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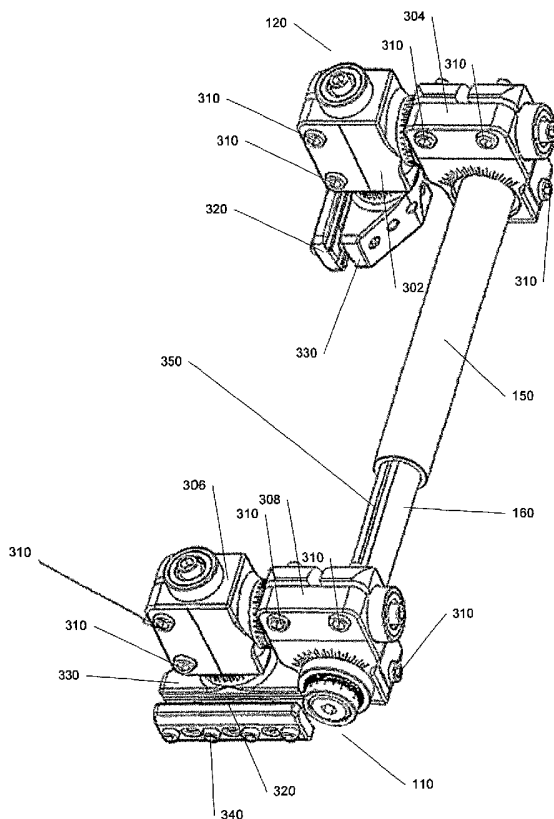
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[Continued on next page]

(54) Title: UNILATERAL FIXATOR

300



(57) Abstract: A unilateral external fixator device that allows for gross manipulation and fine adjustment of deformities in six degrees of freedom. The device may comprise a strut assembly and two compound movable joints, one at each end of the strut assembly. One compound movable joint may comprise two revolute joints, each containing a gear reduction mechanism and may rotate about the strut. The second compound movable joint may contain two revolute joints, each containing a gear reduction mechanism, and may move along the length of the strut assembly. The gear reduction mechanisms may comprise helical spline assemblies that allow for gross and fine adjustment of the fixator.

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## UNILATERAL FIXATOR

### STATEMENT OF RELATED PATENT APPLICATIONS

This non-provisional patent application claims priority under 35 U.S.C. § 119 to U.S. Provisional Patent Application No. 60/411,291, titled *Unilateral Fixator*, filed September 17, 2002, and U.S. Provisional Patent Application No. 60/426,439, titled *Unilateral Fixator Method*, filed November 14, 2002. These provisional applications are hereby fully incorporated herein by reference.

### FIELD OF THE INVENTION

The present invention relates to a unilateral fixator and more specifically to a unilateral fixator that addresses a variety of six-degrees-of-freedom musculoskeletal deformity through both gross and fine manipulation of the fixator during the deformity correction process.

### BACKGROUND OF THE INVENTION

In orthopedic medicine, physicians often need to correct certain skeletal injuries or deformities with external fixator devices. These deformities can either be an acute or chronic condition that may be corrected over a short or long period of time. These devices use pins or wires attached to the separate bone segments and an external structural frame to align, or fix, the bone segments in a way to aid in repairing the injury or correcting the deformity. When the device is engaged with a patient, the device applies forces to maintain the bone fragments in a configuration prescribed by a physician. Often the physician must gradually adjust the orientation of the bone segments over time, optimally with the capability to adjust the orientation along six degrees of freedom to ensure the bone segments are placed in the correct anatomic condition.

Devices and methods for treating musculoskeletal deformities are well known in the art. Although these devices vary considerably in design, they typically fall into two broad categories, circular ring and unilateral devices. The circular ring device category is exemplified by Ilizarov-type systems, which have two rings connected by linear struts with a fixed or hinged connection at each end of each strut. A device called a space frame, which has two rings connected by six linear struts having a spherical joint at each end arranged in a hexapod configuration, e.g., a Stewart frame, represents an advancement on the original Ilizarov concept. Other embodiments can be combinations of rings being attached to what would be considered a unilateral device. These constructs are typically referred to as hybrid devices.

The Ilizarov device is constructed based on the deformity that needs correcting, that is, for a specific patient and a specific deformity on that patient, hinges and struts are added to address each degree of deformity in a specific case. Ilizarov-type devices are often referred to as serial manipulators in that each adjustment relates to a single degree of deformity. This approach requires the frame to be constructed based on the deformity present, resulting in a fairly straightforward method of use but a potentially complex set of multiple and potentially endless configurations. The space frame is a device that conceptually comes in one configuration even though rings and struts can be of differing sizes. The Stewart frame-type space frame is often referred to as a parallel manipulator in that any given adjustment to any of the six struts will result in a change to all six degrees of freedom. This characteristic makes the Stewart frame type device less intuitive to use. A computer program is often required to direct the user in making the adjustments to correct the deformity.

The unilateral device category has several devices that basically consist of a series of orthogonal planar hinges or spherical joints and, in some cases, sliders that can be locked into a particular orientation. Typically these devices can be used to fix bone segments in a particular orientation but not to gradually, and precisely, drive the orientation, since the joints of the device do not have a direct adjustment device

associated with each hinge or slider. Instead, the joints of the device must be loosened and then grossly manipulated on the device as a whole. Like the Ilizarov-type circular ring fixators, some of these devices have the ability to drive certain degrees of freedom, typically compression or distraction and, at times, a single revolution about an axis, although these devices often need to be constructed or mounted in a particular orientation depending on the characterization of the deformity. This requirement complicates their use and also necessitates multiple configurations to address the range of deformities that physicians typically encounter. None of the devices in the prior art allow for precise adjustment in six degrees of freedom while the device is engaged with the patient.

Six-degrees-of-freedom refers to movement relative to three orthogonally-opposed axis plus rotation about each of those three axis. These six degrees of freedom are typically referred to as longitudinal, vertical, lateral, pitch, roll, and yaw.

Also, a space frame or unilateral fixator can be grossly manipulated to position the bone fragments of a deformity in the proper place at the beginning of the a deformity correction process. However, a physician may need to reposition the fixator throughout the deformity correction process, to effectuate a proper correction of the deformity. Typical space frames and unilateral fixators must be disengaged from the patient, that is, the devices need to be loosened while attached to the patient, and grossly adjusted each time the physician needs to adjust the orientation of the fixator during the deformity correction process. One reason for this limitation of existing devices is that the adjustment mechanisms of the devices do not provide sufficient mechanical advantage or range of motion to accomplish the fine adjustment. This inability to finely adjust the fixator in place reduces the utility of these fixators.

What is needed is a device that can address a six-degrees-of-freedom musculoskeletal deformity, that is, a deformity having anterior-posterior (AP), lateral, and axial offsets and angulations or any subset thereof. The desired device should be able to be placed on the deformity in any particular orientation within the limits of practicality and be able to reduce the deformity to the anatomic state without needing

multiple configurations of the same device. Additionally, the device should be able to allow for the gross manipulation of the deformity for acute cases and then to allow for additional precise, fine adjustment to be administered during a deformity correction process while the device remains engaged with the patient to fully restore the deformity to the correct anatomic condition through an adjustment mechanism that offers a high degree of mechanical advantage.

### **SUMMARY OF THE INVENTION**

The present invention provides a unilateral external fixator device that allows for gross manipulation and fine adjustment of deformities in six degrees of freedom. The present invention may require only one configuration of the fixator to address a wide range of deformities. The present invention may include an adjustment mechanism that offers superior mechanical advantage. This system provides a key advantage over the prior art: a unilateral device with six degrees of freedom that can correct, through both gross and fine adjustments, bone deformities in any direction without the need to continually disengage the fixator from the patient during a deformity correction process.

One aspect of the present invention provides a unilateral fixator comprises a strut assembly and two compound movable joints. Each compound movable joint comprises two revolute joints and one compound movable joint is capable of rotating about the linear axis of the strut assembly and the second compound movable joint is capable of moving along the linear axis of the strut assembly. The fixator also comprises a bone fragment attachment apparatus attached to each of the compound movable joints.

In another aspect of the present invention a unilateral fixator comprises a strut and two compound movable joints. One compound movable joint is fixed relative to the strut and comprises three revolute joints and the second compound movable joint comprises two revolute joints and is capable of moving along the linear axis of the strut assembly.

The fixator also comprises a bone fragment attachment apparatus attached to each of the first and second compound movable joints.

In another aspect of the present invention, a compound movable joint for a unilateral fixator comprises a left-hand helical spline, a right-hand helical spline, and a thrust washer positioned between the right-hand helical spline and the left-hand helical spline. The compound movable joint also comprises a helical spool that may slide within the right-hand helical spline and the left hand helical spline and may be rotationally engaged to the right-hand helical spline and the left hand helical spline. The compound movable joint also has a cap screw axially clamping together the left-hand helical spline, the right-hand helical spline, and the thrust washer and allowing for a fine adjustment of the reduction mechanism while the bone fragment attachment apparatus is engaged with a bone fragment.

The aspects of the present invention may be more clearly understood and appreciated from a review of the following detailed description of the disclosed embodiments and by reference to the drawings and claims.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

**FIG. 1** provides an image of a unilateral fixator in accordance with an exemplary embodiment of the present invention.

**FIG. 2** provides an image of Section A-A of the unilateral fixator provided in **FIG. 1**.

**FIG. 3** provides an isomeric image of the exemplary unilateral fixator provided in **FIG. 1**.

**FIG. 4a** provides an alternative image of an exemplary unilateral fixator.

**FIG. 4b** provides an image of Section B-B of the unilateral fixator provided in **FIG. 4a**.

**FIG. 5** provides an image of Detail A of the unilateral fixator provided in **FIG. 2**.

**FIG. 6** provides an image of Section C-C of Detail A of **FIG. 3** showing a gear assembly for a unilateral fixator in accordance with an exemplary embodiment of the present invention.

