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(54) **MECHANISMS FOR STRUT LENGTH MEASUREMENT**

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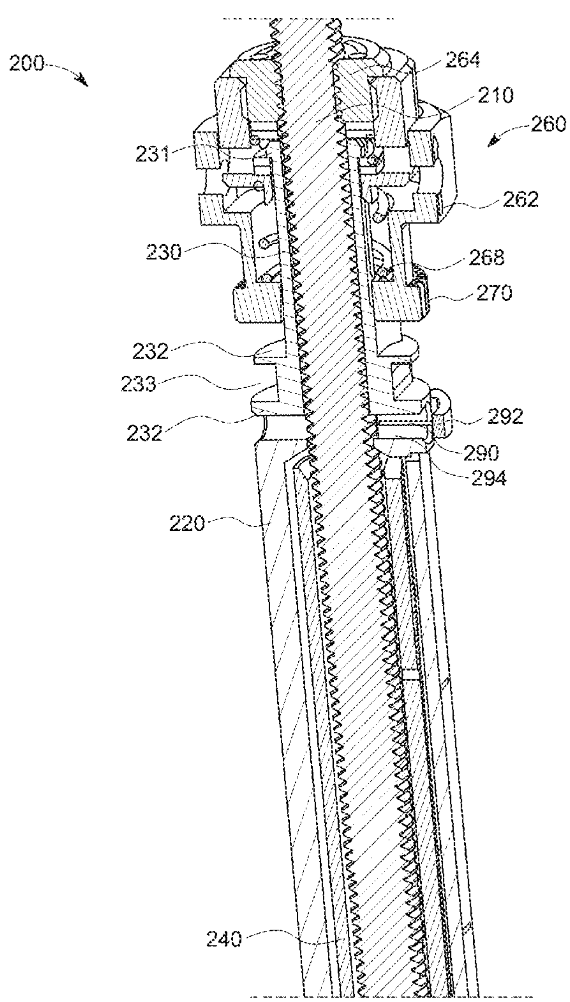
CPC ***A61B 17/6475*** (2013.01); ***A61B 17/66*** (2013.01); ***A61B 90/06*** (2016.02); *A61B 2090/061* (2016.02)

(57) **ABSTRACT**

A strut for use with an external fixation system may include first and second joints proximate the first and second ends of the strut, the first and second joints configured to couple to first and second rings of the external fixation system. The strut may include a threaded rod coupled to the first joint, a tube that receives the threaded rod, a fluctuation counter coupled to the tube, and a needle coupled to the fluctuation counter. The needle may extend through a bore in the outer tube, and the needle may have a free end in contact with the threaded rod. The strut may be an adjustable-length strut whereby the threaded rod is moveable axially into or out of the tube, and while the threaded rod moves into or out of the tube, the free end of the needle may be configured to maintain contact with the threaded rod.



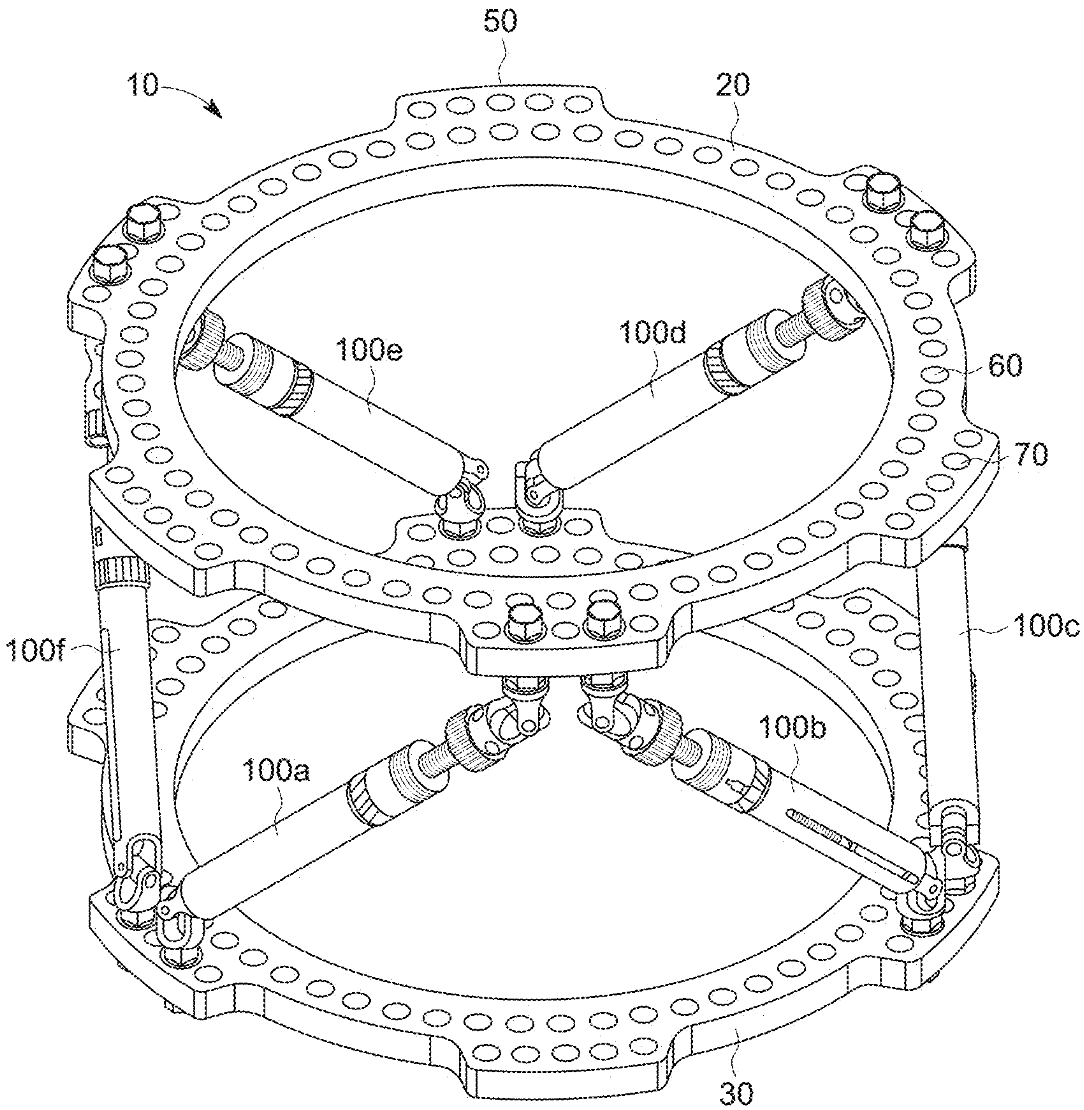


FIG. 1

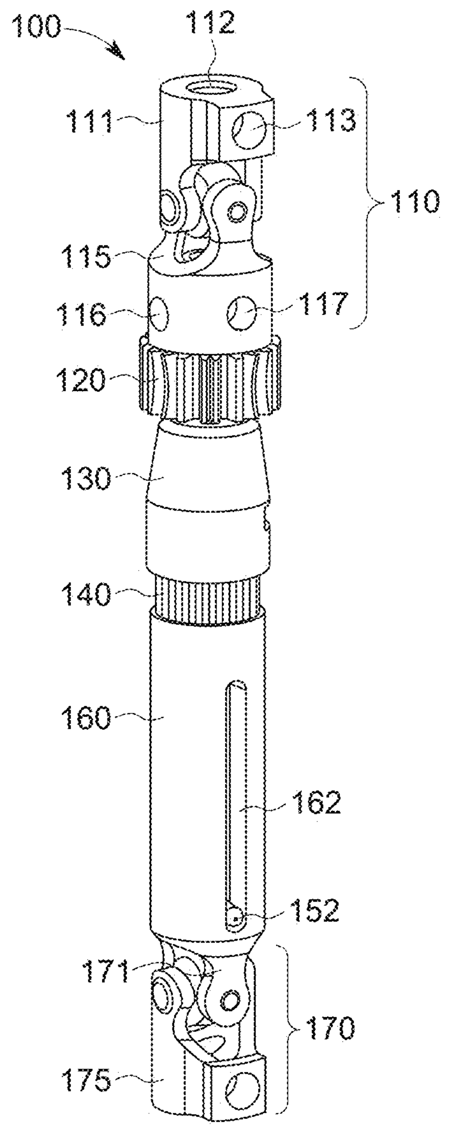

100
112
111
113
110
115
116
117
120
130
140
160
162
152
171
170
175

FIG. 2A

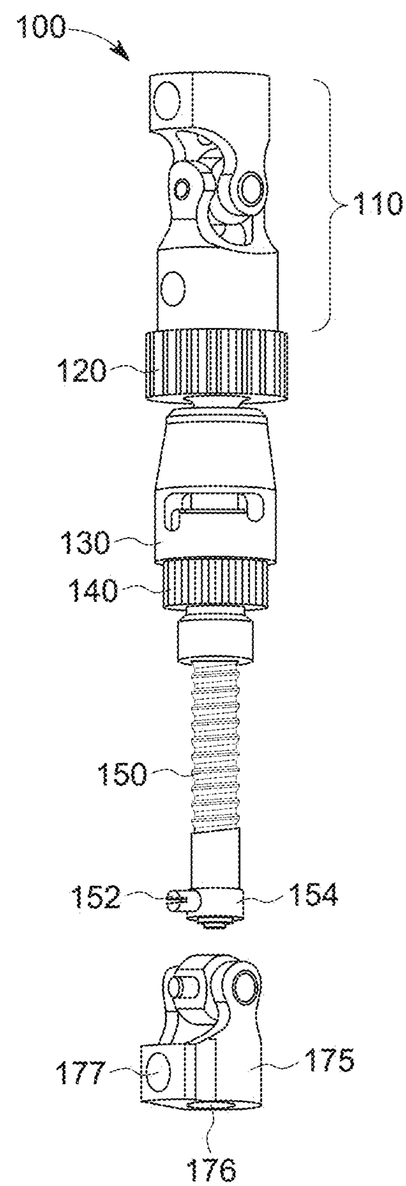

100
110
120
130
140
150
152
154
177
175
176

FIG. 2B

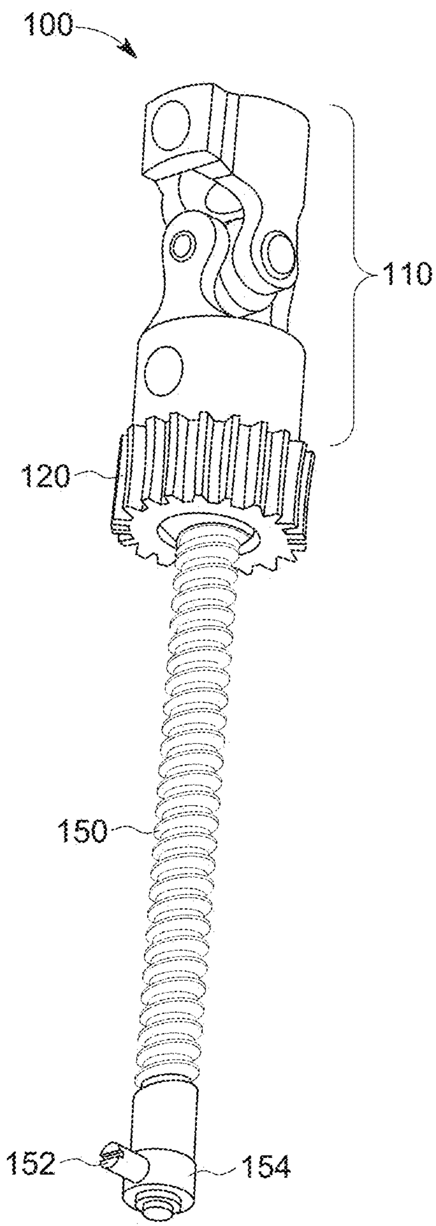


FIG. 2C

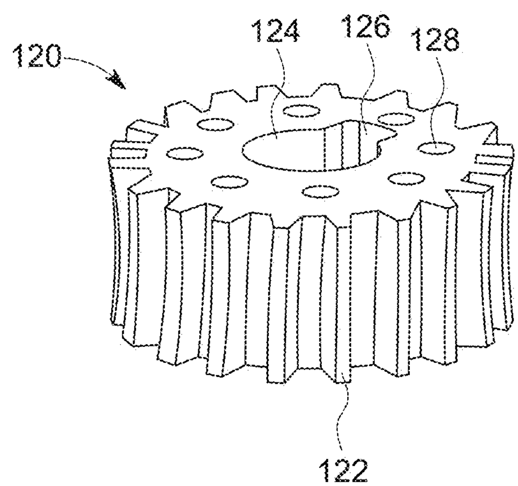


FIG. 2D

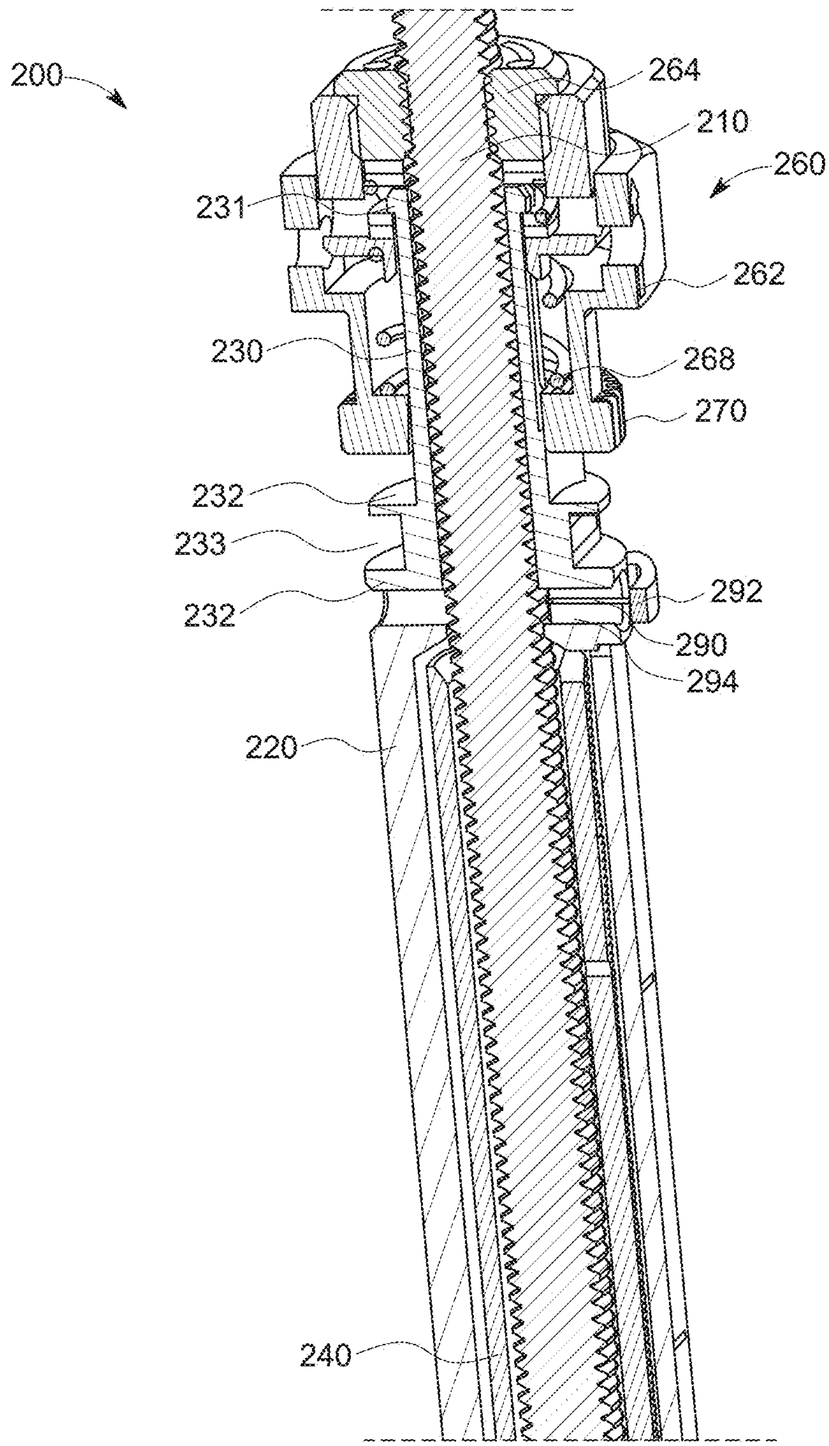

200
264
210
260
231
262
230
268
270
232
233
292
232
290
294
220
240

FIG. 3A

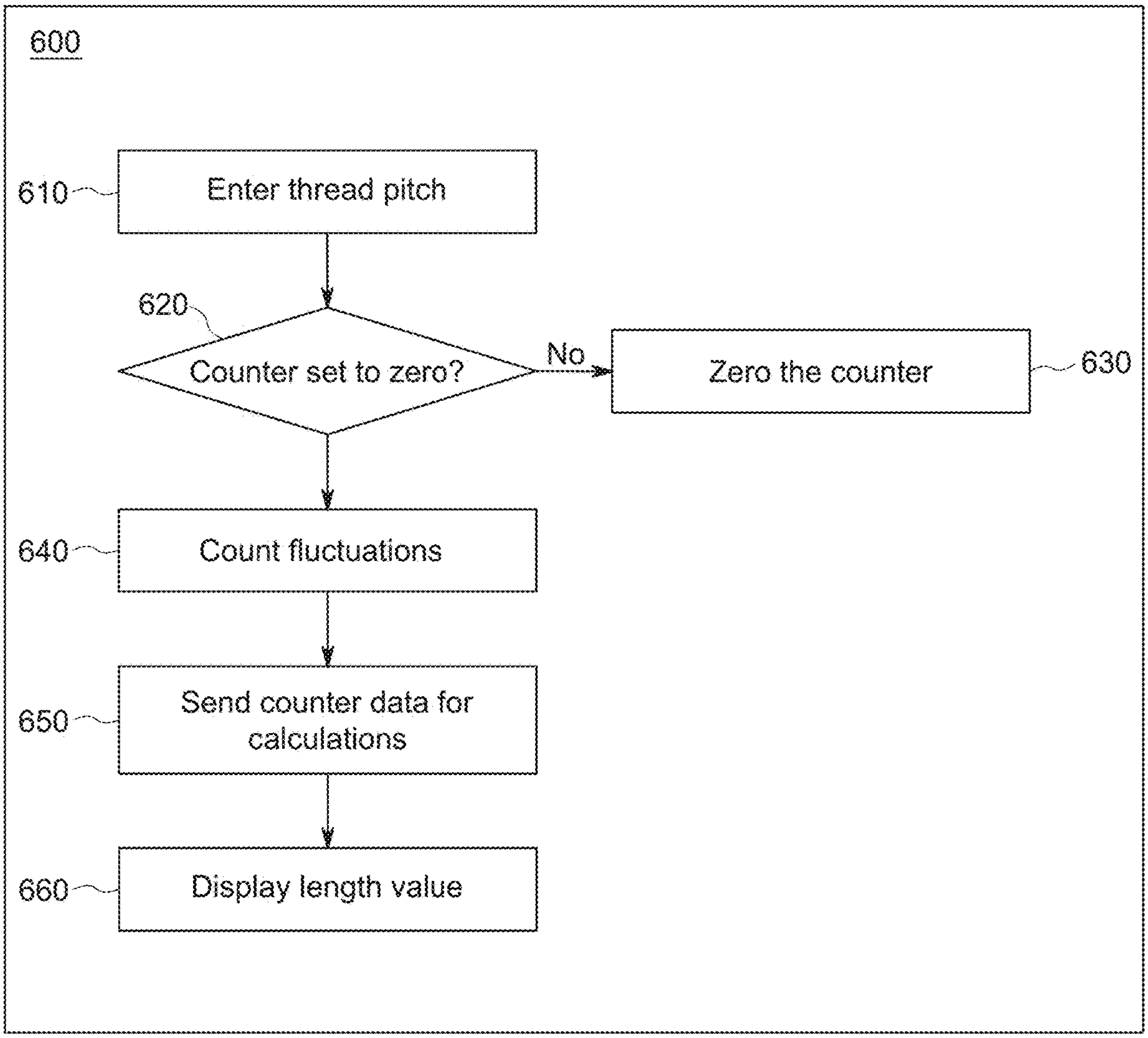

600
610
Enter thread pitch
620
Counter set to zero?
No
Zero the counter
630
640
Count fluctuations
650
Send counter data for calculations
660
Display length value

