. The purpose of the position sensor assembly **470** is to provide position tracking information for the shuttle assembly **310** and more specifically the shuttle housing **401**. The position of the shuttle housing **401** is used for a number of control functions including predicting user intent (surgeon intent feature). The impact tool **300** includes control circuitry, including the position sensor assembly **470**, to predict user intent regarding forward or reverse impacts. Surgeon intent is discussed in more detail below in reference to the flowchart in FIG. **11**.

The position sensor assembly **470** includes two position sensors **478** in order to cover the needed travel distance and to provide both position and directionality of movement. The sensor configuration also allows for on-the-fly calibration as well as tool function verification on start-up (discussed in more detail in reference to FIG. **10** below). In an example, the position sensors **478** are hall-effect sensors. The principle of the "Hall effect" involves a current carrying conductor or semiconductor being introduced to a perpendicular magnetic field, a voltage can be measured at the right angle to the current path. In the present system, the position magnet **474** produces the magnetic field that is then sensed by the position sensors **478**, which produce a voltage ranging from 0-3.3 volts. The control circuit assembly **322** includes processing instructions and/or circuitry that combines the output from the two sensors to determine the position of the shuttle housing **401**. The processing instructions and/or circuitry can also determine movement direction from the sensor output. Sensor output processing is discussed in greater detail in reference to FIGS. **12**A and **12**B below.

FIGS. **9**A-**9**C are cross section views of the shuttle assembly **310** and parts of the linear electric motor assembly **320** illustrating various hammer assembly **430** positions during operation of the impact tool **300**. FIG. **9**A illustrates a reverse impact position for the hammer assembly **430**. In this position, the hammer assembly **430** is at the distal most position within the impact tool **300**. The shuttle housing **401** is compressing the distal bias spring **409** and imparting a reverse impact on any impact instrument attached to the chuck **300**. FIG. **9**B illustrates the hammer assembly **430** and the shuttle housing **401** in a forward impact position. In the forward impact position, the hammer assembly **430** is impacting the impact button **412** and transmitting impact forces to an impact instrument attached to the chuck **330**. The proximal bias spring **408** is fully compressed in this position. FIG. **9**C illustrates the impact assembly **430** and the shuttle housing **401** in a neutral position. In the neutral position, both of the bias springs are operating to center the shuttle housing **401**. With the hammer assembly **430** parked in a neutral position, such as shown in FIG. **9**C, the shuttle housing **401** can be biased distally or proximally by the user pressing down or pulling back on an impact instrument attached to the impact tool **300**. The biasing of the shuttle housing **401** and the resulting change in signals from the position sensor assembly is utilized by the control circuit to predict intent of the user (e.g., to predict whether a forward or reverse impact is desired when the trigger is pulled). If a forward impact is intended, the user will push down on the impact instrument, which will bias the shuttle housing **401** distally. Conversely, if a reverse impact is intended, the user will pull back on the impact tool, which will bias the shuttle housing **401** proximally. Of course, this assumes there is some resistance to pulling the impact instrument out to cause the biasing of the shuttle housing **401**. The surgeon (user) intent technique is discussed further below in reference to FIG. **11**.

FIG. **10** is a flowchart illustrating a homing and calibration technique **1000** for a linear electric impact tool consistent with at least one example of this disclosure. In this example, the technique **1000** can include operations such as initiating homing sequence at **1002**, backing to a hard stop at **1004**, monitoring sensors at **1006**, determining if in distal home position at **1008**, move to forward home position at **1010**, monitoring sensors at **1012**, determining if in proximal home position at **1014** and optionally calibrating sensors at **1016**.