**FIG. 7** provides an image of a compound movable joint in accordance with an exemplary embodiment of the present invention.

**FIG. 8a** provides a front image of a unilateral fixator in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 8b** provides a side image of a unilateral fixator in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 8c** provides a top image of a unilateral fixator in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 9** provides an isomeric image of a unilateral fixator in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 10a** provides a front image of a compound movable joint in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 10b** provides a side image of a compound movable joint in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 10c** provides a top image of a compound movable joint in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 11** provides an isomeric image of a compound movable joint in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 12a** provides a front image of the first of two revolute joints of a compound movable joint in accordance with an alternative exemplary embodiment of the present invention.



**FIG. 12b** provides a side image of the first of two revolute joints of a compound movable joint in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 12c** provides a top image of the first of two revolute joints of a compound movable joint in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 12d** provides a isomeric image of the first of two revolute joints of a compound movable joint in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 12e** provides an image of Section A-A of the first of two revolute joints of the compound movable joint provided in **FIG. 12c**.

**FIG. 12f** provides an image of Section B-B of the first of two revolute joints of the compound movable joint provided in **FIG. 12b**.

**FIG. 12g** provides an image of Section C-C of the first of two revolute joints of the compound movable joint provided in **FIG. 12b**.

**FIG. 12h** provides an image of Section D-D of the first of two revolute joints of the compound movable joint provided in **FIG. 12b**.

**FIG. 13** provides a perspective view of the drive mechanism of the first of two revolute joints of a compound movable joint in accordance with an exemplary embodiment of the present invention.

**FIG. 14a** provides a front image of the second of two revolute joints of a compound movable joint in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 14b** provides a side image of the second of two revolute joints of a compound movable joint in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 14c** provides a top image of the second of two revolute joints of a compound movable joint in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 14d** provides a isomeric image of the second of two revolute joints of a compound movable joint in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 14e** provides an image of Section A-A of the second of two revolute joints of a compound movable joint provided in **FIG. 14c**.

**FIG. 15a** provides a front image of a pin clap unit in accordance with an exemplary embodiment of the present invention.

**FIG. 15b** provides a side image of a pin clap unit in accordance with an exemplary embodiment of the present invention.

**FIG. 15c** provides a top image of a pin clap unit in accordance with an exemplary embodiment of the present invention.

**FIG. 15d** provides a isomeric image of a pin clap unit in accordance with an exemplary embodiment of the present invention.

**FIG. 15e** provides an image of Section A-A of the pin clap unit provided in **FIG. 15c**.

**FIG. 16a** provides a front image of a strut structure in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 16b** provides a side image of a strut structure in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 16c** provides a top image of a strut structure in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 16d** provides a isomeric image of a strut structure in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 17a** provides a front image of a base tube assembly in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 17b** provides a side image of a base tube assembly in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 17c** provides a bottom image of a base tube assembly in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 17d** provides a isomeric image of a base tube assembly in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 17e** provides an image of Section A-A of the base tube assembly provided in **FIG. 17c**.

**FIG. 18a** provides a front image of a top tube assembly in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 18b** provides a side image of a top tube assembly in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 18c** provides a top image of a top tube assembly in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 18d** provides a isomeric image of a top tube assembly in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 19a** provides a front image of a yaw joint of the strut structure of **FIG. 16** in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 19b** provides a side image of a yaw joint of the strut structure of **FIG. 16** in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 19c** provides a bottom image of a yaw joint of the strut structure of **FIG. 16** in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 19d** provides a isomeric image of a yaw joint of the strut structure of **FIG. 16** in accordance with an alternative exemplary embodiment of the present invention.

**FIG. 19e** provides an image of Section A-A of the yaw joint of the strut structure of **FIG. 16** provided in **FIG. 19c**.

### **DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS**

Exemplary embodiments of the present invention provide a unilateral external fixator device that allows for gross manipulation and fine adjustment of deformities in six degrees of freedom, allowing for a large mechanical advantage and adjustments of the fixator through a deformity correction process without disengaging the device from the patient. **FIG. 1** provides an image of a unilateral fixator **100** in accordance with an exemplary embodiment of the present invention. Referring to **FIG. 1**, the fixator **100** comprises two compound movable joints **110, 120**. Attached to each compound movable joint **110, 120** is a pin clamp **130, 140**. The pin clamp can accept a variety of pins (not shown), which can be attached to bone fragments undergoing a deformity correction procedure. The compound movable joint **110** is attached to an extension strut **160**. The compound movable joint **120** is attached to a base strut **150**. The extension strut **160** may slide in and out of the base strut **150**, thereby allow for a change in the distance between the two compound moveable joints **110, 120**. **FIG. 1** also indicates a section line A-A. Details of Section A-A are provided below, in connection with **FIG. 2**.

**FIG. 2** provides an image **200** of Section A-A of the unilateral fixator provided in **FIG. 1**. Referring to **FIG. 2**, a base strut **220** forms the main structure of a strut assembly. An extension strut **210** is able to slide within the base strut **220**. The extension strut **210** and base strut **220** are restrained from rotating relative to one another by a square key **230**, which is inserted into a milled slot (not shown) in the base strut **220**

and captured by a groove 350 (Fig. 3) in the extension strut 210. The extension of the extension strut 210 relative to the base strut 220 is affected through a linear adjuster 270. The linear adjuster 270 is captured within the base strut 220 by two snap rings 260. The linear adjuster 270 has threaded into it a threaded rod 240, whose other end is threaded into a solid threaded locking insert 250, such as a "KEENSERT" insert, which is in turn threaded into the extension strut 210. Once the threaded rod 240 is threaded into the linear adjuster 270, it is locked in place with a suitable thread locking compound. In an alternative embodiment, the threaded rod 240 could be made integral with the linear adjuster 270. The rotation of the linear adjuster 270 forces the threaded rod 240 to translate within the solid, threaded locking insert 250, which forces the extension strut 210 to translate within the base strut 220, thereby effecting extension or contraction of the strut assembly. The linear adjuster may be rotated by way of a knob adjuster or a tool, such as an allen wrench. One skilled in the art would appreciate that other mechanism may be employed to cause the extension strut 210 to move within the base strut 220 while ensuring that the base strut 220 and extension strut 210 may be locked into a fixed position when the exemplary fixator device of image 200 is positioned on a patient. Such a mechanism might resemble a turnbuckle that is engaged to a radial pin at either end that extends from both the base strut and extension strut, adjusting the length of the turnbuckle would thereby either extend or contract the extension strut relative to the base strut

FIG. 3 provides an isomeric image 300 of an exemplary unilateral fixator provided in FIG. 1. Referring to FIG. 1 and FIG. 3, in this exemplary embodiment, a compound movable joint 110 is attached to the base strut 160 and a compound movable joint 120 is attached to the extension strut 150. These two compound movable joints 110, 120 are identical. The compound movable joints 110, 120 each include two revolute joints 302, 304, 306, 308, the axes of which are orthogonally opposed. In alternative embodiments, the axes could be at angles other than ninety degrees.

The compound movable joint **110**, also referred to herein as the wrist, is able to rotate about, but not slide along, the axis of the extension strut **160**. The compound movable joint **120**, also referred to herein as the ankle, is able to slide along, but not rotate about, the axis of the base strut **150**. Both the ankle **120** and the wrist **110** can be locked in place relative to their respective struts **150**, **160** by tightening their corresponding cap screw **310**. In this exemplary embodiment, the ankle **120** and wrist **110** include multiple cap screws **310** (some not shown) to fix a given component of one of the compound movable joints **110**, **120** in a specific configuration. These cap screws **310** are preferably made of corrosion resistant steel (CRES, or stainless steel). One skilled in the art would appreciate that the exact size of the cap screws **310** used will vary with the specific application of the fixator. Similarly, the cap screws **310** may be made of other materials suitable for medical device applications.

In an alternative embodiment, the compound movable joint **110** could be made to slide along, but not rotate about, the axis of the extension strut **160**. Similarly, the compound movable joint **120** could be made to rotate about, but not slide along, the axis of the base strut **150**. Alternatively, the base strut **150** and the extension strut **160** could be made to rotate relative to one another and the compound movable joint **110** and compound movable joint **120** could be fixed to the extension strut **160** and the base strut **150**, respectively.

Attached to each compound movable joint **110**, **120** is a clamp plate **320** and a clamp body **330**. These clamp plates **320** and clamp bodies **330** receive pins (not shown) or other suitable devices for attaching the compound moveable joints **110**, **120** to a patient's body. These clamp plates **320** and clamp bodies **330** may be made from an aluminum alloy #2024 or other materials suitable for medical device applications. The clamp plate **320** is secured to the clamp body **330** with four cap screws **340**. Each cap screw **340** may be threaded into a combination of holes such that cap screws **340** straddle each pin (not shown). In one exemplary embodiment, each pin (not shown), being cylindrical in form, would have around it two split balls (not shown) each of which is

clamped in the grooves of the clamp plate 320 and the clamp body 330. The split balls (not shown) would have the ability to slide along the grooves to allow both divergent and convergent pin arrangements in a given plane.

**FIG. 4a** provides an alternative image of an exemplary unilateral fixator 500. **FIG. 4b** provides an image of Section B-B of the unilateral fixator provided in **FIG. 4a**. Referring to **FIG. 4a** and **FIG. 4b**, the image of the exemplary unilateral fixator 500 shows a B-B section line, cutting through the compound movable joint 120. In this exemplary embodiment, section B-B 401 depicts details common to both compound movable joints 110, 120. Also, the compound movable joints 110 and 120 each comprise two revolute joints 405, 410. As such, **FIG. 4b** depicts a cross section of each of the two revolute joints 405, 410, and specifically illustrates an exemplary gear reduction mechanism. To avoid clutter in **FIG. 4b**, items, although common to both revolute joints 405, 410, are identified once. One skilled in the art would appreciate that an item identified on one of the revolute joints is also present in the other.