FIG. 3B

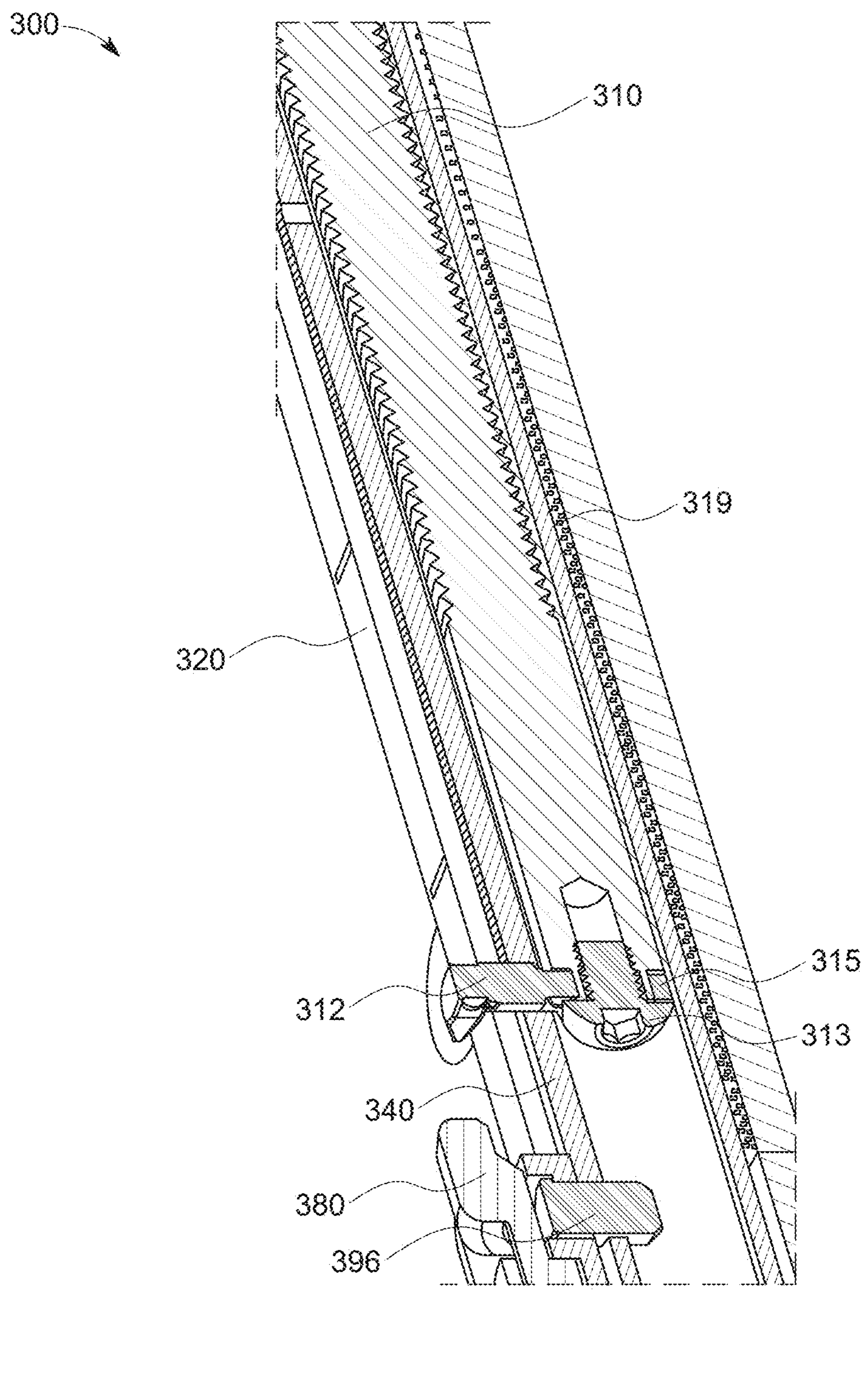


FIG. 4A

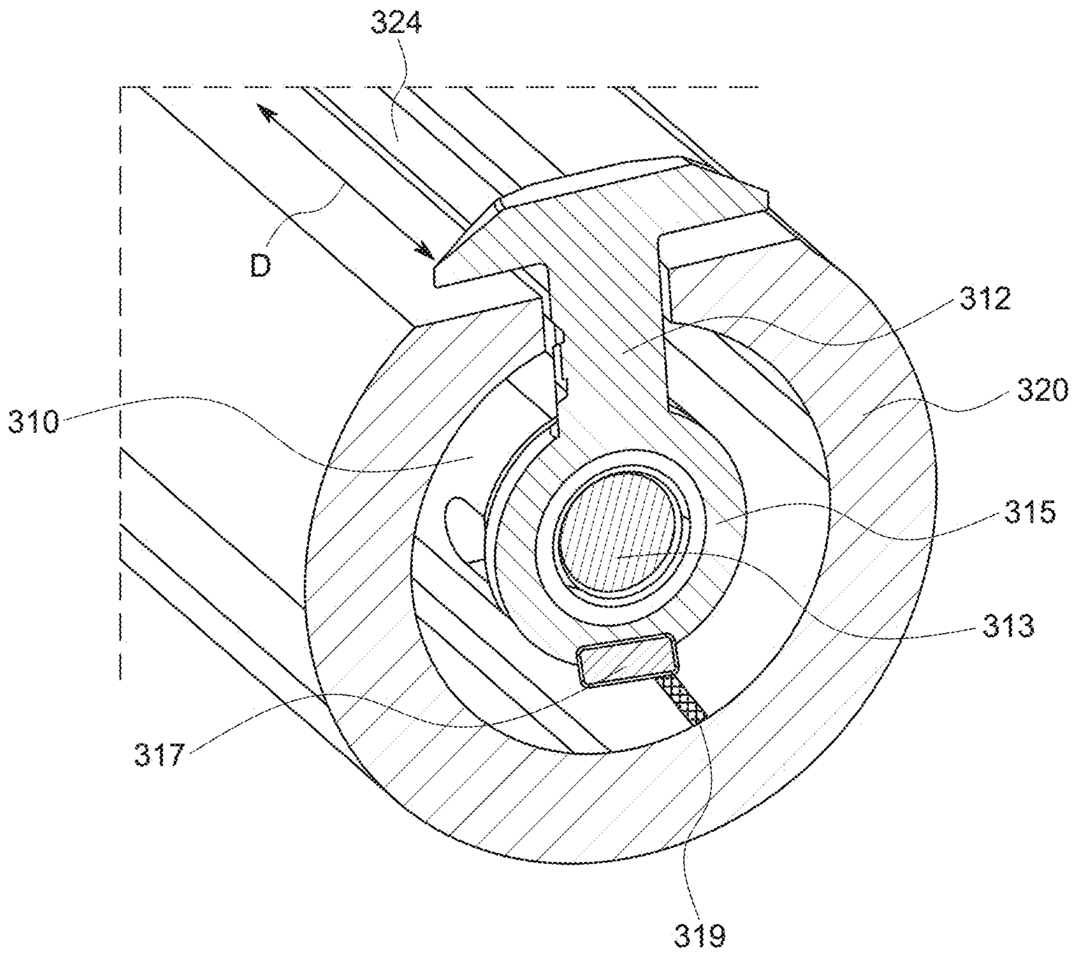


FIG. 4B

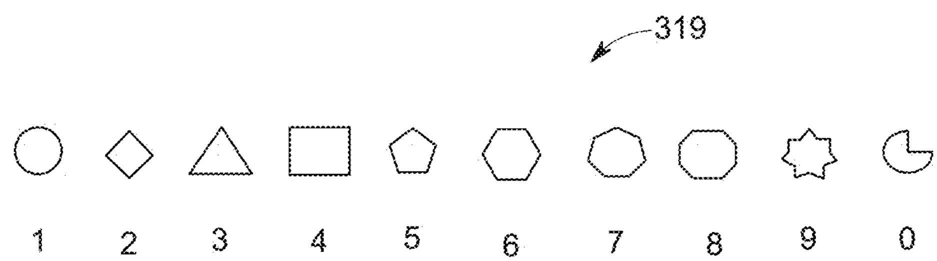

319
1
2
3
4
5
6
7
8
9
0

FIG. 4C

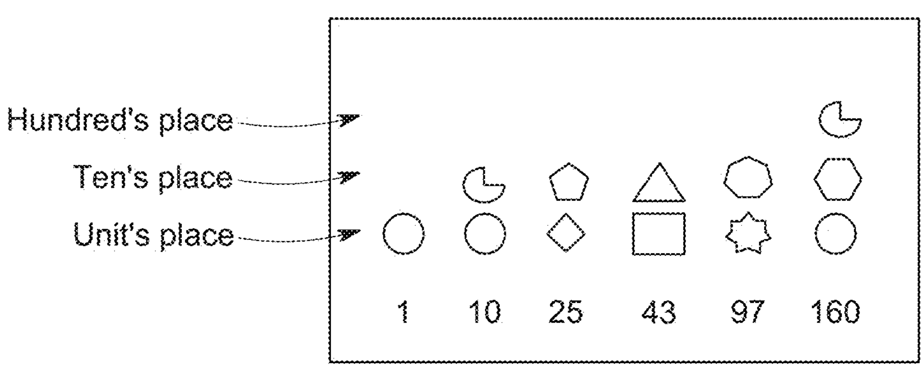

Hundred's place
Ten's place
Unit's place
1
10
25
43
97
160

FIG. 4D

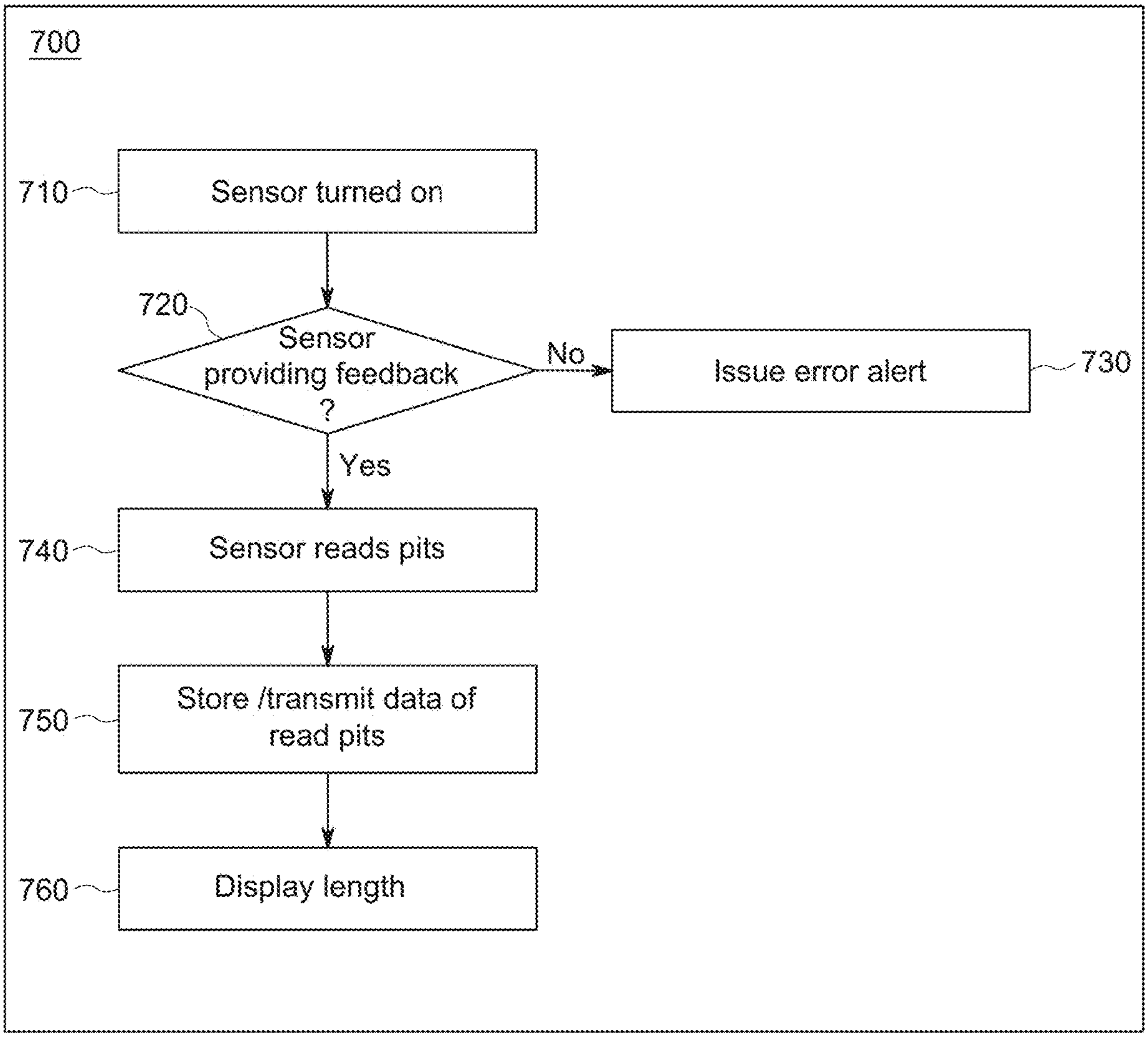

700
710
Sensor turned on
720
Sensor providing feedback ?
No
Issue error alert
730
Yes
740
Sensor reads pits
750
Store /transmit data of read pits
760
Display length