The technique **1000** can begin at **1002** with the impact tool **300** powering up and initiating a home sequence. The home sequence can be initiated at other times if the control circuitry detects a malfunction or through manual initiation as needed. At **1004**, the technique **1000** continues with the linear electric motor assembly **320** moving the hammer assembly **430** in reverse to find a hard stop. During the reserve to hard stop operation, the technique **1000** continues with the control circuitry monitoring sensor outputs at **1006**. The control circuitry monitors sensor outputs from the linear electric motor assembly **320** and the position sensor assembly **470**. One of the monitored outputs is motor torque, with the control circuitry monitoring for a spike in motor torque that should indicate reaching the reverse hard stop. When the motor torque spike above a pre-defined threshold the position sensors are read to see if the hammer assembly **430** reached the expected reverse hard stop position. In the expected full reverse position, the distal position sensor **478**A should be at or near peak voltage of 3.3 volts and the proximal position sensor **478**B should be below a pre-defined threshold, such as below 2.5 volts or below 1.25 volts. The thresholds used in these algorithms can be adjusted during calibration. At **1008**, the technique **1000** continues with the control circuitry determining if the motor torque and sensor output readings indicate that the motor and hammer assembly **430** reached the reverse hard stop position (e.g., distal home), if confirmed the technique **1000** continues to operation **1010**. If not, the technique **1000** loops back to operation **1006** and the control circuitry continues to monitor the sensors back at **1006**.

At **1010**, the technique **1000** continues with the linear electric motor assembly **320** slowly moving the hammer assembly **430** forward to a proximal home position (where the proximal end of the tool includes the impact instrument). At **1012**, the technique **1000** continues with the control circuitry monitoring sensor outputs while the motor moves the hammer assembly **430** to the proximal home position. The sensor outputs monitored at **1012** can include motor torque, distance traveled, and the position sensors **478** (in particular the proximal position sensor **478**B). At **1014**, the technique **1000** continues with the control circuitry determining whether the proximal home position has been reached. Indications of the hammer assembly **430** reaching the proximal home position can include distance traveled (as measured by the linear electric motor assembly **320**), sensing a motor torque peak, and sensing a peak in the proximal position sensor **478**B. If the pre-defined parameters are met, the technique **1000** can continue to optionally calibrate the position sensors at **1016**. If the parameters are not met, then the technique **1000** loops back to operation **1012** and the control circuitry continues to monitor sensor outputs. At **1016**, the technique **1000** can conclude with the control circuitry using the position sensor outputs at the distal and proximal home positions to calibrate the output of the position sensors **478**. During the various homing maneuvers the control circuitry can collect the range of output (maximum voltage and minimum voltage) from each sensor. From the minimum and maximum voltage values, the control circuitry captures the offset and range of each sensor, which then allows the control circuitry to calibrate an offset and gain for each sensor based on this data.

FIG. **11** is a flowchart illustrating a surgeon intent detection technique **1100** consistent with at least one example of this disclosure. The surgeon (e.g., user) intent detection technique describes how the impact tool **300** responds to surgeon input to determine which direction to produce impact forces (e.g., forward impacts versus reverse impacts). The technique is implemented within control circuitry that is part of the linear electric motor assembly **320** and more specifically part of the control circuit assembly **322**. In this example, the technique **1100** can include operations such as detecting a trigger pull at **1102**, determining shuttle housing position at **1104**, determining impact direction at **1106**, initiating a forward impact at **1108** or initiating a reverse impact at **1110**, determining whether to repeat impacts at **1112**, and parking the impact hammer at **1114**.

In this example, the technique **1100** begins at **1102** with the control circuitry detecting a trigger pull has occurred. At

1104, the technique 1100 continues with the control circuitry interrogating the position sensor assembly 470 to determine shuttle housing 401 position within the impact tool 300. At 1106, the technique 1100 continues with the control circuitry determining an intended impact direction based on the position of the shuttle housing 401. If the position sensor assembly 470 indicates that the shuttle is pushed distally into the impact tool, then a forward impact is intended. If the position sensor assembly 470 indicates that the shuttle is being pulled proximally, then a reverse impact is intended. If the shuttle housing 401 is in a neutral position, the control circuitry will initiate an impact in the same direction as the previous impact.

As part of the operation 1106, the technique 1100 includes the control circuitry receiving position information from both of the position sensors 478. The first option for determining impact intent direction involves a logical flip-flop function. With the logical flip-flop, the output from each of the position sensors is feed through a relay function that includes a pre-defined threshold voltage value resulting in an ON or OFF signal (e.g., binary signal) from each of the position sensors. The binary signals are then feed into a flip-flop circuit, such that if the distal position sensor 478A is ON and the proximal position sensor 478B is off the intent direction is set to forward and if the distal position sensor 478A is OFF and the proximal position sensor 478B is ON the intent direction is set to reverse.