Each revolute joint 405, 410 may include left-hand helical spline 460 includes a cylinder having an internal left hand helical spline. In line with the left-hand helical spline 460 is a right-hand helical spline 420, which is a cylinder having an internal right hand helical spline. Separating the left-hand helical spline 460 and the right-hand helical spline 420 is a thrust washer 445. Sliding within and rotationally engaged to both the left-hand helical spline 460 and the right-hand helical spline 420 is a helical spool 440. The helical spool 440 has both a left and a right external helical spline that has the same helix angle as does its mating parts. The left hand internal and external helical splines must have the same diametral pitch, number of teeth, and helix angle as one another and, similarly, the right hand internal and external helical splines must have the same diametral pitch, number of teeth, and helix angle as one another. However, these characteristics for the left hand helical splines could differ from these characteristics for the right hand helical splines.

The left-hand helical spline 460, the right-hand helical spline 420, and the thrust washer 445 are axially-clamped together using a cap screw 465, a thrust washer 470, a spacer 435, a castellated nut 450, and a roll pin 425. First, the thrust washer 470 and spacer 435 are fit over the cap screw 465. Then, the spacer 435 is fit into a counter bore in the left-hand helical spline 460. The helical spool 440 is then engaged with the left-hand helical spline 460 and the cap screw 465 is threaded into the helical spool 440 as it slides with the left-hand helical spline 460. The thrust washer 445 is then held against the left-hand helical spline 460 and the right-hand helical spline 420 is slid onto the helical spool 440 with the counter bore away until it comes up against the thrust washer 445. The spacer 435 is then fitted over the cap screw 465 and into the counter bore of the right-hand helical spline 420. Thrust washer 470 is then fitted over the cap screw 465 and the castellated nut 450 is threaded onto the cap screw 465 with a final preload applied to eliminate any lash from the assembly. The roll pin 425 is then pressed into a hole in the cap screw 465 and aligned to one of the slots in the castellated nut 450.

The helical spline gear reducer assembly, that is, the left-hand helical spline 460, the right-hand helical spline 420, the helical spool 440, the cap screw 465, and the other associated components described above, is then slipped within a split bore of a roll housing 415. The assembly is retained axially within the bore through the use of two cap screws 475, one of which clamps and locks the left-hand helical spline 460 and the other of which clamps and locks the right-hand helical spline 420.

Using two separate cap screws 475 allows for the locking of the ground reference and/or the output of the helical spline gear reducer assembly relative to the roll housing 415. Initially, both cap screws 475 would be in place but not tightened. This configuration would allow the free rotation of the helical spline gear reducer assembly and thus the output within the roll housing 415. Locking of the first cap screw 475 effectively prevents the rotation of the left-hand helical spline 460 relative to the roll housing 415. The right-hand helical spline 420 is then able to rotate only through the rotation of the cap screw 465. Locking of the second cap screw 475 effectively prevents



the rotation of the right-hand helical spline relative to the roll housing 415. The reason for this second locking provision is twofold. First, in the event that no further adjustment is desired, or for added structural integrity, the revoluted joint can be locked. Second, because of the limited length of the left-hand helical spline 460, the right-hand helical spline 420, and the helical spool 440, the output of the helical spline gear reducer operates within a limited rotation angle based on the reduction ratio. If the output rotation needs to be increased, the right-hand helical spline 420 can be locked while the left-hand helical spline 460 is unlocked. This configuration effectively allows the cap screw 465 to be backed off to reposition the helical spool 440 such that the output angulation range can be extended.

In an alternative embodiment, the separate cap screws 475 may be omitted. In this case, the helical spool 440 and the left-hand helical spline 460 and the right-hand helical spline 420 may have helical angles such that they are self-locking. The helical angles for the helical spool and the left-hand helical spline 460 and the right-hand helical spline 420 may be close to a threshold value for self-locking. This value will vary by material and size of the left-hand helical spline 460 and the right-hand helical spline 420, but may be in the range of 15 to 25 degrees. In this case, the cap screw 465 could be configured to be threaded into the helical spool 440 but not threaded or captured with the castellated nut 450. This configuration would allow the cap screw 465 and the helical spool 440 to move axially with the left hand helical spline 460 and the right hand helical spline 420 if the rotational and frictional forces are favorable. The castellated nut 450 and the roll pin 425 would be replaced with another form of axial restraint such as a snap ring that would be engaged when the cap screw 465 was threaded completely into the helical spool 440. Once the snap ring was engaged further axial translation of the helical spool 440 could only be accomplished through the rotation of the cap screw 465 which would allow for fine adjustment.

When the cap screw 465 is not engaged with the snap ring, i.e., when the helical spool 440 is not restrained axially, other than from friction between the helical teeth,

from sliding within the left-hand helical spline **460** and the right-hand helical spline **420** and they are not further locked in place, the compound movable joint **410** could be subjected to an external stimulation, for example, a vibrational force could be applied to the compound movable joint **410**. As such, this vibrational force could overcome the small frictional force that provides the self-locking capability of the helical spool **440** relative to the left-hand helical spline **460** and the right-hand helical spline **420**. So, by applying and removing a vibrational force, or other force that can overcome the frictional forces between the helical spool **440** and the left-hand helical spline **460** and the right-hand helical spline **420** without adversely affecting the unilateral fixator's positioning on the patient, the revolutes joints of the compound movable joint **410** could be instantly loosened and tighten without the need for tightening screws or similar mechanisms.

Once the helical gear reducer assembly is assembled within the roll housing **415**, the pitch housing **430** is then threaded and torqued onto the right-hand helical spline and locked in place using a suitable bonding compound or mechanical retention device. In an alternative embodiment, this assembly could also be done prior to the insertion of the helical spline gear reducer assembly into the roll housing **415**. The pitch housing **430** also has two cap screws **480** that function in the same way as those in the roll housing **415**. In this exemplary embodiment, the pitch housing **430** operates the same in the revolute joint **410** as the roll housing **415** operates in the revolute joint **405**.

The output end of the right-hand helical spline **420** contained in the revolute joint **410**, which has been assembled into the pitch housing **430**, is threaded onto it the clamp assembly consisting of a clamp plate (not shown), a clamp body **455**, and four cap screws (not shown). The clamp body **455**, having been threaded and torqued onto the right-hand helical spline **420**, provides a stable base for one or more pins to be clamped between the clamp body **455** and the clamp plate (not shown).

Operation of the helical spline gear reducer assembly is fairly straightforward. If the left-hand helical spline **460** is considered the ground and the cap screw **465** is rotated counter clockwise, the helical spool **440** must move axially away from the head of the

cap screw 465, since it is threaded onto the cap screw 465. Since the helical spool 440 is rotationally-engaged with the left-hand helical spline 460, the helical spool 440 must also rotate in a counter clockwise fashion in accordance with the left hand helix angle that is common to both the helical spool 440 and the left-hand helical spline 460. Since the helical spool 440 is also rotationally-engaged with the right-hand helical spline 420 as it is forced to translate and rotate within the left-hand helical spline 460 and along the cap screw 465, the right-hand helical spline 420 is forced to rotate counter clockwise due to the nature of the right hand helix that is common to both the helical spool 440 and the right-hand helical spline 420.

The net effect of this movement is based on the pitch of the thread on the cap screw 465 and the helix angles on the left-hand helical spline 460, the right-hand helical spline 420, and the helical spool 440. The effective reduction ratio may be rather large. This large effective reduction enables the gear reduction mechanism to be finely adjusted. This fine adjustment may be implemented when the unilateral fixator device is engaged with the bone fragments of a deformity. For simplicity in reading the position of one of the revolutes joints 405, 410, it may be desirable to have three hundred and sixty, in other words, the number of degrees in a circle, be an integer multiple of the reduction ratio. For example, if the reduction ratio was seventy-two to one, a scale on the output having seventy-two graduations would allow a reading to the nearest five degrees, a scale on the input having fifty graduations would then allow for precise readings down to the tenth of a degree. Interpolation between the graduations on the input or the use of a vernier scale could obtain readings as precise as one one-hundredth of a degree, although this level of precision would be much less than the lash in the system and therefore not necessary. Still, the gear reduction mechanism of the present invention allows for very fine adjustment of the fixator position through the cap screw 465, much finer than is seen in the prior art. Although the arrangement of this exemplary embodiment is an axial construction, one skilled in the art would appreciate that a concentric arrangement would work as well, although this alternative configuration might be more difficult to construct.

**FIG. 5** provides an image of Detail A **500** of the unilateral fixator provided in **FIG. 2**. **FIG. 6** provides an image of Section C-C **600** of Detail A of **FIG. 3** showing a gear assembly for the unilateral fixator in accordance with an exemplary embodiment of the present invention. Referring to **FIG. 4b**, **FIG. 5** and **FIG. 6**, an upper revolute joint **405**, that is, the one revolute joint of the two revolute joints **405**, **410** that comprise a compound movable joint that is attached to the strut assembly, can rotate about the strut assembly of an exemplary fixator. To effect this rotation, ring gear **540** is bonded to a counter bore in an upper portion of the roll housing **415**. A spur gear **610** having two slots, one on either face that are orthogonally opposed, is slideably-engaged to one half of an Oldham disk **530**, which consists of a disk having two rectangular-in-section teeth orthogonally opposed on either face. The Oldham disk **530** is then slideably-engaged into a slot in the face of the extension strut **160** (**FIG. 1**). On top of the spur gear **610** is another Oldham disk **530**, which is slideably-engaged to the slot in the spur gear **610**. A spin dial **550** is then slideably-engaged to the other side of the Oldham disk **530** and centered on the outer diameter of the ring gear **540**. The spin scale **520** indicates the shaft assembly rotation as observed from the upper end of the device. The spin dial **550** is then slipped into the bore of the spur gear **610**. Since the outer diameter of the boss on the spin dial **550** is eccentric to a degree twice of which is the difference of the pitch diameters of the ring gear **540** and the spur gear **610**, the spin dial **550** forces the spur gear **610** to engage the ring gear **540**. Rotation of the spin dial **550** forces each successive tooth on the spur gear **610** to engage with each successive tooth on the ring gear **540**. The resulting ratio is the difference in the number of teeth between the ring gear **540** and the spur gear **610** divided into the number of teeth on the ring gear **540**. Like with the helical spline gear reducer it is desired to have three hundred and sixty, i.e., the number of degrees in a circle, be an integer multiple of the reduction ratio.