FIG. 4E

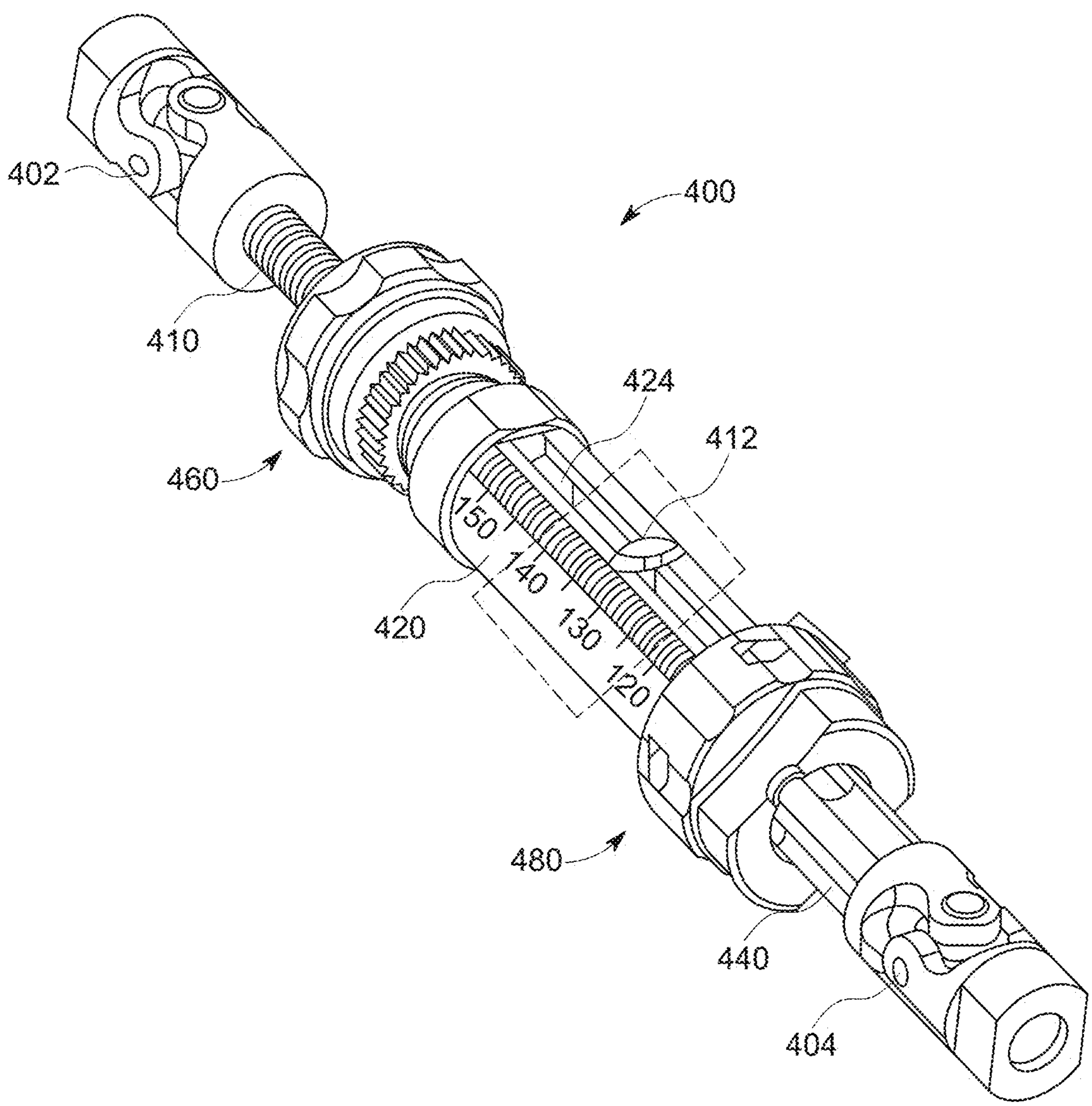


FIG. 5A

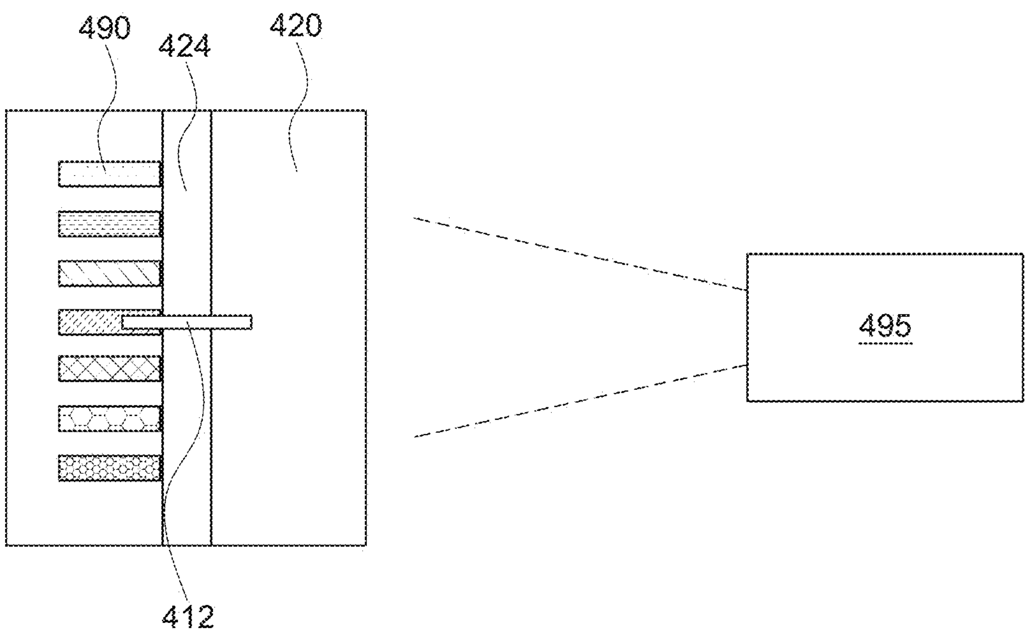


FIG. 5B

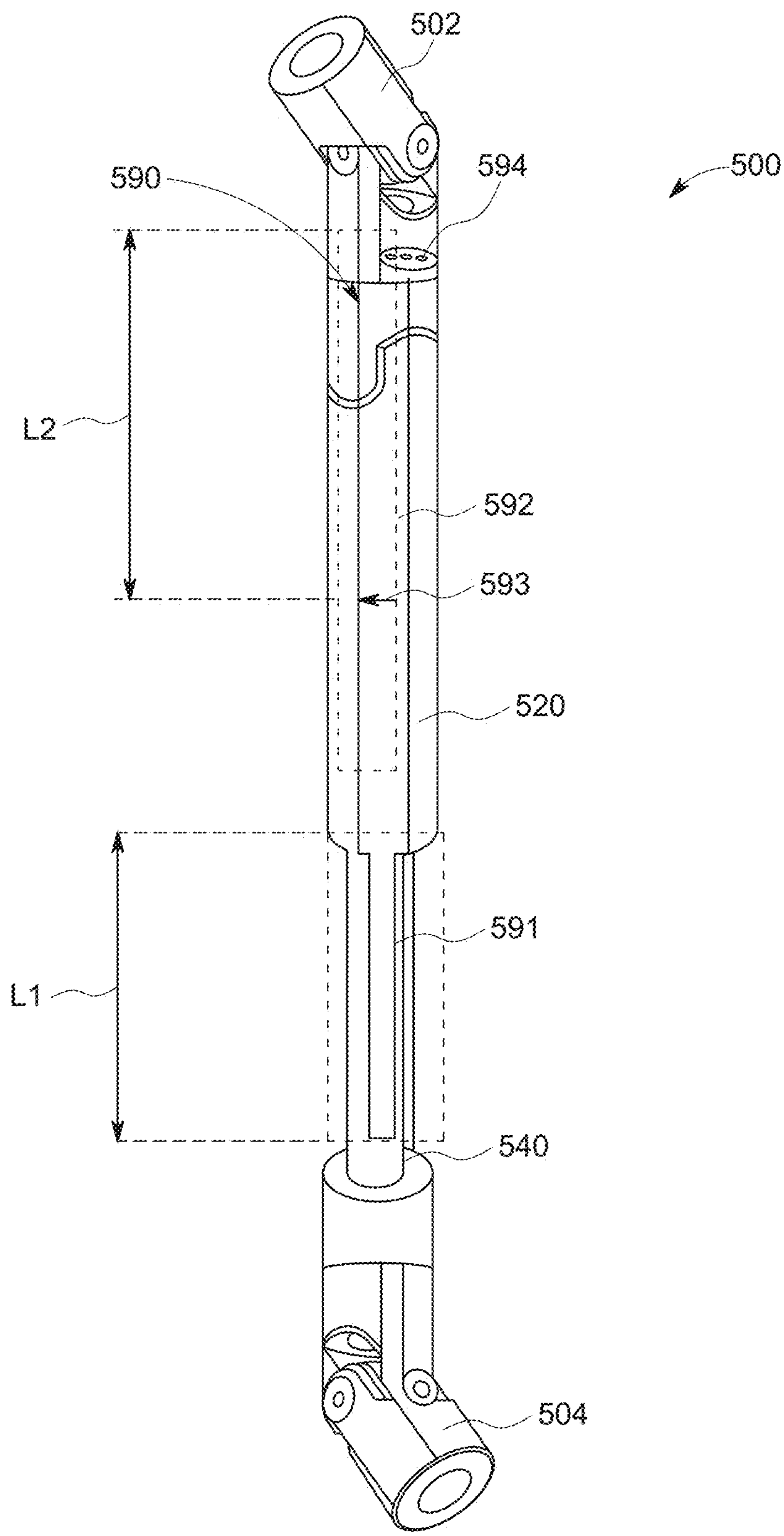


FIG. 6A

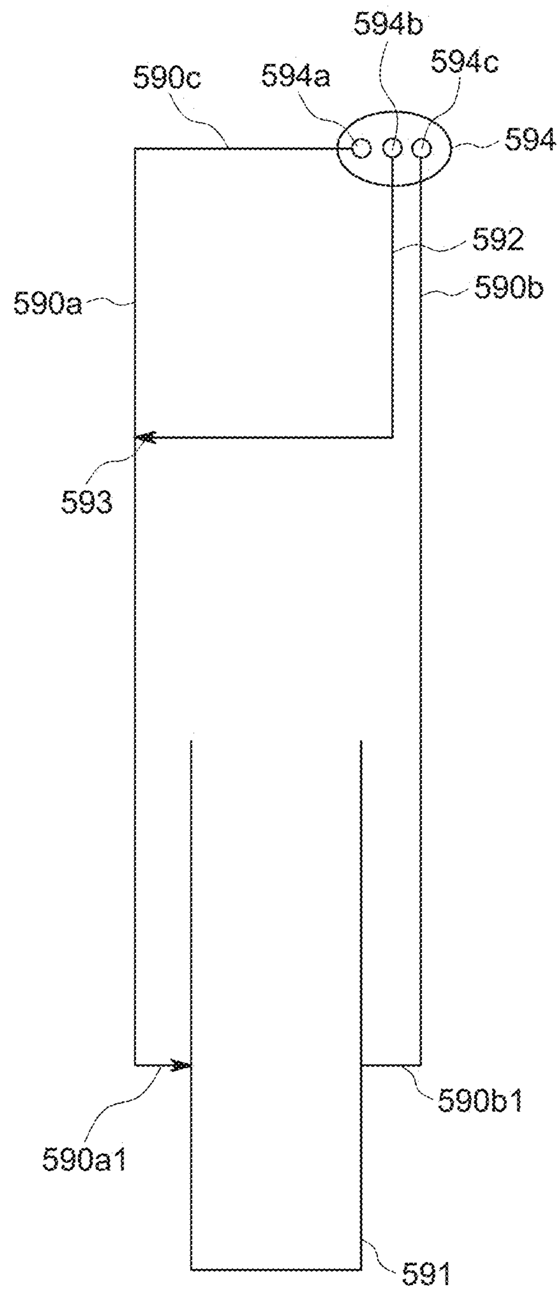


FIG. 6B

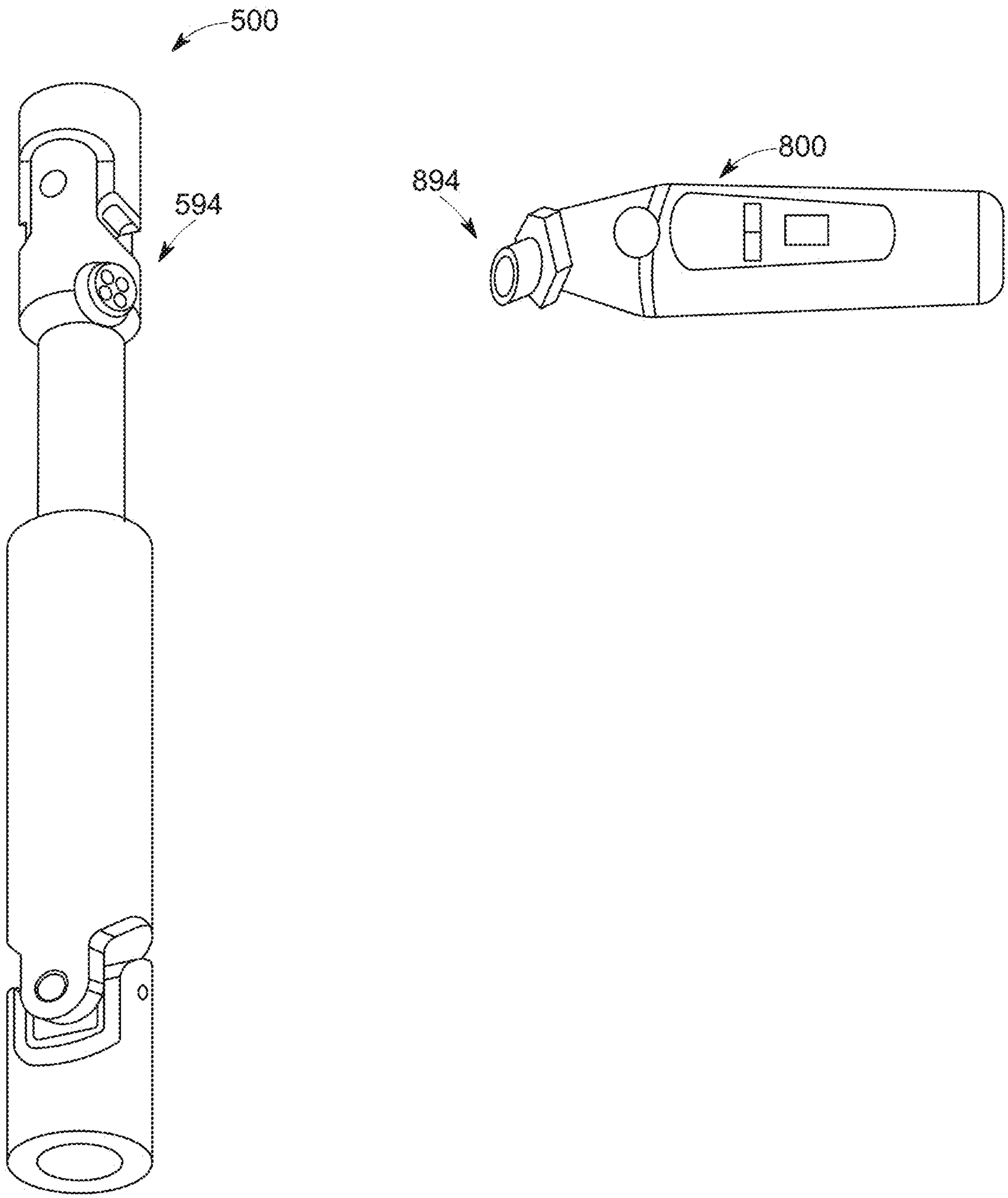


FIG. 6C

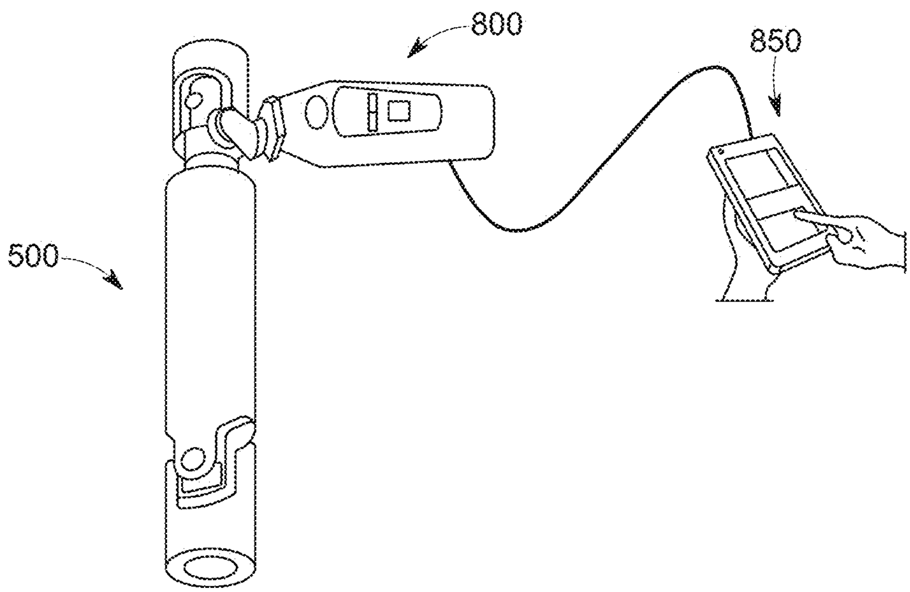


FIG. 6D

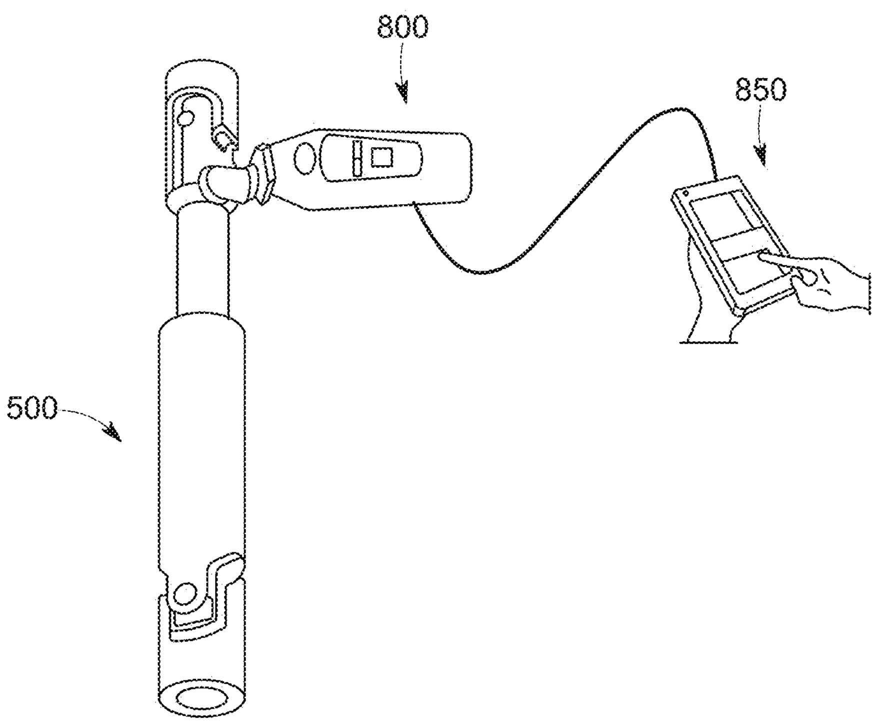


FIG. 6E

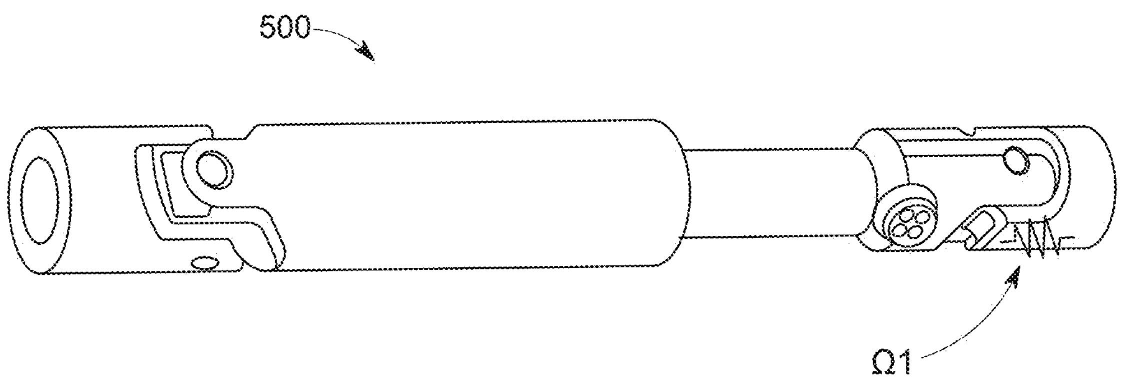


FIG. 6F

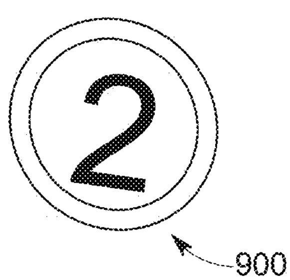


FIG. 6G

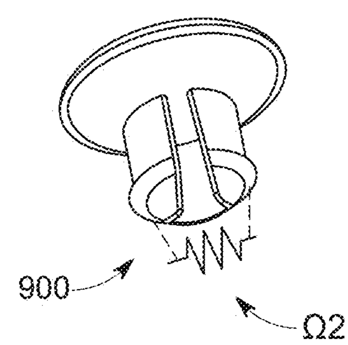


FIG. 6H

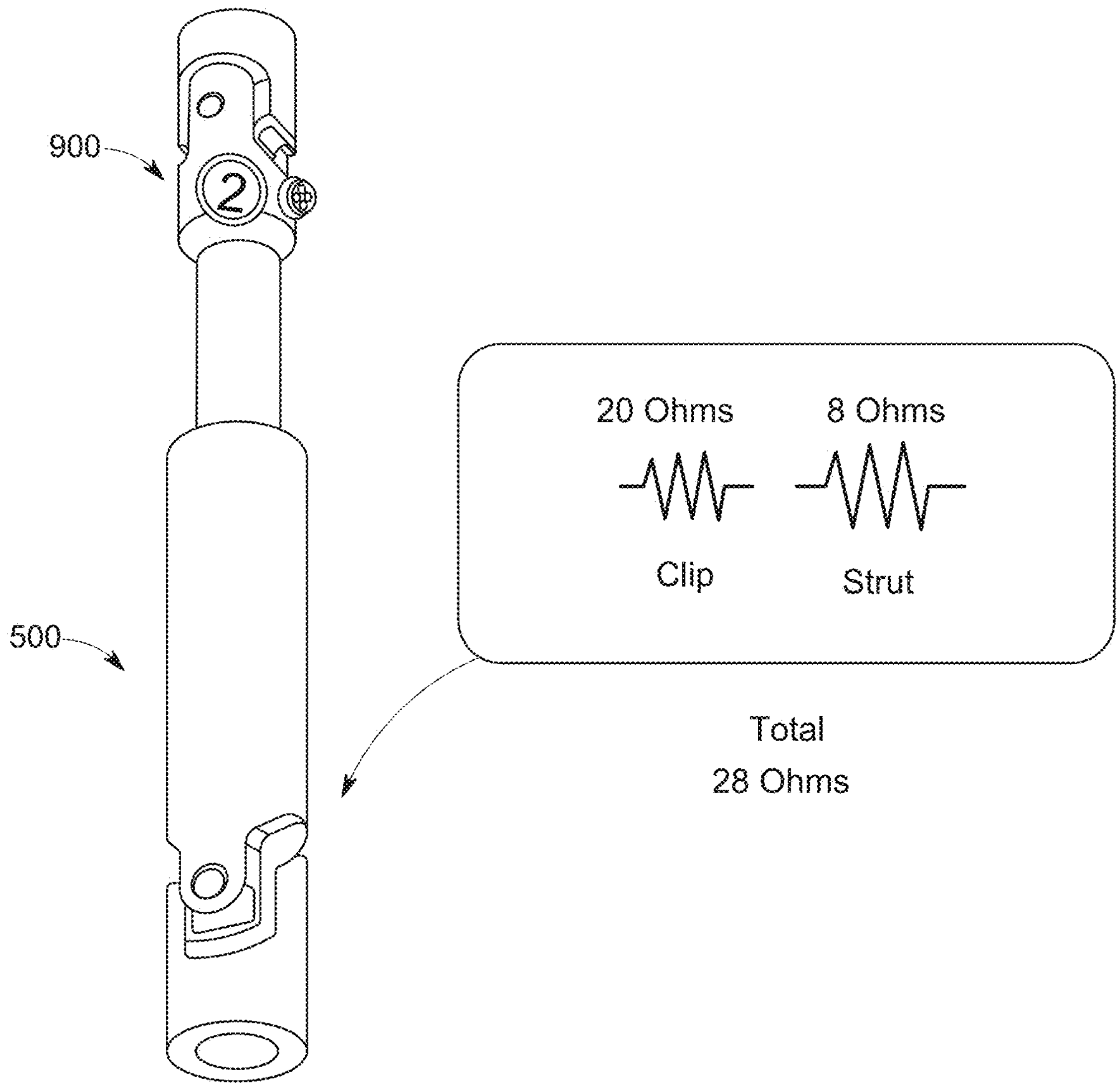


FIG. 6I

Strut Type		Strut Position					
		Position 1 (10 Ohms)	Position 2 (20 Ohms)	Position 3 (30 Ohms)	Position 4 (40 Ohms)	Position 5 (50 Ohms)	Position 6 (60 Ohms)
	Mini Strut (2 Ohms)	12 Ohms	22 Ohms	32 Ohms	42 Ohms	52 Ohms	62 Ohms
	Extra Short Strut (4 Ohms)	14 Ohms	24 Ohms	34 Ohms	44 Ohms	54 Ohms	64 Ohms
	Short Strut (6 Ohms)	16 Ohms	26 Ohms	36 Ohms	46 Ohms	56 Ohms	66 Ohms
	Medium Strut (8 Ohms)	18 Ohms	28 Ohms	38 Ohms	48 Ohms	58 Ohms	68 Ohms
	Long Strut (10 Ohms)	20 Ohms	30 Ohms	40 Ohms	50 Ohms	60 Ohms	70 Ohms

FIG. 6J

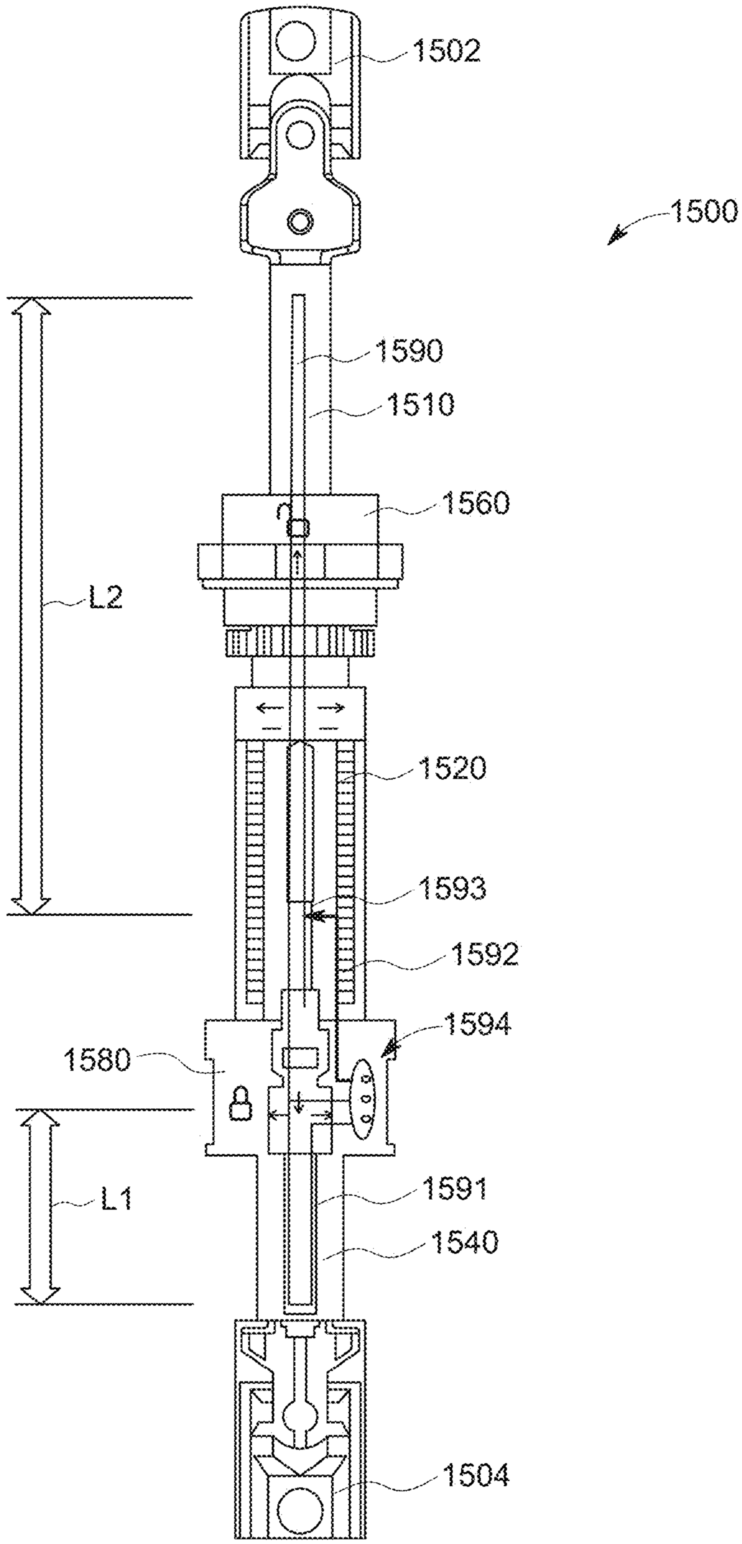

1502
1500
1590
1510
1560
L2
1520
1593
1592
1594
1580
L1
1591
1540
1504

FIG. 6K

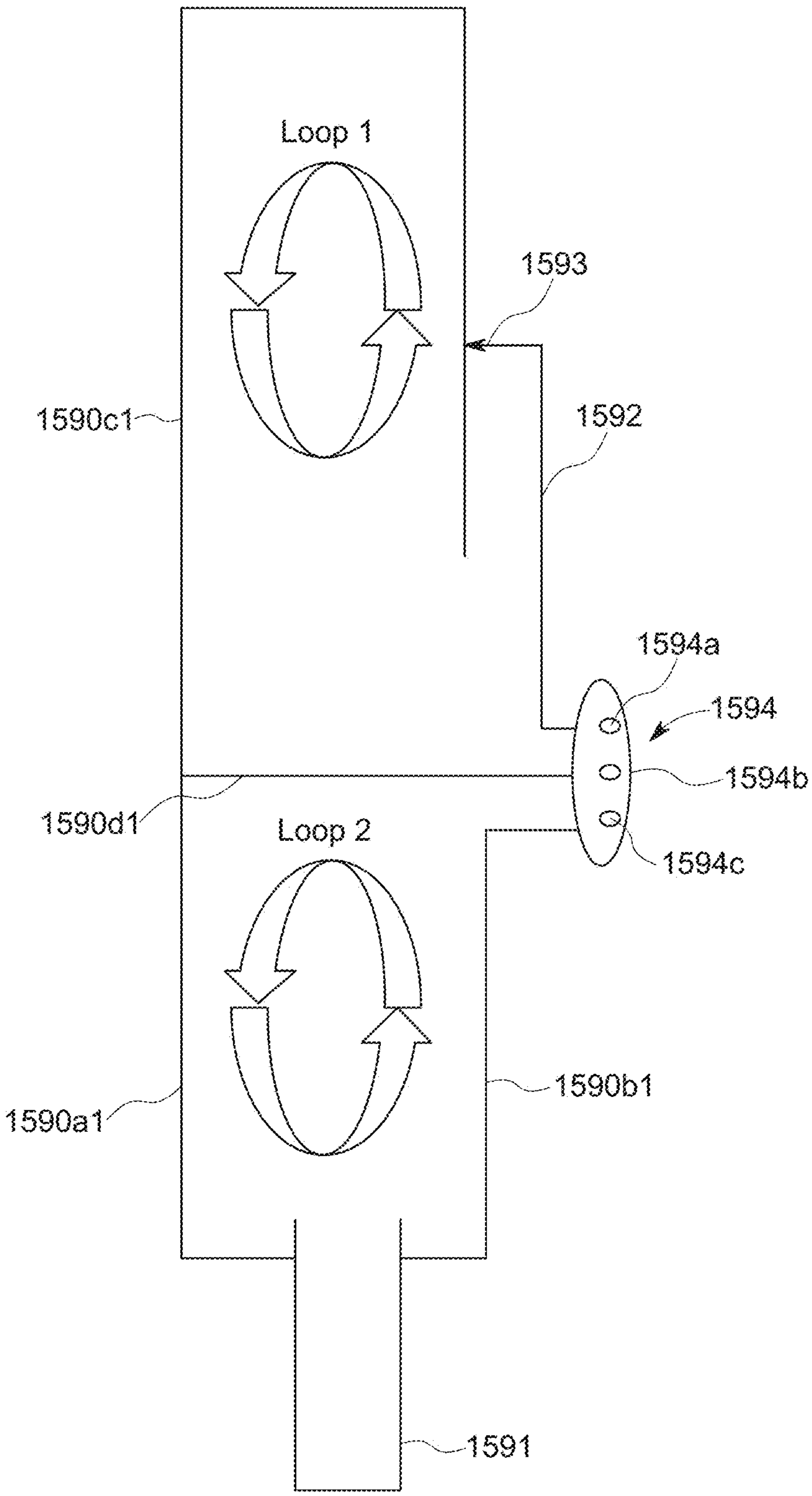

Loop 1
1593
1592
1590c1
1594a
1594
1594b
1590d1
Loop 2
1594c
1590b1
1590a1
1591

FIG. 6L

MECHANISMS FOR STRUT LENGTH MEASUREMENT

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to the filing date of U.S. Provisional Patent Application No. 63/551,438, filed Feb. 8, 2024, the disclosure of which is hereby incorporated by reference herein.

BACKGROUND OF THE DISCLOSURE

[0002] The present disclosure relates to systems and components of external fixation frames. More particularly, the present disclosure relates to struts and strut components using gear mechanisms and/or controller modules for manipulation of an external fixation frame.

[0003] Many different types of bone deformities can be corrected using external fixation systems to perform the distraction osteogenesis process. For example, an Ilizarov device or similar external fixation system may be used. Such systems generally use rings also designated as fixation plates connected by threaded rods or struts for manipulation, lengthening, angulation, rotation, and/or translation of deformities of bones.

[0004] As the struts are manipulated, the rings or fixation plates change positions relative to one another, causing the bones or bone segments attached to the fixation plates to change positions relative to one another, until the bone segments are in a desired position relative to one another. Fixation systems have many areas which may be improved including, for example, the ease and precision with which lengths of the struts may be measured during a correction procedure.

BRIEF SUMMARY