The second option for determining impact intent direction involves merging the outputs of the position sensors and using a relay function to switch between forward intent and reverse intent. In this option, the control circuitry reads the output from each position sensor 478, subtracts an offset from the output values, and feed the result into an arctangent function. The output of the arctangent function is feed through an unwrap function to avoid jumps in the output, with the output of the unwrap function resulting in a linear output of shuttle housing 401 position. The output of the unwrap function is then feed through a relay function with two directional thresholds to switch intent direction. Starting in a distal most position, as the shuttle housing 401 position moves proximally, the forward intent direction is maintained until the processed position data indicates it passes a proximal threshold at which time the intent direction is switched to reverse impacts. The control circuitry maintains the reverse impact intent until the shuttle housing position indicate travel back in a distal direction pass a distal threshold. The proximal and distal thresholds are pre-defined positions that can be programmed within the control circuitry.

At 1108, the technique 1100 continues to initiate a forward impact if the shuttle housing 401 is determined to be positioned more distally within the impact tool 300. In this condition, the control circuitry will trigger a forward impact trajectory that involves moving the hammer assembly 430 distally to a pre-defined position and accelerating the hammer assembly 430 proximally to impact the impact button 412. The control circuitry will determine what intensity setting the tool is on and select a forward impact trajectory accordingly. On a low setting, the hammer assembly 430 can start the forward impact trajectory at a first location that is more proximal than if the tool is set to higher intensity setting. On higher intensity settings, the hammer assembly 430 can be moved close to the distal most range of movement for the linear electric motor assembly 320.

At 1110, the technique 1100 can continue with the control circuitry initiating a reverse impact if the shuttle housing 401 is determined to be positioned more proximally within the impact tool 300. In this condition, the control circuitry will trigger a reverse impact trajectory that involves moving the hammer assembly 430 proximally from a parked position to a pre-defined start position and accelerating the hammer assembly 430 distally to impact the reverse impact cap 416. In an example, the reverse impacts can all be started from the same pre-defined position proximal of a neutral parking position.

At 1112, the technique 1100 continues with the control circuitry determining whether the impact tool 300 is configured for repeated impacts (including whether the trigger remains activated). If no repeated impacts condition is detected, the technique 1100 can conclude at 1114 with the control circuitry commanding the linear electric motor assembly 320 to park the hammer assembly 430. If the repeated impacts condition is detected, then the technique 1100 returns to operation 1104 to determine the shuttle housing 401 position to evaluate surgeon intent for the next impact. The continued monitoring of surgeon intent in this manner allows for impact techniques such as sawing to be performed with the impact tool 300.

NOTES

The above detailed description includes references to the accompanying drawings, which form a part of the detailed description. The drawings show, by way of illustration, specific embodiments in which the invention can be practiced. These embodiments are also referred to herein as "examples." Such examples can include elements in addition to those shown or described. However, the present inventors also contemplate examples in which only those elements shown or described are provided. Moreover, the present inventors also contemplate examples using any combination or permutation of those elements shown or described (or one or more aspects thereof), either with respect to a particular example (or one or more aspects thereof), or with respect to other examples (or one or more aspects thereof) shown or described herein.

In the event of inconsistent usages between this document and any documents so incorporated by reference, the usage in this document controls.

In this document, the terms "a" or "an" are used, as is common in patent documents, to include one or more than one, independent of any other instances or usages of "at least one" or "one or more." In this document, the term "or" is used to refer to a nonexclusive or, such that "A or B" includes "A but not B," "B but not A," and "A and B," unless otherwise indicated. In this document, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Also, in the following claims, the terms "including" and "comprising" are open-ended, that is, a system, device, article, composition, formulation, or process that includes elements in addition to those listed after such a term in a claim are still deemed to fall within the scope of that claim. Moreover, in the following claims, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements on their objects.