The discussion above, in connection with **FIGS. 4a**, **4b**, **5** and **6**, describe a gear reduction mechanism of a revolute joint. One skilled in the art would appreciate that an alternative embodiment may employ a different mechanism. For example, an alternative embodiment may include a pair of roller bearing assemblies in either a face-to-face or a

back-to-back arrangement depending on the moment stiffness required, and they serve to allow one revolute joint to rotate about another revolute joint that is connected to it. The roller bearing assemblies in this alternative embodiment are tapered roller bearings, such bearings are often use in wheel bearing assemblies for automobiles and are well suited for applications requiring a high degree of moment stiffness. One skilled in the art would appreciate that other types of roller bearings assemblies could be used, such as a simple angular contact ball bearing in either a preloaded double or duplex arrangement. Additionally, for lower cost and performance, plain bearings could be used.

In this alternative exemplary embodiment, each of the five revolute joints also houses a worm gear in a bore that is normal to and offset from that which houses the roller bearing assemblies. The worm gear is held in place with two snap rings. Stacked on top of the bearing assemblies is a gear having the same axis of revolution as the roller bearing assemblies.

In this alternative exemplary embodiment, a gear contained in each of the five revolute joints has a face spline on the external face that mates with another face spline on a lock bushing. The lock bushing has a cylindrical spline on the inner diameter that engages with a cylindrical spline on the shaft of a revolute joint. A lock nut threads onto the shaft of the revolute joint and clamps the lock nut, gear, and roller bearing assemblies to the body of the revolute joint. Tightening the lock nut locks the face splines of the gear and the lock nut together. Since the lock nut has a cylindrical spline that is always engaged with a cylindrical spline on the shaft of the revolute joint, tightening the lock nut essentially locks the gear to the shaft of the revolute joint. The gear and lock nut combination contained in each revolute joint enables each joint to be separately locked in a similar manner.

In the locked condition, turning the worm gear that is always meshed with the gear controls the angulation of the associated revolute joint. This alternative exemplary embodiment uses an allen head connected to the worm gear to turn the worm gear, using an allen key. The mesh between worm gear and gear is self-locking and cannot be back

driven, so a lock is not necessary in this embodiment. However if a lock is desired, a spring-loaded detent-style lock can be added. In the loose condition, the lock nut allows the gear and lock nut to rotate relative to one another. This freedom to rotate allows for the rapid, gross, manipulation of the associated joint to get the device mounted and to reduce the gross deformity of the bone in a single step if desired.

In this alternative embodiment, a compound movable joint is capable of sliding along a strut assembly houses either an additional worm gear or similar threaded adjuster. The strut passes through the body of this sliding joint. The worm gear or threaded adjuster allows for the linear height adjustment of the sliding joint. In one alternative embodiment, this linear adjustment is comprised of a rack captured in an extruded aluminum tube. It uses a dovetail type construction to capture it and a screw to keep it from sliding along the length of the strut. For anti-rotation, two guide rails are used. These guide rails also are captured using a dovetail type configuration. Two shoes are then inserted into the revolute joint that moves along the strut to allow the joint to slide along the guide rails to provide anti-rotation and to take up lash. The sliding joint also includes a locking clamp or nut to prevent gross movement of the slider. When unlocked, the sliding joint can be rapidly adjusted. Once locked, it includes an allen nut attached to a worm gear, similar to the worm gear used in the five revolute joints and described above, that allows fine adjustment of the sliding joint along the rack. One skilled in the art would appreciate that a variety of sliding mechanisms could be used in addition to the rack and pinion configuration of this exemplary embodiment.

**FIG. 7** provides an image of a compound movable joint **700** in accordance with an exemplary embodiment of the present invention. Referring to **FIG. 7**, the compound movable joint **700** comprises two revolute joints **710**, **720**. Each revolute joint **710**, **720** may have a scale **730**, **740** integral with the mechanism to accurately establish the needed configuration for the fixator. The roll housing **750** and pitch housing **760** may be tightened around helical spline assemblies (not shown) using cap screws **770** and cap screws **780**, respectively

**FIG. 8a** provides a front image **805** of a unilateral fixator in accordance with an alternative exemplary embodiment of the present invention. **FIG. 8b** provides a side image **810** of a unilateral fixator in accordance with an alternative exemplary embodiment of the present invention. **FIG. 8c** provides a top image **815** of a unilateral fixator in accordance with an alternative exemplary embodiment of the present invention. **FIG. 9** provides an isomeric image **900** of a unilateral fixator in accordance with an alternative exemplary embodiment of the present invention. Referring to **FIGS. 8a, 8b, 8c, and 9**, in this embodiment, the present invention comprises two movable joints **820, 830**, connected by a single strut **840**. Each movable joint has two revolute joint segments **850, 860**, with one movable joint **820** being able to slide along the body of the strut **840**. Each movable joint **820, 830** is then clamped to the strut **840**. The strut **840** allows for both linear motion, by an inner segment of strut **840** moving within an outer segment of strut **840**, as well as rotational motion between the ends where the movable joints **820, 830** are attached. The two movable joints **820, 830** allow for rotation movement in two orthogonally opposed degrees of freedom. Taken together the movable joints **820, 830** and the strut **840** allow for motion in all six degrees of freedom.

**FIG. 10a-10c** provide a front image **1005**, a side image **1010**, and a top image **1015**, respectively, of a compound movable joint in accordance with an alternative exemplary embodiment of the present invention. **FIG. 11** provides an isomeric image **1100** of a compound movable joint in accordance with the alternative exemplary embodiment of the present invention illustrated in **FIGS. 10a-10c**. Referring to **FIGS. 10a, 10b, 10c, and 11**, in this embodiment, the compound movable joint **1005, 1010, 1015, 1020, 1100** is comprised of two revolute joints **1070, 1080** and a clamp assembly **1060**. The first revolute joint, also referred to herein as a roll joint **1070** provides revolute motion between the limits of plus or minus ninety degrees about an axis orthogonal to the main axis of the strut structure **840 (FIG. 8)**. The second revolute joint, also referred to herein as a pitch joint **1080** is directly fixed to the output of the roll joint **1070** and as such follows the revolute motion of the roll joint **1070**. The pitch joint **1080**

provides revolutes motion between the limits of plus or minus sixty degrees about an axis orthogonal to the output axis of the roll joint 1070. The pitch joint 1080 and roll joint 1070 are fixed to one another through the use of a roll-pin 1050. A clamp assembly 1060 is attached to the output of the pitch joint 1080 through the use of a woodruff key, shown in detail in the cross section of the clamp assembly, FIG. 15e.

FIG. 12a provides a front image of the first of two revolutes joints 1210, the roll joint, of a compound movable joint in accordance with an alternative exemplary embodiment of the present invention. FIG. 12b-12d provide a side image 1220, a top image 1230, and an isomeric image 1240 of same revolutes joints. FIG. 12e provides an image of Section A-A 1250 of the first of two revolutes joints of a compound movable joint provided in FIG. 12c. FIG. 12f provides an image of Section B-B 1270 of the first of two revolutes joints of a compound movable joint provided in FIG. 12b. FIG. 12g provides an image of Section C-C 1280 of the first of two revolutes joints of a compound movable joint provided in FIG. 12b. FIG. 12h provides an image of Section D-D 1290 of the first of two revolutes joints of a compound movable joint provided in FIG. 12b. Referring to FIGS. 12a through 12h, Section A-A presents a view of a housing 1257, which provides the structural support of the roll joint 1210, 1220, 1230, 1240 and houses all of the internal components of the roll joint 1210, 1220, 1230, 1240. Screw 1256 provides a clamping load on the strut 840 (FIG. 8a) which the roll joint 1210, 1220, 1230, 1240 is slipped over and is used to lock the position of the roll joint 1210, 1220, 1230, 1240 relative to the strut 840 (FIG. 8a). The remaining mechanism is used to provide fine adjustment of the roll joint 1210, 1220, 1230, 1240.

A plain bearing 1259 supports a drive shaft 1258 in the housing 1257. Coupled to the drive shaft 1258 is an Oldham disk 1255. The Oldham disk 1255 is slideably-engaged to the drive shaft 1258 using a tongue protruding from the plane of the disk and a slot in the drive shaft 1258. Coupled to the other side of the Oldham disk 1255 is a gear 1253, which, like the drive shaft 1258, has a slot that engages a tongue protruding from the plane of the Oldham disk 1255. This arrangement efficiently transmits torque



between the gear 1253 and the drive shaft 1258 while allowing for radial misalignment. The gear 1253 has its radial alignment controlled by a cam 1251, which is of circular cross section having an axis that is eccentric from the axis of rotation, which is defined by the circular protrusion that is within a knob adjuster 1254 interfacing with the tree pan of the cam 1251. This circular protrusion is itself eccentric to the tree pan of the knob adjuster 34, which controls the axis of rotation of the knob adjuster 1254 with respect to the housing 1257. The cam 1251 is affixed to the lock knob 1252, which, when rotated, causes the cam 1251 to rotate. The degree to which the outer diameter of the cam 1251 is eccentric with respect to the tree pan of the cam 1251 is the same as the degree to which the inner protrusion of the knob adjuster 1254 is eccentric to the tree pan of the knob adjuster 1254. This identity allows the eccentricity of the cam 1251 to either cancel out the eccentricity of the knob adjuster 1254, making the gear 1253 concentric with the housing 1257, or acts to double the degree of eccentricity the cam 1251 has with respect to the housing 1257, making the gear 1253 come in contact with the housing 1257.