[0005] According to one aspect of the disclosure, a strut for use with an external fixation system may include a first joint proximate a first end of the strut, the first joint configured to couple to a first ring of the external fixation system. The strut may include a second joint proximate a second end of the strut, the second joint configured to couple to a second ring of the external fixation system. The strut may include a threaded rod having a first end coupled to the first joint, a tube that receives the threaded rod, a fluctuation counter coupled to the tube, and a needle coupled to the fluctuation counter. The needle may extend through a bore in the outer tube and may have a free end in contact with the threaded rod. The strut may be an adjustable-length strut whereby the threaded rod is moveable axially into or out of the tube, and while the threaded rod moves into or out of the tube, the free end of the needle is configured to maintain contact with the threaded rod. While the threaded rod moves into or out of the tube, the free end of the needle may be configured to maintain contact with the threaded rod by riding along peaks and valleys of threads of the threaded rod. As the free end of the needle rides along peaks and valley of threads of the threaded rod, a position of the fluctuation counter may be configured to fluctuate relative to the outer tube. The fluctuation counter may be configured to count a total number of fluctuations as the free end of the needle rides along peaks and valleys of threads of the threaded rod, with one fluctuation corresponding to one complete revolution of the threaded rod.

[0006] According to another aspect of the disclosure, a method of determining a change in length of a strut of an external fixation system may include axially translating a threaded rod of the strut into or out of a tube of the strut to increase or decrease an effective length of the strut such that, during the axial translating, a free end of a needle that is coupled to a fluctuation counter that is coupled to the tube moves radially inward toward thread valleys of the threaded rod or radially outward toward threads peaks of the threaded rod. The method may include counting, via the fluctuation counter, a total number of fluctuation cycles of the needle, each fluctuation cycle corresponding to one revolution of the threaded rod relative to the tube. The method may also include determining a total length change of the strut by multiplying the total number of fluctuation cycles by a pitch of the threaded rod. Each time the free end of the needle moves from one peak of the threaded rod to an axially adjacent peak of the threaded rod, the fluctuation counter may increase the total number of counted fluctuation cycles by one. Each time the free end of the needle moves from one valley of the threaded rod to an axially adjacent valley of the threaded rod, the fluctuation counter may increase the total number of counted fluctuation cycles by one. Prior to counting the total number of fluctuation cycles of the needle, the total number of counted fluctuation cycles may be set to zero. Prior to determining the length change of the strut, the pitch of the threaded rod may be entered into software of a computer system. After counting the total number of fluctuation cycles of the needle, the total number of counted fluctuation cycles may be entered into the software of the computer system, and the step of determining the total length change of the strut may be performed using the software of the computer system.