The above description is intended to be illustrative, and not restrictive. For example, the above-described examples (or one or more aspects thereof) can be used in combination with each other. Other embodiments can be used, such as by one of ordinary skill in the art upon reviewing the above description. The Abstract is provided to comply with 37 C.F.R. § 1.72(b), to allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. Also, in the above Detailed Description, various features can be grouped together to streamline the disclosure. This should not be interpreted as intending that an unclaimed disclosed feature is essential to any claim. Rather, inventive subject matter can lie in less than all features of a particular disclosed embodiment. Thus, the following claims are hereby incorporated into the Detailed Description as examples or embodiments, with each claim standing on its own as a separate embodiment, and it is contemplated that such embodiments can be combined with each other in various combinations or permutations. The scope of the invention should be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

What is claimed is:

1. A linear electric surgical hammer impact tool comprising:

a housing defining a cavity extending along a longitudinal axis of the housing;

a shuttle located inside the cavity and arranged along the longitudinal axis of the housing, the shuttle comprising a first end, a second end, and a wall extending from the first end to the second end, the wall including opposing exterior key grooves extending a length of an exterior portion of the wall;

a hammer assembly located at least partially within a proximal end of the shuttle and arranged along the longitudinal axis of the housing;

a linear electric motor configured to drive a piston along the longitudinal axis in a first direction and a second direction; and

an impact assembly located at least partially within a distal end of the shuttle;

wherein motion of the hammer assembly in a first direction causes the hammer assembly to contact the first end of the shuttle to generate a forward impact and motion of the hammer assembly in a second direction causes the hammer assembly to contact the second end of the shuttle to generate a reverse impact.

2. The impact tool of claim **1**, wherein the hammer assembly includes an impact piston surrounding an impact hammer.

3. The impact tool of claim **2**, wherein the impact hammer includes a curved proximal contact surface.

4. The impact tool of claim **3**, wherein the curved proximal contact surface includes a radius of 100 mm.

5. The impact tool of claim **2**, wherein the impact piston includes a distal circumferential ridge to engage a reverse impact cap to generate reserve impacts.

6. The impact tool of claim **2**, wherein the impact assembly includes an impact button adapted to receive impacts from the impact hammer.

7. The impact tool of claim **6**, wherein the impact assembly includes an impact interface adapted to transfer impacts received on the impact button to an impact tool held in a chuck adjacent a distal end of the impact tool.

8. The impact tool of claim **6**, wherein the impact button is a polymer material and the impact hammer is a dense metal.

9. The impact tool of claim **6**, wherein the impact button includes a pocket formed to receive a radiused proximal surface of the impact hammer.

10. The impact tool of claim **1**, further comprising a proximal bias spring and a distal bias spring that operate to center the shuttle within the house and absorb excess impact energy.

11. The impact tool of claim **1**, further comprising a proximal energy absorption assembly and a distal energy absorption assembly.

12. The impact tool of claim **11**, wherein the proximal energy absorption assembly includes a forward absorption ring and a proximal bias ring.

13. The impact tool of claim **12**, wherein the forward absorption ring is an energy absorbing rubber and the proximal bias ring is a metallic ring structure adapted to receive a proximal bias spring.

14. The impact tool of claim **1**, wherein an impact shaft transmits impact from the impact assembly and extends distally through an impact shaft bearing assembly, the impact shaft bearing assembly operating as a self-aligning shaft bearing on the impact shaft.

15. The impact tool of claim **1**, further comprising a position sensor assembly including a slider clip to removably couple a position slider to the shuttle.

16. A method of homing an impact tool, the method comprising:

operating a linear electric motor to reverse a shuttle mechanism to a distal hard stop;

monitoring a position sensor assembly during operation of the linear electric motor;

determining, based on feedback from the position sensor assembly and the linear electric motor, that a distal home position has been reached;

upon determining that the distal home position was reached, operating the linear electric motor to move the shuttle mechanism to a proximal home position; and

determining, based on feedback from the position sensor assembly and the linear electric motor, that the proximal home position has been reached.

17. The method of claim **16**, wherein the determining the distal home position has been reached includes monitoring voltages on a distal position sensor and a proximal position sensor.

18. The method of claim **16**, further comprising calibrating the sensor assembly based on voltage readings at the distal home and proximal home positions.

19. A method of operating an impact tool, the method comprising:

detecting activation of a trigger mechanism to initiate an impact from the impact tool;

determining a position of a shuttle assembly within a housing of the impact tool, the shuttle assembly including components adapted to generate an impact;

determining, from the position of the shuttle assembly, an intended impact direction; and

delivering an impact in the intended impact direction by operating a linear electric impact mechanism.

20. The method of claim **19**, further comprising after delivering the impact, determining, based on a position of the trigger mechanism, whether to repeat delivery of the impact.

21. The method of claim **20**, further comprising, upon determining not to repeat delivery of the impact, parking the linear electric impact mechanism.

* * * * *