The housing 1257 has internal gear teeth having the same pitch as the external gear teeth of the gear 1253 although the number of teeth on the housing 1257 exceeds that on the gear 1253 by a small fraction of the total number of teeth on the housing 1257. This small difference in the number of teeth does two things. One, the difference allows for clearance such that the gear teeth mesh on the side of contact and that they clear on the side of clearance. Two, by dividing the difference in the number of teeth into the total number of teeth on the housing 1257, the result is a gear reduction ratio. This type of gear reduction is known as cycloidal reduction.

**FIG. 12f** shows a cross section B-B of the gear mesh and shows the degree of eccentricity. Similarly, the same type of reduction can be achieved using a device called a harmonic drive where the inner gear is a flexible member that is deformed into an elliptical shape using an elliptical bearing or two bearings centered on the two foci of the ellipse, which has gear teeth meshing on the major axis of the ellipse and clearance on the minor axis of the ellipse.

To provide a detent lock to the knob adjuster **1254** a ball detent is used. **FIG. 12g** depicts section C-C. The knob adjuster **1254** in the area of the ball detent has a knurling around the inner diameter of the tree pan. This knurling engages a steel ball **1261** that is spring loaded outward through the compression of an elastomeric ball **1260**, both of which lie in a radial flat bottomed hole. Rotation of the knob adjuster **1254** causes compression of the elastomeric ball **1260** to disengage the steel ball **1261** from the knurling of the knob adjuster **1254**.

Referring to **FIG. 12h**, which depicts section D-D, the knob adjuster **1254** is secured to the housing **1257** using a square section wire **1262** that is inserted through holes in the knob adjuster **1254** that come off on a tangent to the inner tree pan. The wire **1262** follows a groove in the wall of the tree pan of the knob adjuster **1254** as well as a groove in the wall of the housing **1257**. One skilled in the art would appreciate that other methods of securing the knob adjuster **1254** to the housing **1257**, such as snap rings or swaging methods could also be used.

The mechanical operation of the roll joint **1210**, **1220**, **1230**, **1240** described above in connection with **FIGS. 12a** through **12h**, is identical to the three other revolute joints that comprise this alternative embodiment, as illustrated in **FIGS. 8a**, **8b**, and **8c**.

**FIG. 13** provides a perspective view of the drive mechanism of the first of two revolute joints of the movable joint structure in accordance with an exemplary embodiment of the present invention. A knob adjuster **1310** is connected to a drive shaft **1330** through an Oldham disk **1320**. The Oldham disk **1320** is slideably-engaged to the drive shaft **1330** using a tongue protruding from the plane of the disk and a slot in the drive shaft **1330**. This coupling arrangement is accomplished through the tongues protruding from either side of the plane of the Oldham disk **1320**, which are orthogonal to each other.

**FIG. 14a** provides a front image of the second of two revolute joints **1410**, the pitch joint, of a compound movable joint in accordance with an alternative exemplary

embodiment of the present invention. **FIG. 14b** provides a side image of the second of two revolute joints **1420** of a compound movable joint in accordance with an alternative exemplary embodiment of the present invention. **FIG. 14c** provides a top image of the second of two revolute joints **1430** of a compound movable joint in accordance with an alternative exemplary embodiment of the present invention. **FIG. 14d** provides a isomeric image of the second of two revolute joints **1440** of a compound movable joint in accordance with an alternative exemplary embodiment of the present invention. **FIG. 14e** provides an image of Section A-A **1450** of the second of two revolute joints of the compound movable joint provided in **FIG. 14c**.

Referring to **FIGS. 14a** through **14e**, section A-A presents a view of a housing **1455**, which provides structural support of the pitch joint **1410, 1420, 1430, 1440, 1450** and houses all of the internal components of the pitch joint **1410, 1420, 1430, 1440, 1450**. Screws **1460, 1465** provide a clamping load in two areas; the first is to clamp on the output boss of the roll joint (not shown) to prevent rotation of the pitch joint **1410, 1420, 1430, 1440, 1450** relative to the roll joint (not shown). This clamping action is meant to provide a safety lock and to ensure that the pitch joint **1410, 1420, 1430, 1440, 1450** does not move by back driving the gear reduction mechanism under shock or heaving load. The second clamp screw clamps a drive shaft **1470** of the pitch joint **1410, 1420, 1430, 1440, 1450** to the housing **1455** of the pitch joint **1410, 1420, 1430, 1440, 1450**. This clamping action was done for the same reason as the first clamping action of the screw, specifically to prevent rotation of the clamp assembly relative to the pitch joint **1410, 1420, 1430, 1440, 1450**. The drive shaft **1470** is supported in the housing **1455** with two plain bearings **1475, 1480**. All other aspects of the pitch joint **1410, 1420, 1430, 1440, 1450** are the same as the aspects described for the roll joint in connection with **FIGS. 12a** through **12h**.

**FIG. 15a** provides a front image of a pin clap unit **1510** in accordance with an exemplary embodiment of the present invention. **FIG. 15b** provides a side image of a pin clap unit **1520** in accordance with an exemplary embodiment of the present

invention. **FIG. 15c** provides a top image of a pin clamp unit **1530** in accordance with an exemplary embodiment of the present invention. **FIG. 15d** provides a isomeric image of a pin clamp unit **1540** in accordance with an exemplary embodiment of the present invention. **FIG. 15e** provides an image of Section A-A of the pin clamp unit **1550** provided in **FIG. 15c**.

Referring to **FIGS 15a** through **15e**, a housing **1555** provides the structural support of the pin clamp **1510**, **1520**, **1530**, **1540**, **1550** and interfaces with the drive shaft **1470** (**FIG. 14e**) through the use of a Woodruff key, the slot **1585** for which is contained in the housing **1550**. Two clamp sleds **1570** are captured in the housing **1555** through the use of a dovetail configuration. The clamp sleds **1570** are preloaded to the ends of the dovetail slot with a spring **1575** and are prevented from sliding out of the dovetail groove by two roll pins **1565**. Two cleats **1580**, one having a right hand threaded bore and the other having a left hand threaded bore, lie in a cut beneath the dovetail groove the upper end of each extending beyond the cut into the dove tail groove. The spring **1575** is captured by a small circular boss on each clamp sled **1570** that fits within the inner diameter of the spring **1575**. A threaded rod **1560** having a right hand male thread on one end and a left hand male thread on the other is located in a transverse bore in the housing **1555** and is threaded into the cleats **1580**. A hex or square head may be on each end of the threaded rod **1560** such that when rotated the cleats **1580** either move toward the center of the rod or towards it ends. In so doing, the cleats **1580** make contact with the clamp sleds as the cleats move outward, clamping pins (not shown) between the clamp sleds **1570** and the housing **1555**. When the cleats **1580** are moves toward the center of the threaded rod **1560**, the spring **1575** provides the clamping force. The spring **1575** allows the pins (not shown) to be snapped into place as the clamp sleds **1570** and the housing **1555** have chamfered edges as a lead into the clamping cavity. The spring **1575** will hold the pins in place while the device is positioned, rotating the threaded rod **1560** such that the cleats **1580** move outward and positively clamp the pins to the housing **1555**. One skilled in the art would appreciate that this clamp configuration is one

example of many possible clamp types that can be used with a unilateral fixator of the present invention.

**FIG. 16a** provides a front image of a strut structure **1610** in accordance with an alternative exemplary embodiment of the present invention. **FIG. 16b** provides a side image of a strut structure **1620** in accordance with an alternative exemplary embodiment of the present invention. **FIG. 16c** provides a top image of a strut structure **1630** in accordance with an alternative exemplary embodiment of the present invention. **FIG. 16d** provides a isomeric image of a strut structure **1640** in accordance with an alternative exemplary embodiment of the present invention. Referring to **FIGS. 16a** through **16d**, the strut structure **1610**, **1620**, **1630**, **1640** is comprised of three components, a main body **1650**, which accepts a top tube **1660** and provides for the linear adjustment of the top tube **1660** relative to the main body **1650**. The top tube **1660** accepts a yaw joint **1670**, which allows for rotation of the yaw joint **1670** relative to the combined main body **1650** and top tube **1660**.

**FIG. 17a** provides a front image of a base tube assembly **1710** in accordance with an alternative exemplary embodiment of the present invention. **FIG. 17b** provides a side image of a base tube assembly **1720** in accordance with an alternative exemplary embodiment of the present invention. **FIG. 17c** provides a bottom image of a base tube assembly **1730** in accordance with an alternative exemplary embodiment of the present invention. **FIG. 17d** provides a isomeric image of a base tube assembly **1740** in accordance with an alternative exemplary embodiment of the present invention. **FIG. 17e** provides an image of Section A-A of the base tube assembly **1750** provided in **FIG. 17c**.

Referring to **FIGS. 17a** through **17e**, screw adjuster **1790** is retained within a strut housing **1760** through the use of a retaining ring **1780**. An O-ring **1770** seats in a circumferential groove around the inner diameter of the strut housing **1760** and squeezes the outer diameter of the screw adjuster **1790** providing friction to keep the screw adjuster **1790** from being back driven or from rotation under shock and vibration.

**FIG. 18a** provides a front image of a top tube assembly **1810** in accordance with an alternative exemplary embodiment of the present invention. **FIG. 18b** provides a side image of a top tube assembly **1820** in accordance with an exemplary alternative exemplary of the present invention. **FIG. 18c** provides a top image of a top tube assembly **1830** in accordance with an alternative exemplary embodiment of the present invention. **FIG. 18d** provides a isomeric image of a top tube assembly **1840** in accordance with an alternative exemplary embodiment of the present invention.