[0007] According to a further aspect of the disclosure, a strut for use with an external fixation system may include a first joint proximate a first end of the strut, the first joint configured to couple to a first ring of the external fixation system. The strut may include a second joint proximate a second end of the strut, the second joint configured to couple to a second ring of the external fixation system. The strut may include a threaded rod having a first end coupled to the first joint, a tube that receives the threaded rod, and a pointer secured to a second end of the threaded rod. The pointer may extend through an axially-extending slot of the tube and the pointer may have a collar and a fastener extending through the collar to secure the pointer to the threaded rod. A sensor may be coupled to the collar. The strut may include a plurality of rows of pits formed in an inner surface of the tube, each row of pits having a unique shape combination corresponding to a unique length value. The threaded rod may be configured to move into or out of the tube to change an effective length of the strut, and the pointer may be rotationally fixed to the tube so that, as the effective length of the strut changes, the sensor maintains a rotational position relative the inner surface of the tube in which the sensor points toward at least one of the plurality of rows of pits. There may be a total number of ten uniquely shapes pits, and each uniquely shaped pit may correspond to a numeral between 0 and 9. The plurality of rows of pits may be organized into three columns, a first of the three columns corresponding to a single-digit place, a second of the three columns corresponding to a double-digit place, and a third of the three columns corresponding to a triple-digit place.

The sensor may be an array or matrix of ultrasonic sensors. The sensor may be an array or matrix of optical sensors. The sensor may be a camera.

[0008] According to yet a further aspect of the disclosure, a method of determining a length of a strut of an external fixation system may include axially translating a threaded rod of the strut into or out of a tube of the strut to increase or decrease an effective length of the strut, the strut including a pointer secured to an end the threaded rod, the pointer extending through an axially-extending slot of the tube, the pointer having a collar, a fastener extending through the collar to secure the pointer to the threaded rod. During the axial translating, a sensor on the collar may axially translate relative to the tube but remain rotationally fixed relative to the tube. The sensor may capture one row of pits of a plurality of rows of pits formed in an inner surface of the tube. Based on the captured row of pits, a length of the strut may be determined based on correspondence between a unique shape combination of the row of pits and a unique length value. There may be a total number of ten uniquely shapes pits, each uniquely shaped pit corresponding to a numeral between 0 and 9. The plurality of rows of pits may be organized into three columns, a first of the three columns corresponding to a single-digit place, a second of the three columns corresponding to a double-digit place, and a third of the three columns corresponding to a triple-digit place. The sensor may be an array or matrix of ultrasonic sensors. The sensor may be an array or matrix of optical sensors. The sensor may be a camera.

[0009] According to still another aspect of the disclosure, a strut system for use with an external fixation system may include a first joint proximate a first end of the strut, the first joint configured to couple to a first ring of the external fixation system. The strut system may include a second joint proximate a second end of the strut, the second joint configured to couple to a second ring of the external fixation system. The strut system may include a threaded rod having a first end coupled to the first joint, a tube that receives the threaded rod, and a pointer secured to a second end of the threaded rod. The pointer may extend through an axially-extending slot of the tube, and the pointer may have a collar and a fastener extending through the collar to secure the pointer to the threaded rod. The threaded rod may be configured to move into or out of the tube to change an effective length of the strut, and the pointer may be rotationally fixed to the tube so that, as the effective length of the strut changes, pointer is configured to move axially along the slot of the tube. The strut system may include a plurality of optical markings on an outer surface of the tube adjacent to the axially-extending slot, and each optical marking may correspond to a unique length value. The strut system may include a camera configured to determine which of the plurality of optical markings aligns with the pointer at a given effective length of the strut, and may be further configured to correlate the optical marking aligned with the pointer into a length value that indicates the effective length of the strut.

[0010] According to yet another aspect of the disclosure, a method of determining a length of a strut of an external fixation system may include axially translating a threaded rod of the strut into or out of a tube of the strut to increase or decrease an effective length of the strut, the strut including a pointer secured to an end the threaded rod, the pointer extending through an axially-extending slot of the tube such that the pointer moves axially along the axially-extending slot as the threaded rod translates into or out of the tube. An image may be captured, via a camera, of a position of the pointer relative to a plurality of optical markings on an outer surface of the tube adjacent to the axially-extending slot. The method may include determining which of the plurality of optical markings aligns with the pointer. The method may include displaying, on a display device associated with the camera, a total length of the strut based on a known relationship between (i) the optical marking that aligns with the pointer and (ii) strut length. Each of the plurality of optical markings may correspond to a different strut length.

[0011] According to another aspect of the disclosure, a strut for use with an external fixation system may include a first joint proximate a first end of the strut, the first joint configured to couple to a first ring of the external fixation system. The strut may include a second joint proximate a second end of the strut, the second joint configured to couple to a second ring of the external fixation system. The strut may include a threaded rod having a first end coupled to the first joint, an outer tube that receives the threaded rod, an inner tube received between the outer tube and the threaded rod, and a connector on the strut. The strut may include a first electrically conductive wire coupled to the outer tube, a second electrically conductive wire coupled to the inner tube, and a third electrically conductive wire coupled to the threaded rod. An electrically conductive loop may be formed between the connector, the first electrically conductive wire, the second electrically conductive wire, and the third electrically conductive wire, a length of the loop changing as an effective length of the strut changes. The inner tube may be configured to axially translate relative to the outer tube in a rapid adjustment stage, and the electrically conductive loop may be a first electrically conductive loop, and the length of the first loop may change during the rapid adjustment stage. The strut may include a second electrically conductive loop that is formed between the connector, the first electrically conductive wire, and the third electrically conductive wire. The threaded rod may be configured to axially translate relative to the outer tube in a gradual adjustment stage, and a length of the second electrically conductive loop may be configured to change during the gradual adjustment stage. The strut may include an internal resistance value that corresponds to a size of the strut. The strut may include a strut clip configured to clip onto the strut, the strut clip having an internal resistance value that corresponds to a position identifier of the strut clip.

[0012] According to still another aspect of the disclosure, a method of determining a length of a strut of an external fixation system may include coupling a connector of a portable device to a connector of the strut and applying electrical current to the connector of the strut. The method may include allowing the electrical current to travel along an electrically conductive loop, the electrically conductive loop defined at least in part by a first electrically conductive wire coupled to an outer tube of the strut, a second electrically conductive wire coupled to an inner tube of the strut positioned within the outer tube, and a third electrically conductive wire coupled to a threaded rod at least partially received within the inner tube. The method may include determining, via the portable device, a resistance of the electrically conductive loop. The method may include, based on the determined resistance, determining an effective length of the strut. The method may include performing a first calibration prior to determining the effective length of the strut. Performing the first calibration may include: (i) when the strut is at a minimum length, coupling the connector of the portable device to the connector of the strut and applying electrical current to the connector of the strut; (ii) allowing the electrical current to travel along the electrically conductive loop while the electrically conductive loop is at a minimum length corresponding to the minimum length of the strut; (iii) determining, via the portable device, the resistance of the electrically conductive loop while the electrically conductive loop is at the minimum length; and (iv) setting, in a calibration device, the resistance of the electrically conductive loop while the electrically conductive loop is at the minimum length to correspond to the minimum length of the strut. The method may include performing a second calibration prior to determining the effective length of the strut. Performing the second calibration may include: (i) when the strut is at a maximum length, coupling the connector of the portable device to the connector of the strut and applying electrical current to the connector of the strut; (ii) allowing the electrical current to travel along the electrically conductive loop while the electrically conductive loop is at a maximum length corresponding to the maximum length of the strut; (iii) determining, via the portable device, the resistance of the electrically conductive loop while the electrically conductive loop is at the maximum length; and (iv) setting, in the calibration device, the resistance of the electrically conductive loop while the electrically conductive loop is at the maximum length to correspond to the maximum length of the strut. The method may also include coupling the connector of a portable device to the connector of the strut and applying electrical current to the connector of the strut, and allowing the electrical current to travel along an electrically conductive pathway that passes through an internal resistor of the strut and an internal resistor of a strut clip that is coupled to the strut. The internal resistor of the strut may have a known resistance value that corresponds to a type of strut, and the internal resistor of the strut clip may have a known resistance value that corresponds to a position of the strut. The method may also include determining a total resistance along the electrically conductive pathway that passes through the internal resistor of the strut and the internal resistor of a strut clip, and based on the determined total resistance, determining the type of the strut and the position of the strut.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. **1** is a perspective view of an external fixation system according to an embodiment of the disclosure.

[0014] FIG. **2**A is a perspective view of a strut of the external fixation system of FIG. **1**.

[0015] FIGS. **2**B-C are a perspective views of the strut of FIG. **2**A with certain components omitted.

[0016] FIG. **2**D is a perspective view of an actuation mechanism of the strut of FIG. **2**A.

[0017] FIG. **3**A is a cross-section of an example of a strut having an embodiment of a length measurement mechanism.

[0018] FIG. **3**B is a flow chart showing example steps of a method of using the length measurement mechanism of the strut of FIG. **3**A.

[0019] FIG. **4**A is a cross-section of an example of a strut having another embodiment of a length measurement mechanism.

[0020] FIG. **4**B is a cutaway view of a portion of the strut of FIG. **4**A.

[0021] FIG. **4**C is one example of a correspondence between individual codes and units of length measurement for use with the length measurement mechanism of FIGS. **4**A-**4**B.

[0022] FIG. **4**D shows examples of unique codes corresponding to lengths for use with the length measurement mechanism of FIGS. **4**A-**4**B.

[0023] FIG. **4**E is a flow chart showing example steps of a method of using the length measurement mechanism of the strut of FIGS. **4**A-**4**B.

[0024] FIG. **5**A is a perspective view of an example of a strut having another embodiment of a length measurement mechanism.

[0025] FIG. **5**B is an enlarged view of an example of a portion of the strut of FIG. **5**A within the dashed box of FIG. **5**A.

[0026] FIG. **6**A is front view of an example of a strut, shown in partial phantom, having another embodiment of a length measurement mechanism.

[0027] FIG. **6**B is a highly schematic circuit diagram of resistance wires of the strut of FIG. **6**A.

[0028] FIG. **6**C illustrates a portable device being connected to the strut of FIG. **6**A.

[0029] FIGS. **6**D-**6**E illustrate two individual stages of a calibration process using the portable device of FIG. **6**C and a calibration device.

[0030] FIG. **6**F shows an example of a medium-length strut having an internal resistance.

[0031] FIGS. **6**G-**6**H show examples of a strut clip for a second position, the strut clip having an internal resistance.

[0032] FIG. **61** shows an example of a medium length strut with a second position strut clip providing for a total internal resistance value.

[0033] FIG. **6**J shows a chart illustrating unique values of combined internal resistances for different types of struts and different position strut clips.

[0034] FIG. **6**K is front view of an example of a strut, shown in partial phantom, having another embodiment of a length measurement mechanism similar to that shown in FIG. **6**A.

[0035] FIG. **6**L is a highly schematic circuit diagram of resistance wires of the strut of FIG. **6**B.

DETAILED DESCRIPTION

[0036] FIG. **1** shows an external fixation frame **10** in an assembled condition according to one aspect of the disclosure. Generally, fixation frame **10** includes a first ring **20** and a second ring **30**, with six adjustable length telescopic struts **100***a-f* coupling the first ring **20** to the second ring **30**. The first ring **20** may also be referred to as a proximal ring or a reference ring, while the second ring **30** may also be referred to as a distal ring or a moving ring. In the illustrated embodiment, each strut **100***a-f* includes a threaded portion that may thread into or out of a tube portion, for example by interaction with quick release mechanism **130**, to decrease or increase the length, respectively, of the telescopic strut. Each end of each strut **100***a-f* may be coupled to the first ring **20** and second ring **30** via a joint mechanism, such as a ball joint, a constrained hinge joint, or a universal joint as illustrated. The use of universal joints on each end of the strut provides for six degrees of freedom of motion of the external fixation system **10**. It should be understood that although the disclosure is generally described in the context of closed circular rings, the concepts described herein may apply with equal force to other types of rings, such as open rings and/or U-shaped rings.

[0037] In external fixation system **10**, telescopic struts **100***a-f* are used to reduce fractures and/or correct deformities over time. Patients correct the deformities by prescribed adjustments of the struts **100***a-f*. The lengths of the struts **100***a-f* are adjusted over time to change the position and orientation of the two rings **20**, **30** with respect to one another, which in turn repositions and reorients the bone fragments, with a goal of correcting the bone deformity. The adjustment of the external fixator **10** should strictly comply with the predetermined correction plan.

[0038] Rings **20** and **30** of external fixation system **10** may include a plurality of extension tabs **50**. In the illustrated example, each ring **20** and **30** includes six extension tabs **50** spaced circumferentially around the perimeter of the respective rings, although more or fewer may be suitable depending on the particular components of the fixation system. In addition to what is described directly below, extension tabs **50** may help increase the cross-sectional area of rings **20**, **30** and thus provide for increased stiffness of the rings.

[0039] With this configuration, each ring **20**, **30** includes a first inner circumferential row of holes **60** and a second outer circumferential row of holes **70**. As illustrated, the second outer circumferential row of holes **70** may be only positioned on the plurality of extension tabs **50** on the rings **20** and **30**. It should be understood that although the second outer circumferential row of holes **70** is shown in FIG. **1** as being positioned solely on extension tabs **50**, top ring **20** and/or bottom ring **30** may contain two complete rows of holes, for example with a completely circular (or nearly completely circular) geometry. The use of extension tabs **50**, compared to two full circumferential rows of holes, may help reduce overall bulk of rings **20**, **30** and also provide for intuitive strut placement for surgical personnel. The completely circular version of rings **20**, **30** with two full (or nearly full) rows of circumferential holes may be particularly suited for relatively small diameter rings, although indentations or other features may be introduced to provide an intuitive interface for strut placement by surgical personnel. Further, in the illustrated embodiment, the first and second circumferential rows of holes **60** and **70** are positioned so that the first row of holes **60** does not align radially with the second row of holes **70**. In other words, the first row of holes **60** has a staggered configuration with respect to the second row of holes **70**. The additional hole options may also be utilized for connecting other components, such as fixation pins to couple the rings **20**, **30** to the respective bone fragments. Still further, the staggered configuration of holes between the first and second rows **60**, **70** may also help prevent interference between components attached to nearby holes, for example such as a strut **100***a-f* positioned in a first hole and a fixation pin or other fixation member attached to an adjacent or nearby second hole. For example, a relatively thin wire extending radially from one of the holes in the first circumferential row **60** may not radially interfere with a hole positioned in the second circumferential row **70** because of the radial staggering. It should be understood that the size of the tabs **50** may increase or decrease depending on the diameter of the rings **20** and **30**, with greater diameter rings **20** and **30** having larger tabs **50** with more holes **70** compared to smaller diameter rings. For example, the illustrated tabs **50** include six holes **70**, and a smaller ring may include smaller tabs with four holes each, for example.

[0040] FIG. **2**A illustrates a perspective view of one telescopic strut **100** from the external fixation system **10** of FIG. **1**. It should be understood that the components of struts **100***a-f* may be identical to one another, although some struts **100***a-f* may have different sizes than other struts **100***a-f* and may include different indicia, such as colors or markings for identification purposes, as described in greater detail below. For purposes of this disclosure, the term proximal refers to the top of the strut **100** in the orientation of FIG. **2**A, and the term distal refers to the bottom of the strut **100** in the orientation of FIG. **2**A. The proximal end portion of strut **100** may include a first joint **110**, which is shown in this example as a universal joint. Joint **110** may include a proximal portion **111**, which may include a first aperture **112** aligned substantially parallel with the longitudinal axis of strut **100** and a second aperture **113** aligned substantially transverse or orthogonal to the first aperture **112**. The first aperture **112** may be configured to receive a fastener that passes through a hole in proximal ring **20** to secure the proximal portion **111** of joint **110** to proximal ring **20**. The fastener may be connected so that the proximal portion **111** does not rotate relative to proximal ring **20**. The second aperture **113** may be configured to receive a portion of a tool to prevent proximal portion **111** from rotating, for example while a fastener is being screwed into or otherwise inserted into first aperture **112**. Joint **110** may also include a distal portion **115** with a first aperture **116** and a second aperture **117**, the first and second apertures **116**, **117** being aligned substantially transverse and/or orthogonal to one another and to the longitudinal axis of strut **100**. First and second apertures **116**, **117** may be used as attachment points for attaching additional components to strut **100**.

[0041] Still referring to FIG. **2**A, strut **100** may include additional components including an actuation mechanism **120**, a quick-release mechanism **130**, a strut identifier **140**, a threaded rod **150** (not visible in FIG. **2**A), a tube **160**, and a second joint **170**. As noted above, the effective length of strut **100**, which may be thought of as the distance between the proximal end and distal end of strut **100**, may be adjusted by threading the threaded rod **150** of strut **100** into or out of tube **160** through interaction with quick-release mechanism **130**.

[0042] FIG. **2**B illustrates strut **100** with tube **160** omitted for clarify of illustration. FIG. **2**C illustrates strut **100** with tube **160**, as well as quick-release mechanism **130**, strut identified **140**, and second joint **170** omitted for clarity of illustration.

[0043] Actuation mechanism **120** is shown isolated in FIG. **2**D. Actuation mechanism **120** may be generally a short, cylindrical component with a plurality of ridges or gear teeth **122** extending around the circumference of actuation mechanism **120**. The actuation mechanism **120** may be rotatably coupled to threaded rod **150** so that rotation of actuation mechanism **120** causes a corresponding rotation of threaded rod **150**. For example, actuation mechanism **120** may have a channel **124** extending therethrough, with an extension **126** in channel **124** that mates with a corresponding extension in threaded rod **150**, so that rotation of actuation mechanism **120** causes rotation of threaded rod **150**. It should be understood that the threaded rod **150** may rotate with respect to the first joint **110**, with portions of the first joint **110** and second joint **170** being rotatably fixed to rings **20** and **30**, respectively. The proximal surface of actuation mechanism may include a plurality of divots or grooves **128** sized to accept a ball which is biased into the groove via a spring. The spring may have a first end in contact with a distal surface of first joint **110**, with a distal end pressing a ball into the proximal surface of actuation mechanism **120**. With this configuration, an amount of force is required to rotate actuation mechanism **120** to overcome the force of the spring pushing the ball into the divot **128**. As rotation of actuation mechanism **120** continues, the ball will eventually be positioned adjacent to an adjacent groove **128**. As rotation continues further, the spring will force the ball into the next groove **128** when the ball is aligned with the groove **128**, causing a tactile and/or audible click. Each "click" may correspond to a particular axial change in length so that a user knows, for example, that four "clicks" correspond to 1 mm of length adjustment. Similar "clicking mechanisms" are described in greater detail in U.S. Pat. No. 8,834,467, the contents of which are hereby incorporated by reference herein.