Referring to **FIGS 18a** through **18d**, top tube housing **1850** provides the main structural support for the top tube **1810, 1820, 1830, 1840**. Attached to top tube **1810, 1820, 1830, 1840** is guide rail **1890**, which has a graduated scale to read off elongation and it also serves to prevent rotation of the top tube **1810, 1820, 1830, 1840** relative to the top tube housing **1850**. The guide rail **1890** slides into a dovetail groove in the top tube housing **1850** and itself has a dovetail shape for a cross section and a roll pin **1880** for retention. At the top of the top tube housing **1850** is a bore **1845** that receives the yaw joint (not shown). Within the bore **1845** is a keyway **1895** such that the drive shaft of the yaw joint (not shown) is fixed from a rotational standpoint to the top tube housing **1850**. To lock up the yaw joint (not shown), a clamp screw **1870** is used in conjunction with two clamp bushings **1860**, one being threaded and the other having a clearance hole. Tightening the clamp screw **1870** locks the rotation of the top tube housing **1850**.

**FIG. 19a** provides a front image of the yaw joint **1910** of the strut structure of **FIG 16**. in accordance with an alternative exemplary embodiment of the present invention. **FIG. 19b** provides a side image of the yaw joint **1920** of the strut structure of **FIG 16**. in accordance with an alternative exemplary embodiment of the present invention. **FIG. 19c** provides a bottom image of the yaw joint **1930** of the strut structure of **FIG 16**. in accordance with an alternative exemplary embodiment of the present invention. **FIG. 19d** provides a isomeric image of the yaw joint **1940** of the strut structure of **FIG. 16** in accordance with an alternative exemplary embodiment of the

present invention. **FIG. 19e** provides an image of Section A-A of the yaw joint **1950** of the strut structure of **FIG 16**, provided in **FIG. 19c**.

Referring to **FIGS. 18d** and **19a** through **19e**, a Woodruff key **1960** engages the slot in the top tube housing **1850**. The drive shaft **1970** is supported in the bore **1845** at the top end of the top tube **1840**. The yaw joint housing **1965** provides the main structural support and houses all of the components of the yaw joint **1910**, **1920**, **1930**, **1940**, **1950** and provides the upper movable joint (not shown) a mount point around the outer diameter of the yaw joint housing **1965**. The operation and mechanical description of the yaw joint is identical to the roll joint described in above, in connection with **FIGS. 12a** through **12h**.

One skilled in the art would appreciate that the components of the exemplary unilateral fixators can be fabricated from corrosion resistant steel (CRES, or stainless steel), aluminum alloys, brass, or other materials typically used for medical devices.

One skilled in the art would appreciate that the present invention supports a unilateral external fixator device that allows for gross manipulation and fine adjustment of deformities in six degrees of freedom. The device may comprise a strut assembly and two compound movable joints, one at each end of the strut assembly. One compound movable joint may comprise two revolute joints, each containing a gear reduction mechanism and may rotate about the strut. The second compound movable joint may contain two revolute joints, each containing a gear reduction mechanism, and may move along the length of the strut assembly. The gear reduction mechanisms may comprise helical spline assemblies that allow for gross and fine adjustment of the fixator.

**CLAIMS**

What is claimed is:

1. A unilateral fixator comprising:
  - a strut assembly, having a proximate end and a distal end;
  - a first compound movable joint attached to the proximate end of the strut assembly having a first revolute joint with a first axis and a second revolute joint with a second axis;
  - a second compound movable joint attached to the distal end of the strut assembly having a third revolute joint with a third axis and a fourth revolute joint with a fourth axis; and
  - a bone fragment attachment apparatus attached to each of the first and second compound movable joints.
  
2. The device of claim 1 wherein the first axis and second axis are orthogonally opposed and the third axis and the fourth axis are orthogonally opposed.
  
3. The device of claim 1 wherein the first compound movable joint is capable of rotating about the linear axis of the strut assembly and the second compound movable joint is capable of sliding along the linear axis of the strut assembly.
  
4. The device of claim 1 wherein each of the revolute joints comprises a gear reduction mechanism.



5. The device of claim 4 wherein the gear reduction mechanism comprises an axial helical spline mechanism.

6. The device of claim 4 wherein the gear reduction mechanism comprises a concentric helical spline mechanism.

7. The device of claim 4 wherein the gear reduction mechanism comprises  
a left-hand helical spline;  
a right-hand helical spline;  
a thrust washer positioned between the right-hand helical spline and the left-hand helical spline;

a helical spool, wherein the helical spool slides within the right-hand helical spline and the left hand helical spline and is rotationally engaged to the right-hand helical spline and the left hand helical spline; and

a cap screw axially clamping together the left-hand helical spline, the right-hand helical spline, and the thrust washer and allowing for a fine adjustment of the reduction mechanism while the bone fragment attachment apparatus is engaged with a bone fragment.

8. The device of claim 4 wherein the gear reduction mechanism comprises:
- a knob adjuster;
  - a drive shaft;
  - a bearing supporting the drive shaft;
  - an Oldham disk having a tongue that engages a slot on the drive shaft;
  - a gear having a slot that engages a tongue on the Oldham disk;
  - a cam; wherein the cam has a circular cross section having an axis that is eccentric from the axis of rotation and controls the radial alignment of the gear;
  - a lock knob, wherein the cam is affixed to the lock knob and a movement of the lock knob causes a movement of the cam; and
  - a housing comprising internal gear teeth having the same pitch as the external gear teeth of the gear and the number of internal gear teeth of the housing exceeds the number of external gear teeth of the gear.
9. The device of claim 1, wherein the strut assembly comprises:
- a base strut; and
  - an extension strut; wherein the extension strut moves linearly within the base strut.
10. The device of claim 9, wherein the base strut further comprises a square key inserted into a milled slot and the extension strut further comprises a groove able to receive the square key to prevent the base strut and extension strut from rotating relative to each other.

11. The device of claim 10 wherein the extension strut further comprises a linear adjuster, a threaded rod and a solid, threaded locking insert, wherein the linear adjuster is connected to the base strut and the threaded rod, the threaded rod is also connected to the Solid, threaded locking insert which is connected to the extension strut.

12. The device of claim 11 wherein when the linear adjuster is rotated, the extension strut moves linearly within the base strut.

13. The device of claim 1 wherein the bone fragment attachment apparatus comprises a pin clamp and one or more pins.

14. The device of claim 1 wherein the first and second compound movable joints each comprise a plurality of locking devices, wherein one or more of the locking devices restricts one of the degrees of freedom associated with each compound movable joint.

15. The device of claim 14 wherein each of the locking devices comprises at least one cap screw, wherein the cap screw secures a housing containing the gear reduction mechanism to allow for the gross positioning of the first compound movable joint and the second compound movable joint.

16. A unilateral fixator comprising:
- a strut; having a proximate end and a distal end;
  - a first compound movable joint attached to the proximate end of the strut having a first revolute joint with a first axis, a second revolute joint with a second axis, and a third revolute joint having a third axis;
  - a second compound movable joint attached to the distal end of the strut having a fourth revolute joint with a fourth axis and a fifth revolute joint and a fifth axis, wherein the fourth axis and the fifth axis are orthogonally opposed; and
  - a bone fragment attachment apparatus attached to each of the first and second compound movable joints.
17. The device of claim 16 wherein the first axis, the second axis, and the third axis are orthogonally opposed to each other and the fourth axis and the fifth axis are orthogonally opposed to each other.
18. The device of claim 16 wherein the first compound movable joint is fixed relative to the strut and the second compound movable joint is capable of moving along the linear axis of the strut.
19. The device of claim 16 wherein each revolute joint comprises a gear reduction mechanism.
20. The device of claim 19 wherein the gear reduction mechanism comprises an axial helical spline mechanism.

21. The device of claim 19 wherein the gear reduction mechanism comprises a concentric helical spline mechanism.

22. The device of claim 19 wherein the gear reduction mechanism comprises  
a left-hand helical spline;  
a right-hand helical spline;  
a thrust washer positioned between the right-hand helical spline and the left-hand helical spline;

a helical spool, wherein the helical spool slides within the right-hand helical spline and the left hand helical spline and is rotationally engaged to the right-hand helical spline and the left hand helical spline; and

a cap screw axially clamping together the left-hand helical spline, the right-hand helical spline, and the thrust washer and allowing for a fine adjustment of the reduction mechanism while the bone fragment attachment apparatus is engaged with a bone fragment.

23. The device of claim 19 wherein the gear reduction mechanism comprises:
- a knob adjuster;
  - a drive shaft;
  - a bearing supporting the drive shaft;
  - an Oldham disk having a tongue that engages a slot on the drive shaft;
  - a gear having a slot that engages a tongue on the Oldham disk;
  - a cam; wherein the cam has a circular cross section having an axis that is eccentric from the axis of rotation and controls the radial alignment of the gear;
  - a lock knob, wherein the cam is affixed to the lock knob and a movement of the lock knob causes a movement of the cam; and
  - a housing including an internal gear teeth having the same pitch as the external gear teeth of the gear and the number of internal gear teeth of the housing exceeds the number of external gear teeth of the gear.
24. The device of claim 18, wherein the strut comprises a rack and the second compound movable joint comprises a pinion that allows the second compound movable joint to move along the rack of the strut.
25. The device of claim 16 wherein the bone fragment attachment device comprises a pin clamp and one or more pins.

26. A compound movable joint for a unilateral fixator comprising a first revolute joint with a first axis and a second revolute joint with a second axis.

27. The device of claim 26 wherein the first axis and the second axis are orthogonally opposed.

28. The device of claim 26 further comprising a gear reduction mechanism having an axial helical spline mechanism with a right-handed helical spline and a left-handed helical spline.