[0044] Referring now to FIGS. **2**A-B, quick-release mechanism **130** may generally take the form of an outer housing that surrounds a portion of threaded rod **150**. Quick-release mechanism **130** may have a disengaged state and an engaged state. In the disengaged state, threaded rod **150** may be capable of moving into or out of tube **160** without rotation of the threaded rod **150**, for quick adjustments of the length of strut **100**, which may be useful for example while initially assembling the fixation frame **10**. Rotating the quick-release mechanism **130** may transition the quick-release mechanism **130** into the engaged state, in which threaded rod **150** may only move axially into or out of tube **160** via rotation of the threaded rod **150**. The mechanism for keeping the quick-release mechanism **130** in the engaged state may include a ball or other feature that is forced between adjacent threads of threaded rod **150** so that axial translation of the threaded rod **150** is only possible via rotation, so that rotation of threaded rod **150** axially moves the threaded rod **150** into the tube **160**, without requiring the tube **160** to have internal threading. It should be understood that the quick-release mechanism **130** is not a necessary component of strut **100**, and may be omitted from strut **100** if desired. If quick-release mechanism **130** is omitted, it may be preferably to include internal threads on tube **160** to correspond to external threads on threaded rod **150**. Further details of quick-release mechanisms have been described elsewhere, including, for example, in U.S. Pat. No. 9,101, 398, the contents of which are hereby incorporated by reference herein.

[0045] A strut identifier **140** may be coupled to strut **100** at any desired location, for example between the quick-release mechanism **130** and the tube **160**. Strut identifier **140** may take the form of a clip or any other suitable shape that can be quickly and securely clipped onto the strut **100** and removed from strut **100**. For example, in the illustrated embodiment, strut identifier **140** is a "C"-shaped clip that is flexible enough to open for easy connection to strut **100**, but rigid enough that the strut identifier **140** is not easily removed from strut **100** without intentional application of force. Strut identifier **140** may have a color or other identifier such as a number, letter, or shape pattern. Each strut **100***a-f* may have a strut identifier **140** that is structurally similar or identical, but that each has easily distinguishable indicia, such as different colors, different numbers, etc. Strut identifiers **140** may be used so that each strut **100***a-f* is easily distinguished from one another, and so that other matching indicia may be provided on other components, described in greater detail below, that may be added onto struts **100***a-f* so that each additional component may be easily matched with the correct corresponding strut **100***a-f*. Strut identifier **140** may also function to prevent unintentional disengagement of the quick release mechanism **130**.

[0046] Referring again to FIG. **2**A, tube **160** may be a generally hollow cylindrical tube configured to allow threaded rod **150** to move axially into or out of tube **160** to decrease or increase the effective length of strut **100**, respectively. As noted above, such axial movement may be produced by rotation of threaded rod **150** when the quick release mechanism **130** is in the engaged position, so that the threads of the threaded rod **150** engage the ball or other mechanism within the quick release mechanism **130**. If omitting the quick release mechanism **130**, the tube **160** may include internal threads that mate directly with the external threads of the threaded rod **150**. A slot **162** may extend along part of the length of the tube **160**, the slot **162** opening the hollow inside of the tube **160** to the exterior of the tube. The slot **162** may have a width slightly larger than the width of button **152**. Referring now to FIGS. **2**B-C, the distal end of threaded rod **150** may include a button **152** coupled to a collar **154**, the collar **154** surrounding the distal end of threaded rod **150**. Collar **154** may be positioned with a groove at the distal end of threaded rod **150** so that collar **154** may rotate freely around the axis of the strut **100** while being axially fixed with respect to the threaded of **150**. Referring again to FIG. **2**A, as threaded rod **150** is threaded into or out of tube **160**, button **152** travels up or down the slot **162** of the tube **160**, which is possible because button **152** and collar **154** are free to rotate with respect to threaded rod **150**. Tube **160** may include indicia, such as hash marks and/or measurements, on or adjacent to slot **162**. The position of button **152** along slot **162** may correspond to the effective length of the strut **100**, so that a user can easily determine the effective length of the strut based on the indicia adjacent to the position of button **152** at any particular time.

[0047] Referring still to FIG. **2**A, the distal end of tube **160** may include two extensions that form a proximal portion **171** of second joint **170**. Second joint **170** may include a distal portion **175** that, together with proximal portion **171** and an internal mechanism form a universal joint similar to first joint **110**. Distal portion **175** may include a first aperture **176** that is aligned substantially parallel with strut **100**. Aperture **176** may be adapted to receive a fastener therein to couple second joint **170** to distal ring **30**. The fastener may be a screw or other type of fastener, and may be adapted to tightly couple the second joint **170** to the distal ring **30** so that the second joint **170** does not rotate with respect to distal ring **30**. With this configuration, the slot **162** of tube **160** may be positioned outward (away from the center of proximal and distal rings **20**, **30**) so that the position of button **152** with respect to indicia on tube **160** may be easily read at all times. The distal portion **175** of second joint **170** may include a second aperture **177** aligned substantially orthogonal to first aperture **176** and adapted to receive a tool to keep second joint **170** from rotating, for example while a fastener is screwed into first aperture **176**. This may help ensure, for example, the slot **162** of tube **160** is facing away from the center of the rings **20**, **30** as the strut **100** is tightened to the rings **20**, **30**. It should also be understood that in some prior art devices, rotational freedom of the strut was provided by loosely coupling the joint(s) to the ring(s) so that the joints themselves could swivel. In the present disclosure, the rotational degree of freedom is provided by the ability of threaded rod **150** to rotate, while the tight attachment of the first joint **110** and second joint **170** to the first ring **20** and second ring **30** provides for a more stable connection.

[0048] It should be understood that strut **100** as described above may be designed for manual actuation, for example by a user gripping the actuation mechanism **120** with his hand and manually rotating the actuation mechanism **120**. However, it should be understood that a tool may be used, either directly on actuation mechanism **120** or with intervening components, to adjust the length of strut **100**.

[0049] Although the struts **100***a*-**100***f* shown and described in connection with FIGS. **1**-**2**D are one type of strut suitable for use as part of an external fixation system, various other types of struts may be suitable. For example, additional types of struts are described in U.S. Patent Application Publication No. 2023/0255665 ("the '665 Publication"), the contents of which are hereby incorporated by reference herein. The '665 Publication also describes controller modules that can be used with struts to partially or fully automate strut adjustments. Still other types of struts, such as double-telescoping struts, are described in U.S. Patent Application Publication No. 2023/0193936 ("the '936 Publication"), the disclosure of which is hereby incorporated by reference herein. Various apparatus and methods are described below to assist with more precisely determining the length of a given strut at a given time during a correction procedure. Although these apparatus and methods are described in the context of particular struts, it should be understood that the apparatus and methods may be equally applicable to other types of struts, including struts **100***a*-**100***f*, as well as struts disclosed in the '665 Publication and/or the '936 Publication.

[0050] When the external fixation frame is initially assembled on the patient, it is generally important to correctly identify the length of each strut. For example, in order to use software to generate a correction plan, it is generally important that the initial state of the external fixation frame, which includes the length of each strut, be correctly entered into the software. Similarly, the correction plan starts and continues, it may be important throughout the correction to confirm the length of the struts as the struts are adjusted, for example to confirm that the struts are at their correct lengths for the particular stage of the correction. If the struts are at length other than the prescribed length at the relevant stage of correction, an update to the correction plan may become required. At any of these points that the length of a particular strut needs to be known, there are up to two issues that may currently exist. First, if the lengths of the struts are manually determined (e.g., by simply viewing the struts), there is a potential source of human error that is introduced. Second, in addition to possible error, it may take an undesirable amount of time to manually determine the length of each strut (typically there are six struts in an external fixation frame), especially if the strut lengths need to be determined at multiple points from the start to the end of the correction process. Further, if strut lengths are determined using x-ray images of the external fixation frame post-implantation, errors may be introduced due to parallax errors in the x-ray images. Thus, it would be desirable to have a mechanism and/or method for accurately, quickly, objectively, and/or remotely determining the lengths of the struts of an external fixation frame at any desired point in time.

[0051] FIG. **3**A illustrates an example of a strut **200** that has structure in common with struts described in the '936 Publication, with at least one significant difference regarding a mechanism for determining the length of the strut **200**. In the illustrated embodiment, strut **200** is a double-telescoping strut that may include a threaded rod **210**, one end of which may be coupled to a joint, including for example similar to joint **110**. Threaded rod **210** may extend through an adjustment knob **260**. In some embodiments, the adjustment knob **260** includes a correction wheel **264** that includes threading which intermeshes with threads of threaded rod **210**. The adjustment knob **260** may also include a thumb knob **262**. In some examples, a spring **268** or other biasing member may tend to push the thumb knob **262** away from the correction wheel **264**. In the illustrated example, the thumb knob **262** is prevented from rotating until it is pulled upwardly toward the correction wheel **264**, compressing the spring **268**. When pulled upwardly, the thumb knob **262** is capable of rotating, which in turn rotates the thumb knob correction wheel **264** and causes the adjustment knob **260** and outer tube **220** to move axially relative to the threaded rod **210**, increasing or decreasing the effective length of the strut **200**. The thumb knob **262** may be connected to a gear mechanism **270** which may be manually gripped for rotation (when the spring **268** is compressed) or which may intermesh with a gear of a motorized controller (such as that described in greater detail in the '665 Publication) for partially or fully automated length adjustment of the strut **200**.

[0052] Still referring to FIG. **3**A, the outer tube **220** may include a plurality of flexible extensions **230** which may each end in a protrusion or lip **231** which is received within a recess in the correction wheel **264** which may, in part, keep the outer tube **220** axially fixed relative to the correction wheel **264**. In the illustrated embodiment, the outer tube **220** may include one or more flanges **232** defining one or more recesses **233**, which may be sized and shaped to receive a corresponding member of a motorized controller (such as that described in greater detail in the '665 Publication). In the illustrated example, the threads of the threaded rod **210** do not engage any corresponding threads within the outer tube **220**. An inner tube **240** may be at least partially received within the outer tube **220**, and may at least partially surround the threaded rod **210**. An end of the inner tube **240** (not shown in FIG. **3**A) may be coupled to a second joint, for example similar to second joint **170**. In some examples, the length of the strut **200** may be gradually adjusted by rotating the adjustment knob **260** relative to the threaded rod **210**. A quick adjust mechanism, not shown in FIG. **3**A, may be operated to either lock the inner tube **240** relative to the outer tube **220**, or to unluck the inner tube **240** relative to the outer tube **220** so that the length of the strut **200** may be rapidly adjusted, for example when initially assembling the external fixation frame **10** that uses strut **200**. Examples of suitable quick adjustment mechanisms are described in greater detail in the '665 Publication.

[0053] At least one main difference between strut **200** and struts described in the '665 Publication is that strut **200** includes a mechanism for mechanically determining how much the threaded rod **210** has rotated relative to the outer tube **220**, and thus how much length adjustment has occurred due to gradual adjustment of the strut **200**. In the illustrated example, the length measurement mechanism may include a needle **290** or other similar structure that has a free end that is positioned to touch the external threading of the threaded rod **210**. The opposite end of the needle **290** may be coupled to an arm, which may be referred to as a fluctuation counter **292**. The arm or fluctuation counter **292** may have a first end coupled to (e.g., formed integrally with, or otherwise coupled mechanically or via adhesives to) outer tube **220**, and extend to a free or cantilevered second end, to which the needle **290** is coupled. In the illustrated example, the outer tube **220** includes a bore **294** which allows the needle **290** to extend from the arm or fluctuation counter **292**, through a wall of the outer tube **220**, and into contact with the threading of the threaded rod **210**.

[0054] In some examples, the fluctuation counter **292** and needle **290** are positioned so that the tip of the needle **290** tends to contact the valley of the threads of the threaded rod **210**. In some examples, the "valley" of the thread may refer to the position of the thread that is closest to the central axis of the threaded rod **210**. As the adjustment knob **260** is rotated to drive the threaded rod **210** axially away from the outer tube **220** (to increase the length of the strut **200**) or further into the outer tube **220** (to decrease the length of the strut **200**), the threads of the threaded rod **210** move axially relative to the tip of the needle **290**. During this relative motion, the needle **290** is driven away from the central axis of the threaded rod **210** as the tip of the needle **290** moves from the valley of the threads toward the peaks of the threads of the threaded rod **210**. In some examples, the "peak" of the thread may refer to the position of the thread that is farthest away from the central axis of the threaded rod **210**. In other words, as the threaded rod **210** move axially relative to the outer tube **220** and needle **290**, the needle **290** rides along the peaks and valleys of the threaded rod **210**, with the tip of the needle **290** always in contact with a portion of the thread of the threaded rod **210**. In some examples, the cantilevered configuration of the fluctuation counter **292** allows for some amount of flexing to allow the needle **290** to move radially inwardly toward the threaded rod **210** (when the needle **290** is moving toward a thread valley) or radially outward away from the threaded rod **210** (when the needle **290** is moving toward a thread peak). Each time the needle **290** moves through one full cycle (e.g., from one thread valley to an adjacent thread valley, or from one thread peak to an adjacent thread peak), the threaded rod **210** will have undergone exactly one complete revolution. As the needle **290** moves inwardly or outwardly, the amount of movement may be captured by the fluctuation counter **292** and each full cycle (or portion thereof) may be recorded by the fluctuation counter **292**. Because the pitch of the thread of the threaded rod **210** is known, the amount of cycles of movement of the needle **290** may be directly translated into axial movement of the threaded rod **210** (and thus length change of the strut **200**) by multiplying the number of cycles of movement of the needle **290** by the pitch of the thread of the threaded rod **210**. The fluctuation counter **292** may be configured to detect the fluctuation in one or more ways. For example, since the needle **290** may oscillate about a mean position, at both the extremes of oscillation, switches may be mounted and/or capacitance change or resistance change can be measured to detect the fluctuations.

[0055] FIG. 3B is a flow chart of an example of a method **600** for using the length measurement mechanism of strut **200** to determine a change in length of the strut **200** during gradual length adjustment. In one example, method **600** may be performed after an external fixation frame, such as external fixation frame **10**, has been implanted onto a patient using struts **200** (e.g., a total of six struts **200** in place of struts **100***a-f*). It should be understood that struts **200** may be set to an initial length using a combination of gradual and/or rapid adjustment as described above. Once the external fixation frame **10** has been implanted and is ready for use, but before correction has begun, information may be entered into fixation frame software if not already entered. For example, in step **610**, a user may enter the pitch of the thread of threaded rods **210** into fixation frame software. In some examples, the fixation frame software is a web or mobile application that is used to track and/or manage the fixation frame correction. In step **620**, the fluctuation counter **292** may be checked to determine if the counter is zeroed out (e.g., showing zero adjustment or showing zero length change). If the fluctuation counter **292** is not set to zero, it may be set to zero in step **630**. If the fluctuation counter is set to zero, correction may proceed per the correction schedule generated by the fixation frame software. Suitable software for generating correction schedule is described in, for example, U.S. Pat. Nos. 10,194,944 and 10,154,884, the disclosures of both of which are hereby incorporated by reference herein.

[0056] As correction progresses and the lengths of the struts **200** are gradually adjusted, for example either manually or via motorized actuation of a controller coupled to the struts **200**, the needle **290** rides along the threads of the threaded rod **210** between the valleys and peaks of the threads. As this occurs, the fluctuation counter **292** counts the number of total fluctuation cycles. As used herein, the term "fluctuation cycle" may refer to the movement of the needle **290** that corresponds to one full revolution of the threaded rod **210** (e.g., fluctuation from the valley of one thread to the adjacent valley, or from the peak of one thread to the adjacent peak, etc.). In some embodiments, the fluctuation counter **292** may count discrete fluctuation cycles, for example whole numbers of one, two, three, etc. fluctuations corresponding to one, two, three, etc. complete revolutions of the threaded rod **210**. In other embodiments, the fluctuation counter **292** may count portions of discrete fluctuation cycles, for example including every quarter cycle, every half cycle, etc. Either way, the fluctuations of needle **290** may be counted in step **640** as the lengths of the struts **200** are adjusted to advance the correction. At any desired point in the correction, data from the fluctuation counter **292** may be transmitted to software, in step **650**, that can translate the number of fluctuations counted to the total length of adjustment, for example by multiplying the total number of fluctuations (e.g., the total number of thread revolutions) by the pitch of the thread. After this calculation is performed, the length of the strut **200** (and/or the length of total adjustment of the strut **200** achieved) may be displayed in step **660** on the desired software (e.g., on a web or mobile app). In some examples, the total length of the strut **200** may be determined based on the initial starting length of the strut **200** adjusted to account for the total increase or decrease in length determined using the fluctuation counter **292**. In other examples, only the total length of adjustment **200** may be provided based on the increase or decrease in length determined using the fluctuation counter **292**. As should be understood, the length measurement mechanism described in connection with strut **200** and method **600** eliminates any need for ongoing manual checking of the lengths of the struts **200**, which may reduce the effort needed to determine strut length as well as reduce the likelihood of errors introduced via human error.

[0057] It should be understood that, in some examples, the fluctuation counter **292** may include memory, a processor, and/or a communication module that is capable of transmitting, via a wired or wireless connection, information relating to the fluctuation count. In some examples, information regarding the thread pitch may be transmitted to the fluctuation counter **292** (e.g., after being entered into a fixation frame correction web application) so that the calculation of length adjustment can be performed within the fluctuation counter **292**, and that information transmitted to an external computer such as one running a mobile or web application for planning and/or monitoring of the fixation frame progress. In some examples, if smart controller modules are being used with struts **200**, for example those described in the '665 Publication, information regarding the current count of the fluctuation counter **292** may be transmitted directly to the smart controller module which may process information to determine the total length of adjustment (and/or relay information to another computer, such as one running the mobile or web application, to determine the total length adjustments). In some examples, information regarding the current count of the fluctuation counter **292** may be transmitted directly from the fluctuation counter **292** to another computer, such as one running the mobile or web application, to determine the total length adjustments.