29. The device of claim 26 further comprising a gear reduction mechanism having a concentric helical spline mechanism.

30. The device of claim 28 wherein the axial helical spline mechanism comprises:
- a left-hand helical spline;
  - a right-hand helical spline;
  - a thrust washer positioned between the right-hand helical spline and the left-hand helical spline;
  - a helical spool, wherein the helical spool slides within the right-hand helical spline and the left hand helical spline and is rotationally engaged to the right-hand helical spline and the left hand helical spline; and
  - a cap screw axially clamping together the left-hand helical spline, the right-hand helical spline, and the thrust washer and allowing for a fine adjustment of the reduction mechanism while the bone fragment attachment apparatus is engaged with a bone fragment.



31. The device of claim 26 further comprising a gear reduction mechanism having:
- a knob adjuster;
  - a drive shaft;
  - a bearing supporting the drive shaft;
  - an Oldham disk having a tongue that engages a slot on the drive shaft;
  - a gear having a slot that engages a tongue on the Oldham disk;
  - a cam; wherein the cam has a circular cross section having an axis that is eccentric from the axis of rotation and controls the radial alignment of the gear;
  - a lock knob, wherein the cam is affixed to the lock knob and a movement of the lock knob causes a movement of the cam; and
  - a housing, including an internal gear teeth having the same pitch as the external gear teeth of the gear and the number of internal gear teeth of the housing exceeds the number of external gear teeth of the gear.

32. The device of claim 26 further comprising a gear reduction mechanism having:

a shaft having a cylindrical spline;

a first roller bearing assembly and a second roller bearing assembly;

a worm gear normal to and offset from the first roller bearing assembly and the second roller bearing assembly;

a gear positioned on top of the first bearing assembly and the second bearing assembly and having the same axis of revolution as the first bearing assembly and the second bearing assembly and also having a first face spline on the external face of the gear;

a lock bushing having a second face spline wherein the first face spline of the gear and the second face spline mate and having a cylindrical spline on an inner diameter of the lock bushing that engages with the cylindrical spline on the shaft; and

a lock nut threaded onto the shaft that locks the gear to the shaft.

33. A strut for a unilateral fixator , wherein the strut assembly comprises:

a base strut; wherein the base strut further comprises a square key inserted into a milled slot and

an extension strut; wherein extension strut comprises a linear adjuster, a threaded rod and a Solid, threaded locking insert, wherein the linear adjuster is connected to the base strut and the threaded rod, the threaded rod is also connected to the solid, threaded locking insert which is connected to the extension strut, further wherein when the linear adjuster is rotated, the extension strut moves within the base strut.

100

1/29

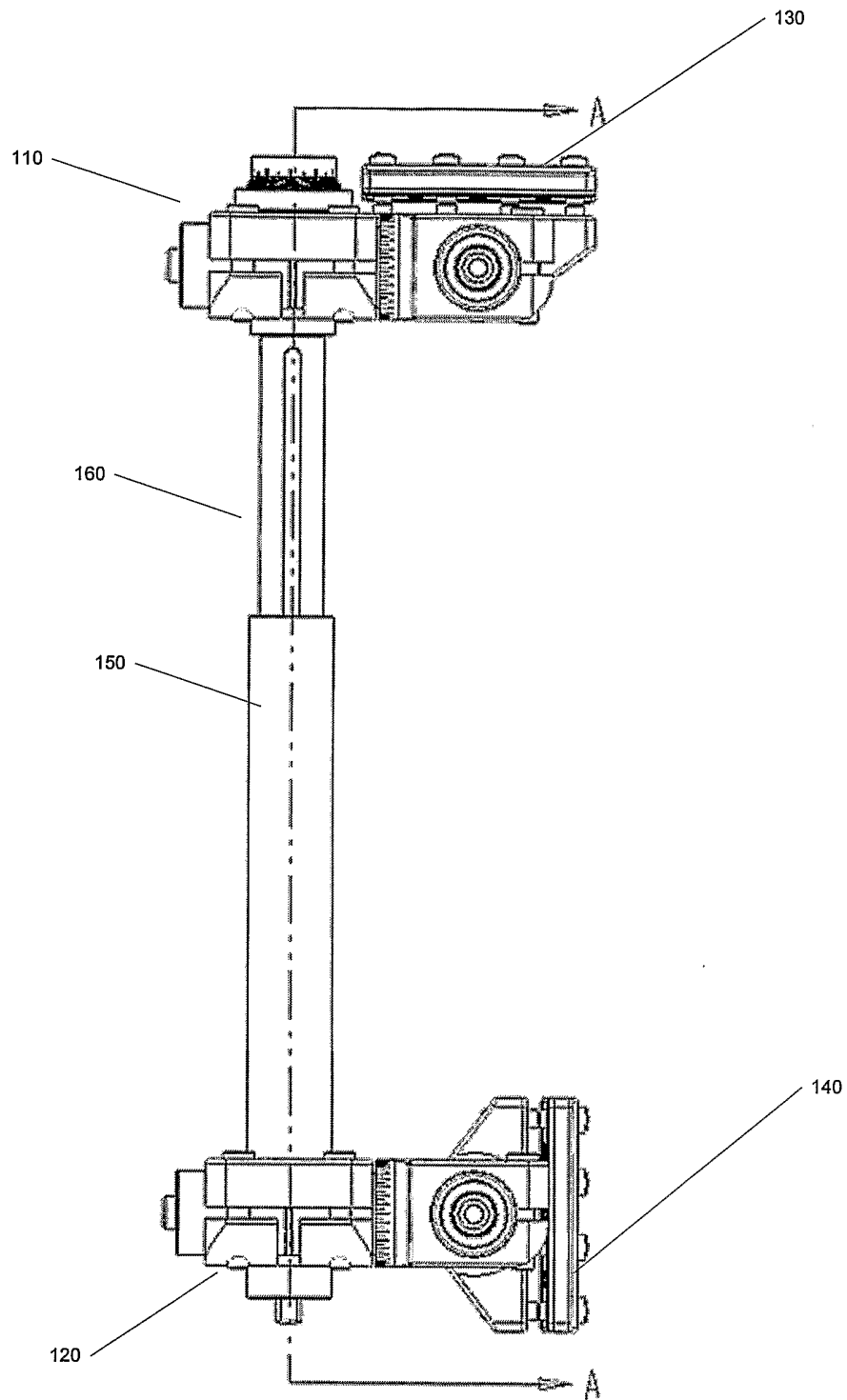
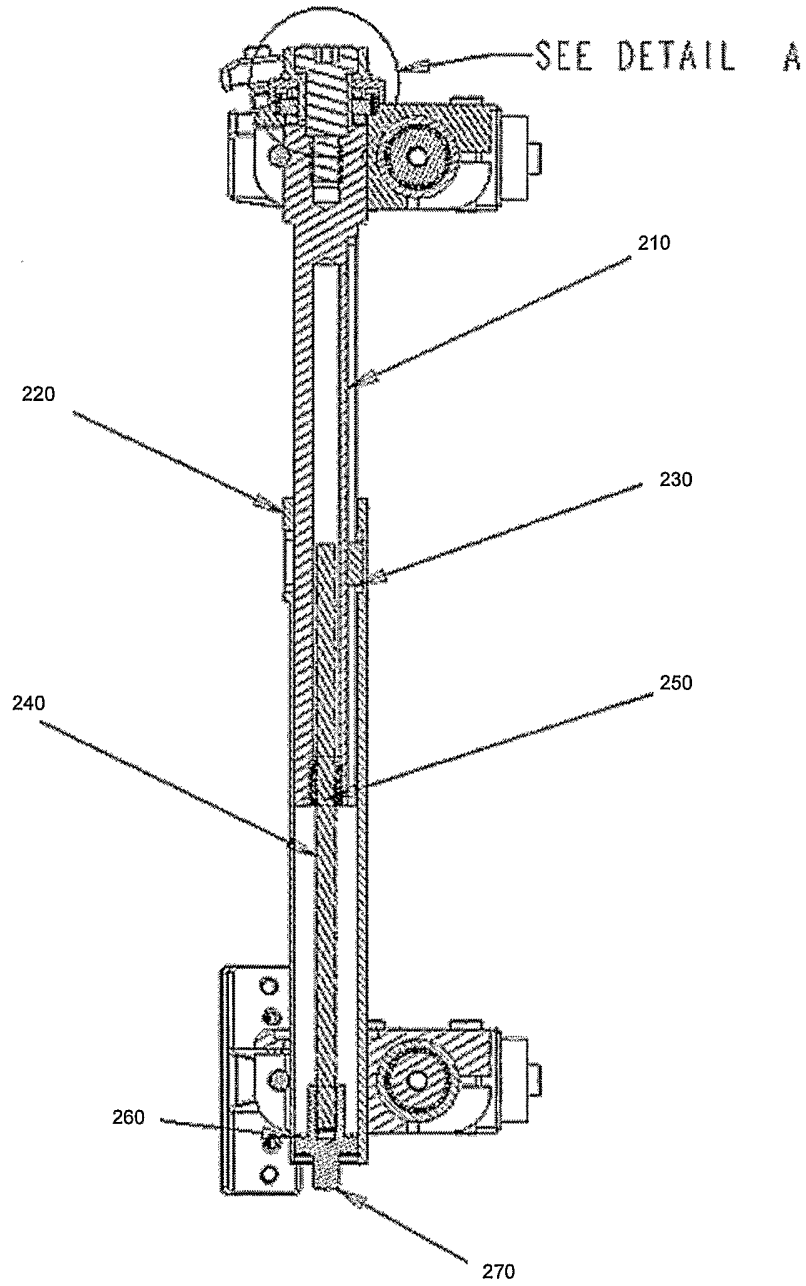