[0058] The length measurement mechanism described in connection with strut **200** and method **600** may be highly capable of accurate reading of changes in length based on cycles of fluctuation of needle **290**. However, in other examples, it may be preferably to be able to reliably read an absolute length of the strut at any given time. On such example is described below.

[0059] FIG. **4**A is a cross-section of an example of a strut **300** that has structure in common with struts described in the '936 Publication, with at least one significant difference regarding a mechanism for determining the length of the strut **300**. In some examples, other than the features relating to the length measurement mechanisms, strut **300** may be identical to strut **200**. In the illustrated embodiment, strut **300** is a double-telescoping strut that may include a threaded rod **310**, one end of which may be coupled to a joint, including for example similar to joint **110**. Threaded rod **310** may extend through an adjustment knob (not shown) similar to adjustment knob **260**. Threaded rod **310** may be actuated relative to the adjustment knob in the same way as described in connection with actuation of threaded rod **210** relative to adjustment knob **260**, and thus these structures and functions are not described herein. It should be understood that, in the view of FIG. **4**A, the adjustment knob would be on the top end of the strut **300**.

[0060] Still referring to FIG. **4**A, strut **300** may include an outer tube **320** that may be similar or identical to outer tube **220**, with at least one exception related to the length measurement mechanism of strut **200** compared to that of strut **300**. In the illustrated example, the threads of the threaded rod **310** do not engage any corresponding threads within the outer tube **320**. An inner tube **340** may be at least partially received within the outer tube **320**, and may at least partially surround the threaded rod **310**, at least in some configurations. An end of the inner tube **340** (not shown in FIG. **4**A) may be coupled to a second joint, for example similar to second joint **170**. As with strut **200**, in some examples, the length of the strut **300** may be gradually adjusted by rotating the adjustment knob relative to the threaded rod **310**. A quick adjust mechanism **380** (which may also be referred to a gross adjustment knob, only a portion of which is shown in FIG. **4**A) may be operated to either lock the inner tube **340** relative to the outer tube **320**, or to unluck the inner tube **340** relative to the outer tube **320** so that the length of the strut **300** may be rapidly adjusted, for example when initially assembling the external fixation frame **10** that uses strut **300**. A pin **396** may rotationally lock the inner tube **340** relative to the outer tube **320** so that the inner tube **340** and outer tube **320** can only move axially relative to each other during gross length adjustment, while staying rotationally static relative to each other. Examples of suitable quick adjustment mechanisms or gross adjustment knobs are described in greater detail in the '665 Publication.

[0061] Still referring to FIG. **4**A, the terminal end of threaded rod **310**, opposite the side of the top joint (e.g., similar to joint **110**), may exclude threading and have a collar member to which length indicator or pointer **312** is coupled. The pointer **312** is preferably axially fixed with respect to threaded rod **310**, but rotationally free. The pointer **312** may include a relatively narrow portion that is sized and shaped to protrude through axially extending slots in both the outer tube **320** and the inner tube **340**. The end of pointer **312** may be wider than the width of the slots, and include extensions that are parallel to hash marks of indicia printed on the outside of the outer tube **320** and/or inner tube **340**, to allow a user to manually identify what hash marks or other indicia that the pointer **312** is pointing. Collar mechanisms to allow for axial fixation but rotational freedom of pointer **312** are shown in more detail, for example, in U.S. Pat. No. 10,010,350, the disclosure of which is hereby incorporated by reference herein. As should be understood, as the threaded rod **310** rotates and telescopes into or out of the outer tube **320** (and/or into or out of the inner tube **340**), the pointer **312** is capable of sliding along the slots of the inner tube **340** and outer tube **320** without rotation, even though the threaded rod **310** is rotating. Although pointer **312** is one type of length measurement mechanism, other struts described herein may include features similar to pointer **312** in case it is desired for a manual review of the current length of the strut. The length measurement mechanism of strut **300** that provides for enhanced length measurement (e.g., faster and/or more accurate measurements) is described in greater detail below.

[0062] Still referring to FIG. **4**A, the pointer **312** may be axially fixed to the terminal end of the threaded rod **310** via a screw **313** or other fastener which may pass through a collar **315** of the pointer **312**, and into an internal bore of the threaded rod **310**. It is on this collar **315** on which one component of an enhanced length measurement mechanism may be provided. FIG. **4**B is a cutaway view of a portion of the strut **300** showing the terminal end of the threaded rod **310** where it connects to pointer **312** via fastener **313** extending through collar **315**. It should be understood that, in the view of FIG. **4**B, fastener **313** may be a screw or bolt, but the head of the screw or bolt is omitted for clarity of illustration. It should also be understood that, in the view of FIG. **4**B, the strut **300** may have a configuration in which the inner tube **340** is spaced away from the threaded rod **310** so that the inner tube **340** is not visible in the FIG. **4**B. In the illustrated embodiment, collar **315** is an annular or circular member that allows for the threaded rod **310** to rotate relative to the outer tube **320** while the pointer **312**, via its interaction with the slot **324** of outer tube **320**, restricts the pointer **312** (and collar **315**) from rotating relative to the outer tube **320**. Thus, as the threaded rod **310** rotates relative to the outer tube **320**, the pointer **312** moves up or down through slot **324** in direction D, with the collar **315** remaining rotationally fixed relative to the outer tube **320**.

[0063] At least one main difference between strut **300** and the struts described in the '665 Publication is that strut **300** includes a mechanism for automatically determining the length of the strut **300** at any particular time during the correction process. In the illustrated example of FIGS. **4**A-**4**B, the length measurement mechanism may include a sensor **317** (which may also be referred to as an absolute linear encoder), which may be coupled to collar **315** generally opposite the extension of the pointer **312**, although other positions may be suitable. The length measurement mechanism may also include a column of pits **319** formed in the inner surface of the outer tube **320** generally aligned with and confronting the position of the sensor **317**. In some examples, pits **319** may be formed as laser markings, laser etchings, mechanically-formed pits, etc.

[0064] In some examples, the sensor **317** includes an array or matrix of ultrasonic sensors, or an array or matrix of optical sensors, or a camera, any of which are capable of detecting the shape of the pits **319**. The pits **319** may be physical shapes that are etched into the otherwise smooth inner cylindrical surface of the outer tube **320**.

[0065] FIG. **4**C shows an example of ten different unique shapes that may be used for pits **319**. In this particular example, a circular pit **319** corresponds to the numeral one, a diamond pit **319** corresponds to the numeral two, a triangular pit **319** corresponds to the numeral three, a rectangular pit **319** corresponds to the numeral four, a pentagonal pit **319** corresponds to the numeral five, a hexagonal pit **319** corresponds to the numeral six, a septagonal pit **319** corresponds to the numeral seven, an octagonal pit **319** corresponds to the numeral eight, a seven-pointed star pit **319** corresponds to the numeral nine, and a three-quarter circle shape pit **319** corresponds to the numeral zero. It should be understood that the legend of correspondence between differently shaped pits **319** and numerals zero through nine shown in FIG. **4**C are merely exemplary, and any ten unique shapes may be provided to correspond to the numerals zero through nine any desired combination.

[0066] FIG. **4**D shows examples of unique codes of pits **319** corresponding to specific lengths. In some examples, the column of pits **319** may be provided as three adjacent columns, with one column representing the single unit place, the next column representing the tens place, and the following column representing the hundreds place. FIG. **4**D shows an example of various rows of pits **319** that may be positioned at different places along the length of the column of pits **319**. For example, a row of pits **319** that includes only a circular pit **319** in the single unit place may correspond to the numeral one. A row of pits **319** that includes a circular pit **319** in the single unit place and a three-quarter circle shape pit **319** in the tens place may correspond to the numeral ten (the numeral one followed by the numeral zero). A row of pits **319** that includes a rectangular pit **319** in the single unit place and a triangular pit **319** in the tens place may correspond to the numeral forty-three (the numeral four followed by the numeral three). As one final example, a row of pits **319** that includes a circular pit **319** in the single unit place, a hexagonal pit **319** in the tens place, and a three-quarter circle shape pit **319** in the hundreds place may correspond to the numeral one hundred sixty (the numeral one followed by the numeral six followed by the numeral zero). It should be understood that the options shown in FIG. **4**D are merely exemplary individual options, based on the legend of FIG. **4**C, to show how rows of pits corresponding to up to one-thousand unique numbers may be formed in the inner surface of the outer tube **320** if using three rows of pits **319**.

[0067] In one example, the pits **319** may be formed in the inner surface of the outer tube **320** so that each row represents a number that corresponds to the length of the strut **300** when the sensor **317** is aligned with the particular row of pits **319**. In other words, the pits **319** may be formed so that the unique combination of shapes of pits **319** provides sequential numbering that is representative of length. For example, when the sensor **317** is aligned with a row of pits **319** that have shapes corresponding to the numeral one hundred, at that position of the threaded rod **310** relative to the outer tube **320**, the length of the strut **300** may be one hundred millimeters. Again, it should be understood that the specific numbers and shapes of pits **319** described herein are merely exemplary of the concept.

[0068] FIG. **4**E is a flow chart of an example of a method **700** for using the automated length measurement mechanism of strut **300** to determine an absolute length of the strut **300** at any point during the correction procedure. In one example, method **700** may be performed after an external fixation frame, such as external fixation frame **10**, has been implanted onto a patient using struts **300** (e.g., a total of six struts **300** in place of struts **100***a-f*). In a first example step **710**, the sensor **317** (which may also be referred to as an absolute linear encoder) is turned on, and in step **720** it is determined whether the sensor **720** is providing any feedback. If it is determined that no feedback is being provided, in example step **730**, an error alert may be issued to the user in order to allow for troubleshooting. If it is determined that feedback is being provided, in example step **740**, the sensor **317** may read the particular row of pits **319** on the inner surface of the outer tube **320** that the sensor **317** confronts. This data may be stored within memory on (or operably coupled to) the sensor **317** for immediate or future transmission to a computer system that may, in step **760**, display the length of the strut **300** based on the unique combination of pits **319** read by the sensor **317**. It should be understood that, because the sensor **317** is positioned on the collar **315** of the pointer **312**, and because the pits **319** are provided in a column on the inner surface of the outer tube **320** in alignment with the sensors **317**, the sensor **317** will always face the pits **319** due to the point **312** (and collar **315** and sensor **317**) being rotationally fixed to the outer tube **320** (and pits **319**).

[0069] It should be understood that, in some examples, the sensor **317** may include memory, a processor, and/or a communication module that is capable of transmitting, via a wired or wireless connection, information relating to information determined from reading pits **319**. In some examples, information regarding the unique codes of pits **319** may be transmitted to the sensor **317** so that the calculation of total length correlating to the unique code of pits **319** can be performed within the fluctuation sensor **317**, and that information transmitted to an external computer such as one running a mobile or web application for planning and/or monitoring of the fixation frame progress. In some examples, if smart controller modules are being used with struts **300**, for example those described in the '665 Publication, information regarding the data of pits **319** read by the sensor **317** may be transmitted directly to the smart controller module which may process information to determine the total length the strut **300** (and/or relay information to another computer, such as one running the mobile or web application, to determine the total length adjustments). In some examples, information regarding the data of pits **319** read by the sensor **317** may be transmitted directly from the sensor **317** to another computer, such as one running the mobile or web application, to determine the total length adjustments.

[0070] One of the benefits of the automated length measurement described in connection with strut **300** is that a unique signal can be provided by pits **319** for any given length of the strut **300**. Because of this, a zero-point reference is not required for using this type of length measurement, for example because it is not changes that are being measured or determined, but rather absolute values that are being read directly by the sensor **317** at any given length of the strut **300**. Even if the sensor **317** or related component has been turned off of lost power for a certain amount of time, re-calibration is not needed.

[0071] FIG. **5**A is a perspective view of an example of a strut **400** that has structure in common with struts described in the '936 Publication, with at least one significant difference regarding a mechanism for determining the length of the strut **400**. In some examples, other than the features relating to the length measurement mechanisms, strut **400** may be identical to struts **200** and **300**. In the illustrated embodiment, strut **400** is a double-telescoping strut that may include a threaded rod **410**, one end of which may be coupled to a joint **402**. Threaded rod **410** may extend through adjustment knob **460**, which may be similar or identical to adjustment knob **260**. Threaded rod **410** may be actuated relative to the adjustment knob **460** in the same way as described in connection with actuation of threaded rod **210** relative to adjustment knob **260**.

[0072] Still referring to FIG. **5**A, strut **400** may include an outer tube **420** that may be similar or identical to outer tube **220**, with at least one exception related to the length measurement mechanism of strut **200** compared to that of strut **400**. In the illustrated example, the threads of the threaded rod **410** do not engage any corresponding threads within the outer tube **420**. An inner tube **440** may be at least partially received within the outer tube **420**, and may at least partially surround the threaded rod **410**, at least in some configurations. An end of the inner tube **440** may be coupled to a second joint **404**, for example similar to second joint **170**. As with struts **200** and **300**, in some examples, the length of the strut **400** may be gradually adjusted by rotating the adjustment knob **460** relative to the threaded rod **410**. A quick adjust mechanism **480** may be operated to either lock the inner tube **440** relative to the outer tube **420**, or to unluck the inner tube **440** relative to the outer tube **420** so that the length of the strut **400** may be rapidly adjusted, for example when initially assembling the external fixation frame **10** that uses strut **400**.

[0073] Still referring to FIG. **5**A, the terminal end of threaded rod **410**, opposite the side of the top joint **402**, may exclude threading and have a collar member to which length indicator or pointer **412** is coupled. The pointer **412** may be similar or identical to pointer **312**, and is thus not described again here, except that the sensor **319** on pointer **312** may be omitted from pointer **412**. As with strut **300**, as the threaded rod **410** moves into or out of the outer tube **420** as the length of the strut **400** increases or decreases, the pointer **412** may move axially along slot **424**. In some examples, optical marking may be provided on the outer tube **420** that the pointer **412** may align with. Although in FIG. **5**A the markings on the outer tube **420** are shown as hash marks with length indicators, it should be understood that the markings may instead be optical markers.

[0074] FIG. **5**B is an enlarged view of the portion of strut **400** in FIG. **5**A bounded in a dashed rectangle. In the view of FIG. **5**B, the pointer **412** is shown extending through the slot **424** of tube **420**. A plurality of optical markings **490** are provided on the outer tube **420** adjacent the slot **424**. Each optical marking **490** may be any suitable unique marking that is readable by a camera **495** or other scanner. Each unique marking **490** may correspond to a length of the strut **400** when the pointer **412** is aligned with a particular marking **490**. In use, a camera **495** may be pointed at any strut **400**. In some examples, camera **495** may be a smart phone camera of a user, but in other examples the camera **495** may be any suitable standalone camera or otherwise a camera coupled a component of the fixation frame **10**. In use, when the camera **495** is pointed at a particular strut **400** similar to the configuration of FIG. **5**B, the camera **495** (or software running on a computer, such as a smart phone operatively coupled to the camera **495**) may determine which optical marking **490** is overlapped by the pointer **412**, and determine that the optical marking **490** overlapped by the pointer **412** is the relevant optical marking **490** to read. In some examples, the optical markings **490** may be read by a camera **495** in a similar fashion as optical mark recognition ("OMR") and/or optical character recognition ("OCR"). Upon determining which optical marking **490** is overlapped by the pointer **412**, the camera **495** may read that particular optical marking **490** and translate the pattern or characters on the optical marking **490** to the corresponding unique length of strut **400**. In some examples, if the camera **495** is part of a smart phone, an application being used to operate the camera **495** may overlay the actual length measurement information onto the image of the strut **400** shown on the smart phone screen. With this embodiment, the absolute length of the strut **400** may be determined by the camera **495** recognizing the relevant optical marking **490** that the pointer **412** aligns with, and provide a quick and accurate measurement reading to the user.

[0075] FIG. **6**A is front view of an example of a strut **500**, shown in partial phantom, having another embodiment of a length measurement mechanism. Strut **500** is shown in generally simplified form, but may have the same overall components as struts **200**, **300**, **400**, with the exception of the particular mechanism for automatically measuring the overall length of the strut **500**. As such, these components or not described in greater detail herein, other than to state that the strut **500** may include an inner tube **540** coupled to a joint **504**, the inner tube **540** being positioned within an outer tube **520**. The outer tube **520** may house a threaded rod (not separately labeled) similar to threaded rods **210**, **310**, **410**, with the threaded rod being coupled to another joint **502**.

[0076] As with other double-telescoping struts described herein, the total length of the strut **500** may be based on two length components. A first length component may be an acute or rapid length adjustment achieved by moving the inner tube **540** farther out of or farther into the outer tube **520**, for example using a locking mechanism such as any of the quick adjust mechanisms (or gross adjustment knobs) described above. As with other embodiments described herein, this acute or rapid adjustment may be performed when initially assembling the external fixation frame **10** to the patient, which includes assembling the struts **500** to the rings **20**, **30**. A second length component may be a gradual length achievement achieved by moving the threaded rod farther out of or farther into the outer tube **520**, for example using a gradual adjustment knob which may be similar to adjustment knobs **260**, **460** described above.

[0077] In the illustrated example of FIG. **6**A, a first resistance wire **590** may be provided in the outer tube **520** with both ends connected to a connector **594**. A second resistance wire **591** may be provided in the inner tube **540** having points of contact with the first resistance wire **590**. A third resistance wire **592** may be provided on the threaded rod, the third resistance wire **592** having a point of contact **593** with the first resistance wire **590**, the third resistance wire **592** also being coupled to the connector **594**. In use, the three resistance wires **590**, **591**, **592** may create two separate loops from the connector **594** through the three moving components of the strut **500**, such that as the overall strut **500** length changes due to acute length adjustment, a first effective length L**1** of the resistance wire changes in one area of one of the loops, and while overall strut **500** length changes due to gradual length adjustment, a second effective length L**2** of the resistance wire changes in a second area of the other loop. As will be explained in greater detail below, one of the effective loop lengths changes only during gradual correction, while the other effective loop length changes only during rapid or acute length change.

[0078] This electrically conductive wire loop is shown in isolation schematically in FIG. **6**B. In the schematic illustration of FIG. **6**B, the third resistance wire **592** extends from a connection point **594***b* of the connector **594** to a point of contact **593**. As noted above the third resistance wire **592** moves up or down with movement of the threaded rod, changing the position of the point of contact **593** that connects the third resistance wire **592** to the first resistance wire **590**, and specifically a first portion **590***a* of the first resistance wire **590**. The first portion **590***a* of the first resistance wire **590** may have a first end **590***c* that connects back to connector **594** at connection point **594***a*, creating a first electronically conductive loop. The first portion **590***a* of the first resistance wire **590** may have another end that terminates in a point of connection **590***a***1** that contacts one leg of the second resistance wire **591**. Similarly, a second portion **590***b* of the first resistance wire **590** may terminate in a point of connection **590***b***1** that contacts the other leg of the second resistance wire **591**, with the second portion **590***b* of the first resistance wire **590** also connecting to connector **594** but at connection point **594***c*.

[0079] During gradual correction, the point of contact **593** between the third resistance wire **592** and the first portion **590***a* of the of the first resistance wire **590** changes (for example as the threaded rod, not shown, advances into or out of the outer tube **520**). Thus, during gradual correction, the overall length of a first wire loop changes, the first wire loop extending from connection **594***b* of connector **594**, along third resistance wire **592**, down the first portion **590***a* of the first resistance wire **590**, along second resistance wire **591**, and back up the second portion **590***b* of the first resistance wire **590** back to connector **594** at connection point **594***c*. Thus, if an external device is connected to connections **594***b* and **594***c*, and power is applied to connector **594** at connection **594***b*, electricity moves through the first loop of resistance wires back to the connector **594**. As one particular example, current may flow through the third resistance wire **592**, down the first portion **590***a* of the first resistance wire **590**, along second resistance wire **591**, and back to connector **594** via the second portion **590***b* of the first resistance wire **590**. A resistance determined based on the electricity flowing through this first loop may represent the total current length of the strut, based on the sum of the acute length and the gradual length. However, before being able to determine the total length of the strut, the acute length of the strut may be determined.

[0080] During acute adjustment, as the inner tube **540** moves during acute or gross strut length adjustment, the points of connection **590***a***1**, **590***b***1** change where they make contact with the respective legs of the second resistance wire **591**. Thus, if an external device is connected to connections **594***a* and **594***c*, and power is applied to connection **594***a* of connector **594**, in one example, electricity moves through a second loop of resistance wires back to the connector **594**. As one particular example, in this second loop, current may flow along the third portion **590***c* and then the first portion **590***a* of the first resistance wire **590**, into the second resistance wire **591** via connection point **590***a***1**, then into second portion **590***b* of the first resistance wire **590** via connection point **590***b***1**, and then back to the connector **594** via third connection **594***c*. This second loop may result in a resistance equal to the resistance of the gradual length (a constant, known value) and the effective resistance of the acute length. Thus, the resistance resulting from interrogating this second loop may allow for the acute length of the strut to be determined (using the known constant of the maximum gradual length). Then, the resistance resulting from interrogating the first loop may provide a resistance value that corresponds to the total strut length, and since the total strut length is equal to the sum of the gradual and acute strut lengths, and the acute strut length was calculated via the interrogation of the second loop, the interrogation of the first loop may allow for the gradual strut length to be calculated. In other words, via these two example interrogations of two different loops, the resulting resistances can be used to determine both the acute strut length and the gradual strut length.

[0081] By Ohm's law, in which voltage is equal to the product of current and resistance, as current is applied to each individual circuit (the first wire loop and the second wire loop), the total length of each circuit may be determined by applying current and measuring voltage. The determined resistance may be calibrated to determine actual strut length, as described below. In some examples, as shown in FIG. **6**C, a portable device **800**, which may have its own power source, may include a connector **894** configured to couple to connector **594** of strut **500**. Power (e.g., 3.3 volts) may be applied from the portable device **800** to each individual circuit, with the resistance of each circuit being determined by applying Ohm's law where the voltage and current is known. Based on a prior calibration step (described in more detail below), the calculated resistance may be used to determine the total length of strut **500**, which may be displayed on a screen of the portable device **800**. In some examples, a 16-bit ADC (analog-to-digital) converter may be used with portable device **800** to measure the circuit voltage and convert it to digital form. With the resolution of a 16-bit ADC, and using a 100 mm resistance wire that corresponds to the maximum strut length, the accuracy of the system may be high enough to detect length changes with a resolution of 0.001 mm.

[0082] In some examples, the system (including struts **500** and portable device **800**) may be calibrated during the manufacturing process, although the option remains to calibrate the system at another later point by using the calibration device. In one example, during calibration, the strut **500** may be adjusted to its minimum possible length, as shown in FIG. **6**D, and a calibration device **850** may be connected to portable device **800**. As a second part of the calibration, the strut **500** may be adjusted to its maximum possible length, as shown in FIG. **6**E, and the calibration device **850** may be connected to portable device **800**. In both stages of calibration, the resistance determined by portable device **800** may be calibrated to the strut length which is entered into the calibration device **850** during the calibration steps. Based on this calibration, the portable device **800** will be able to determine the total length of the strut **500** based on resistance values at any length between the minimum and maximum lengths of the strut **500**.

[0083] In some examples, features may be provided to assist with auto-detection of the type of strut (e.g., long strut, medium strut, short strut, extra short strut, mini strut) as well as the location of the strut (e.g., position one through six if six struts are used). In such examples, two components may be leveraged to detect the type and position of the strut. For example, each type of strut **500** may be provided with a unique internal resistance. For example, FIG. **6**F shows a medium size strut **500** which may include an internal resistance **Ω1** of 8 Ohms. Other size struts may be provided with different internal resistances, such as a long strut having an internal resistance of 10 Ohms, a short strut having an internal resistance of 6 Ohms, an extra short strut having an internal resistance of 4 Ohms, and a mini strut having an internal resistance of 2 Ohms. A second component to leverage the strut position may be a strut clip **900**, shown in FIGS. **6**G-**6**H. The strut clip **900** may have a color and/or number unique to each strut. The strut clip **900** shown in FIGS. **6**G-**6**H is meant to identify the second strut and be coupled to the second strut, as shown in FIG. **6**I. The strut clip **900** may be provided with its own internal resistance **Ω2**. If six struts **500** are used, a total of six strut clips **900** may be used, each strut clip **900** having a different internal resistance **Ω2**. For example, the strut clip **900** for the first strut position may have an internal resistance of 10 Ohms, the strut clip **900** for the second strut position may have an internal resistance of 20 Ohms, the strut clip **900** for the third strut position may have an internal resistance of 30 Ohms, the strut clip **900** for the fourth strut position may have an internal resistance of 40 Ohms, the strut clip **900** for the fifth strut position may have an internal resistance of 50 Ohms, and the strut clip **900** for the sixth strut position may have an internal resistance of 60 Ohms.

[0084] When a strut clip **900** is attached to its corresponding strut **500**, the internal resistance **Ω1** of the strut (based on type of strut) and the internal resistance **Ω2** of the strut clip **900** (based on position of strut) are combined, resulting in a unique resistance value. This value may be measured by the ADC in the portable device **800** to identify the specific location and strut type. For example, referring to FIG. **61**, when the strut clip **900** of the second position (having an internal resistance **Ω2** of 20 Ohms) is connected to a medium-length strut **500** (having an internal resistance **Ω1** of 8 Ohms), the total resistance of the system is 28 Ohms, providing a unique resistance value that allows for identification of both the type of strut (e.g., length-type of strut) and the position of the strut (e.g., positions one through six). Based on the example values of internal resistances **Ω1** of the different type of struts and internal resistances **Ω2** of the different position strut clips **900**, a chart is provided in FIG. **6**J showing how all combinations of strut types and strut positions provide for a unique total resistance value that can identify uniquely the position and type of each strut **500**.

[0085] In use, when it is desired to measure the length of one or more of the struts **500**, the portable device **800** (after calibration has previously performed) may be coupled to a corresponding strut **500** by connecting connector **894** to connector **594**. By determining the combined internal resistance of the strut **500** and the clip **900** (e.g., **Ω1+Ω2**), the portable device **800** may determine which position strut it is connected to, as well as what type of strut it is connected to. As described above, the portable device **800** may apply power to the strut **500** and, based on the resistances of the resistance wire loops, the length of the strut **500** may be determined. In some examples, the length of the strut **500** may be stored along with identifying information about the type and position of the strut **500**. In some examples, each strut **500** may be measured individually, and after each measurement, the portable device **800** may transmit, e.g. via Bluetooth or any other suitable communication modality, the length and identification of the strut, for example to web or mobile software that manages the correction schedule. In some examples, each strut **500** may be measured by the portable device **800**, and then all strut length measurements (along with corresponding strut identification information) may be transmitted together to the web or mobile application managing the correction schedule. In some examples, instead of transmitting the information wirelessly, the strut lengths and identification may be displayed on the portable device **800** for the user to enter manually into the relevant software application as desired.

[0086] FIGS. **6**K-L illustrate other examples of interrogating resistance wires in struts to calculate the relevant lengths of those struts, generally similar to those shown in FIGS. **6**A-B. It should be understood that the disclosure provided in connection with FIGS. **6**C-**6**J may similarly apply to the example of FIGS. **6**K-L.

[0087] FIG. **6**K is front view of an example of a strut **1500**, with center portions thereof shown in partial phantom, having another embodiment of a length measurement mechanism, similar to that of FIG. **6**A. Strut **1500** may have the same overall components as struts **200**, **300**, **400**, with the exception of the particular mechanism for automatically measuring the overall length of the strut **1500**. As such, these components or not described in greater detail herein, other than to state that the strut **1500** may include an inner tube **1540** coupled to a joint **1504**, the inner tube **1540** being positioned within an outer tube **1520**. The outer tube **1520** may house a threaded rod **1510** similar to threaded rods **210**, **310**, **410**, with the threaded rod being coupled to another joint **1502**.

[0088] As with other double-telescoping struts described herein, the total length of the strut **1500** may be based on two length components. A first length component may be an acute or rapid length adjustment achieved by moving the inner tube **1540** farther out of or farther into the outer tube **1520**, for example using a locking mechanism, such as quick adjustment mechanism **1580**, which may be similar or identical to any of the quick adjust mechanisms (or gross adjustment knobs) described above. As with other embodiments described herein, this acute or rapid adjustment may be performed when initially assembling the external fixation frame **10** to the patient, which includes assembling the struts **1500** to the rings **20**, **30**. A second length component may be a gradual length achievement achieved by moving the threaded rod **1510** farther out of or farther into the outer tube **1520**, for example using a gradual adjustment knob **1560**, which may be similar to adjustment knobs **260**, **460** described above.

[0089] Now referring to both FIGS. **6**K and **6**L, a first resistance wire **1590** may include a first end connected to connector **1594**, for example at connection **1594***b*. A fourth portion **1590***d***1** of first resistance wire **1590** may extend from the connection **1594***b* and include a first portion **1590***a***1** extending downward from an end of fourth portion **1590***d***1** toward inner tube **1540**, and a third portion **1590***c***1** extending upward from an end of fourth portion **1590***d***1** toward threaded rod **1510**, where it may loop backward toward connector **1594**. A third resistance wire **1592** may include a first end coupled to connection **1594***a* of connector **1594**, and terminate in a second end with a contact point **1593** that can ride along the looped back portion of the third portion **1590***c***1** of first resistance wire **1590** as the threaded rod **1510** moves farther into or out of the outer tube **1520**. A second resistance wire **1591** may be positioned on or in inner tube **1540** similar to second resistance wire **591**. For example, the first portion **1590***a***1** of first resistance wire **1590** may terminate in a contact point with a first leg of the third resistance wire **1591**, and a second portion **1590***b***1** of the first resistance wire **1590** may have a first end that terminates in a contact point with a second leg of the third resistance wire **1591**, and a second end that connects to a connection **1594***c* of connector **1594**. It should be understood that, although the term "connection wire" is used herein, the term "connection wire" does not necessarily refer to a single continuous wire, but rather may include multiple wire portions.

[0090] Referring mainly to FIG. **6**L, this configuration may generally create two loops, with a first loop generally corresponding to the gradual length (e.g., L**2** of FIG. **6**K) and a second loop generally corresponding to the acute length (e.g., L**1** of FIG. **6**K). For example, in order to measure the gradual length, a portable device **800** may be connected to connections **1594***a* and **1594***b* of connector **1594**, and power applied to one of the connections. With this configuration, electric current may flow along third resistance wire **1593**, then to the third portion **1590***c***1** of the first resistance wire **1590** and then to the fourth portion **1590***d***1** of the first resistance wire **1590**, back to the connector **1594** at connection point **1594***b*. As the threaded rod **1510** moves farther into or out of the outer tube **1520**, the effective length of the first loop changes, resulting in a corresponding change in effective resistance of the loop. In order to measure the acute length, a portable device **800** may be connected to connections **1594***b* and **1594***c* of connector **1594**, and power applied to one of the connections. With this configuration, electric current may flow along the fourth portion **1590***d***1** of the first resistance wire **1590**, down the first portion **1590***a***1** of the first resistance wire, along the second resistance wire **1591**, and back up the second portion **1590***b***1** of the first resistance wire **1590** back to the connector **1594** at connection **1594***c*. As the inner tube **1540** moves farther into or out of the outer tube **1520**, the effective length of the second loop changes, resulting in a corresponding change in effective resistance of the loop. Thus, the gradual and acute length may each be detected directly by determining the resistance of each loop individually and comparing to the known reference values, and the total length of the strut may be determined by summing the acute and gradual lengths.

[0091] Although the invention herein has been described with reference to particular embodiments, it is to be understood that these embodiments are merely illustrative of the principles and applications of the present invention. For example, features described in relation to one particular embodiment may be combined with features of other embodiments described herein. It is therefore to be understood that numerous modifications may be made to the illustrative embodiments and that other arrangements may be devised without departing from the spirit and scope of the present invention as defined by the appended claims.

1. A strut for use with an external fixation system, the strut comprising:

a first joint proximate a first end of the strut, the first joint configured to couple to a first ring of the external fixation system;

a second joint proximate a second end of the strut, the second joint configured to couple to a second ring of the external fixation system;

a threaded rod having a first end coupled to the first joint;

a tube that receives the threaded rod;

a fluctuation counter coupled to the tube; and

a needle coupled to the fluctuation counter, the needle extending through a bore in the tube, the needle having a free end in contact with the threaded rod,

wherein the strut is an adjustable-length strut whereby the threaded rod is moveable axially into or out of the tube, and while the threaded rod moves into or out of the tube, the free end of the needle is configured to maintain contact with the threaded rod.

2. The strut of claim **1**, wherein while the threaded rod moves into or out of the tube, the free end of the needle is configured to maintain contact with the threaded rod by riding along peaks and valleys of threads of the threaded rod.

3. The strut of claim **2**, wherein as the free end of the needle rides along peaks and valley of threads of the threaded rod, a position of the fluctuation counter is configured to fluctuate relative to the tube.

4. The strut of claim **3**, wherein the fluctuation counter is configured to count a total number of fluctuations as the free end of the needle rides along peaks and valleys of threads of the threaded rod, with one fluctuation corresponding to one complete revolution of the threaded rod.

5. A method of determining a change in length of a strut of an external fixation system, the method comprising:

axially translating a threaded rod of the strut into or out of a tube of the strut to increase or decrease an effective length of the strut such that, during the axial translating, a free end of a needle that is coupled to a fluctuation counter that is coupled to the tube moves radially inward toward thread valleys of the threaded rod or radially outward toward threads peaks of the threaded rod;

counting, via the fluctuation counter, a total number of fluctuation cycles of the needle, each fluctuation cycle corresponding to one revolution of the threaded rod relative to the tube; and

determining a total length change of the strut by multiplying the total number of fluctuation cycles by a pitch of the threaded rod.

6. The method of claim **5**, wherein each time the free end of the needle moves from one peak of the threaded rod to an axially adjacent peak of the threaded rod, the fluctuation counter increases the total number of counted fluctuation cycles by one.

7. The method of claim **5**, wherein each time the free end of the needle moves from one valley of the threaded rod to an axially adjacent valley of the threaded rod, the fluctuation counter increases the total number of counted fluctuation cycles by one.

8. The method of claim **5**, wherein prior to counting the total number of fluctuation cycles of the needle, the total number of counted fluctuation cycles is set to zero.

9. The method of claim **6**, wherein prior to determining the length change of the strut, the pitch of the threaded rod is entered into software of a computer system.

10. The method of claim **9**, wherein after counting the total number of fluctuation cycles of the needle, the total number of counted fluctuation cycles is entered into the software of the computer system, and the step of determining the total length change of the strut is performed using the software of the computer system.

11. A strut for use with an external fixation system, the strut comprising:

a first joint proximate a first end of the strut, the first joint configured to couple to a first ring of the external fixation system;

a second joint proximate a second end of the strut, the second joint configured to couple to a second ring of the external fixation system;

a threaded rod having a first end coupled to the first joint;

a tube that receives the threaded rod;

a pointer secured to a second end of the threaded rod, the pointer extending through an axially-extending slot of the tube, the pointer having a collar, a fastener extending through the collar to secure the pointer to the threaded rod;

a sensor coupled to the collar; and

a plurality of rows of pits formed in an inner surface of the tube, each row of pits having a unique shape combination corresponding to a unique length value.

12. The strut of claim **11**, wherein the threaded rod is configured to move into or out of the tube to change an effective length of the strut, and the pointer is rotationally fixed to the tube so that, as the effective length of the strut changes, the sensor maintains a rotational position relative the inner surface of the tube in which the sensor points toward at least one of the plurality of rows of pits.

13. The strut of claim **12**, wherein there is a total number of ten uniquely shapes pits, each uniquely shaped pit corresponding to a numeral between 0 and 9.

14. The strut of claim **13**, wherein the plurality of rows of pits are organized into three columns, a first of the three columns corresponding to a single-digit place, a second of the three columns corresponding to a double-digit place, and a third of the three columns corresponding to a triple-digit place.

15. The strut of claim **11**, wherein the sensor is an array or matrix of ultrasonic sensors.

16. The strut of claim **11**, wherein the sensor is an array or matrix of optical sensors.

17. The strut of claim **11**, wherein the sensor is a camera.

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