Fig. 1

200

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SECTION A-A

Fig. 2

300

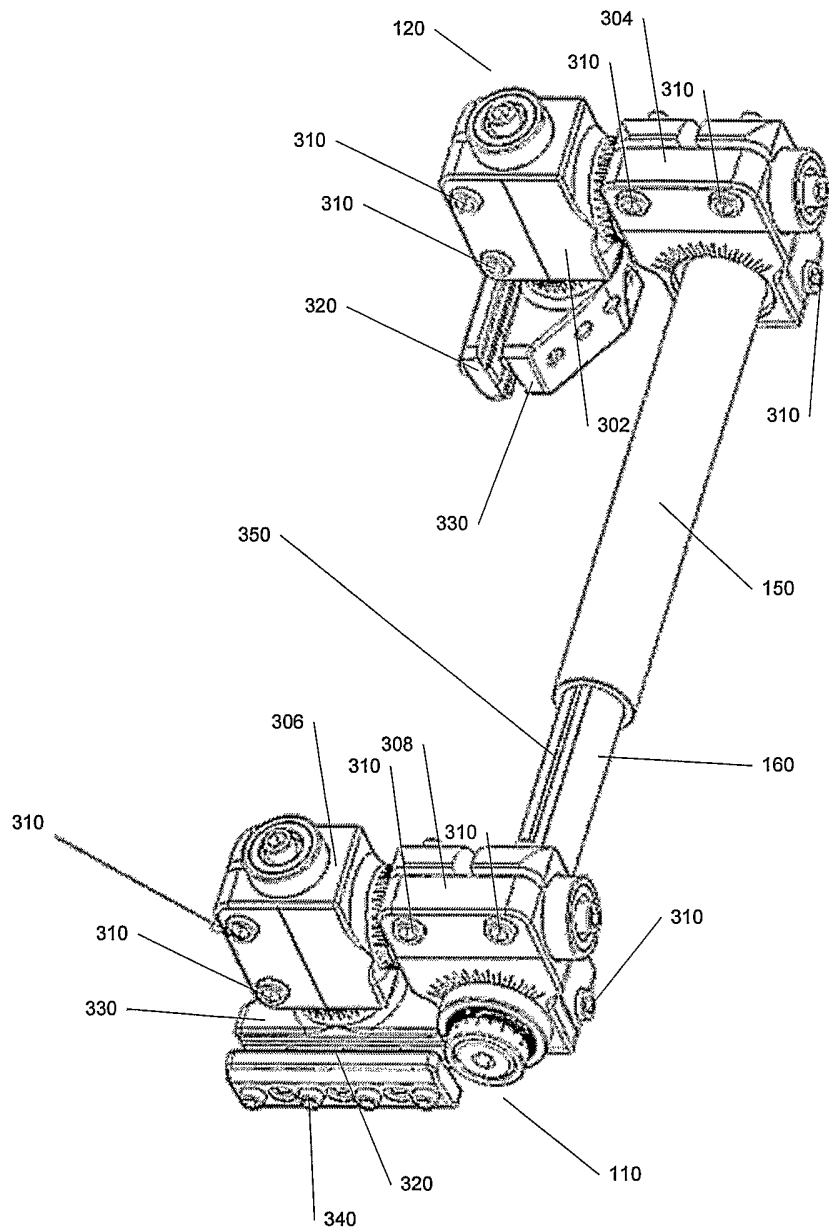


Fig. 3

401

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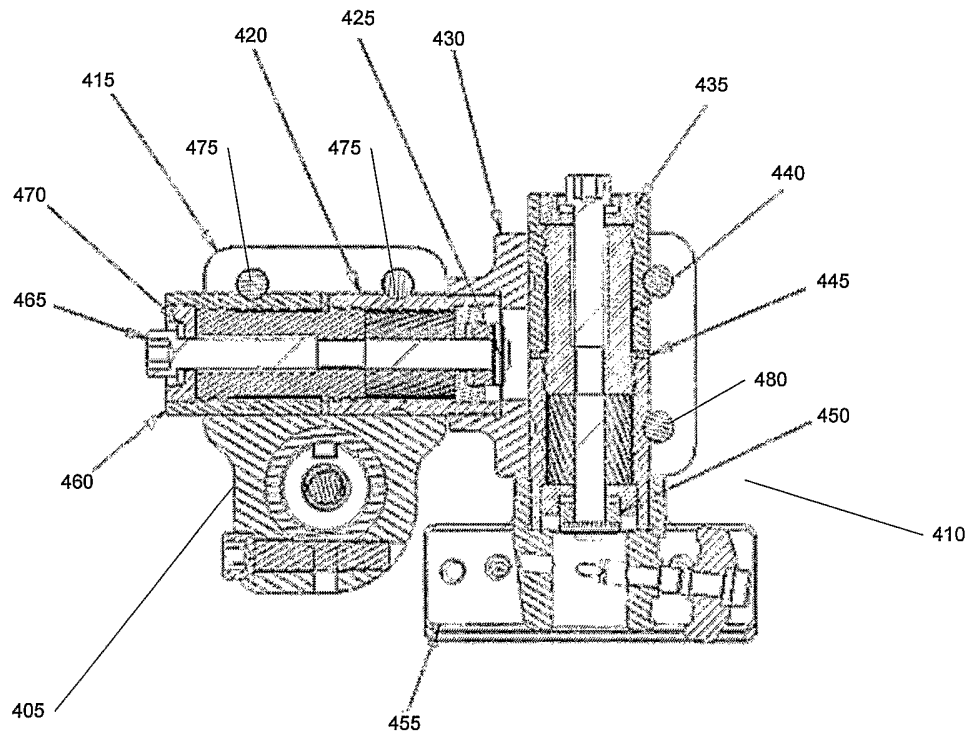


Fig. 4b

SECTION B-B

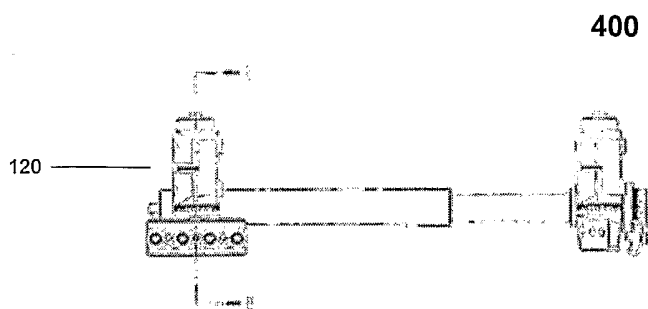


Fig. 4a

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500

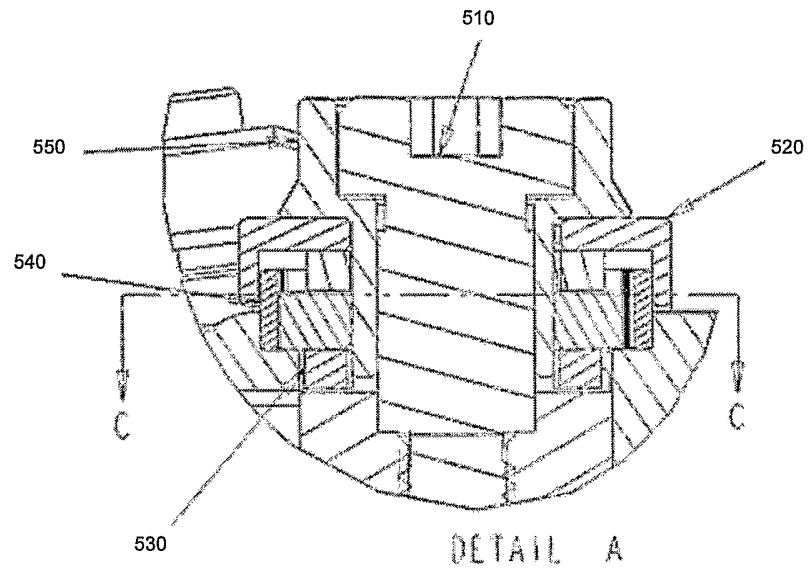


Fig. 5



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600

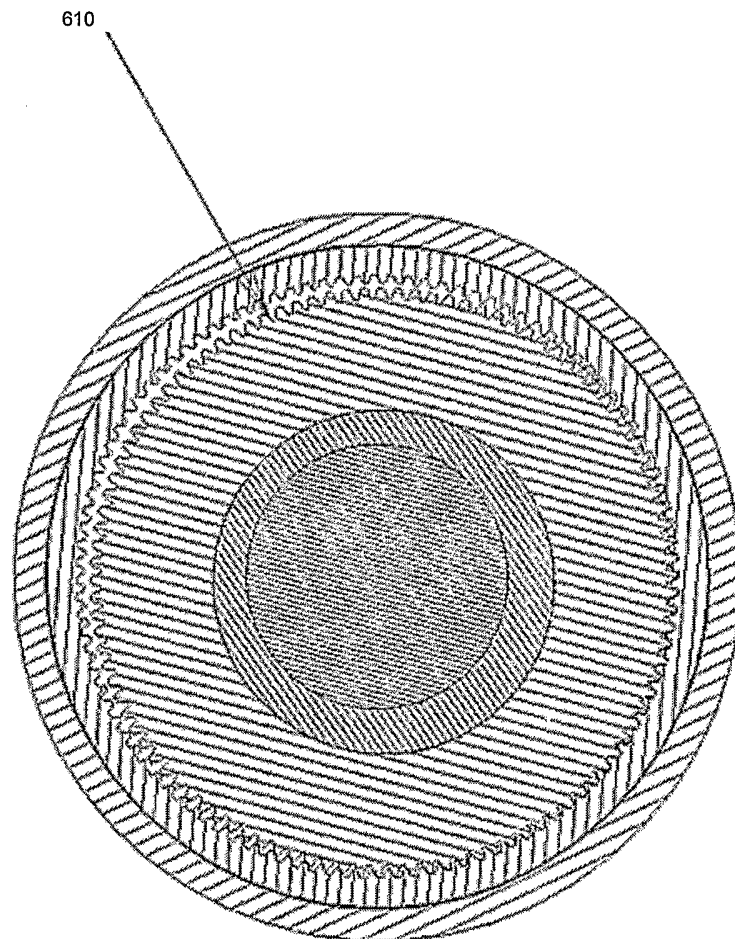
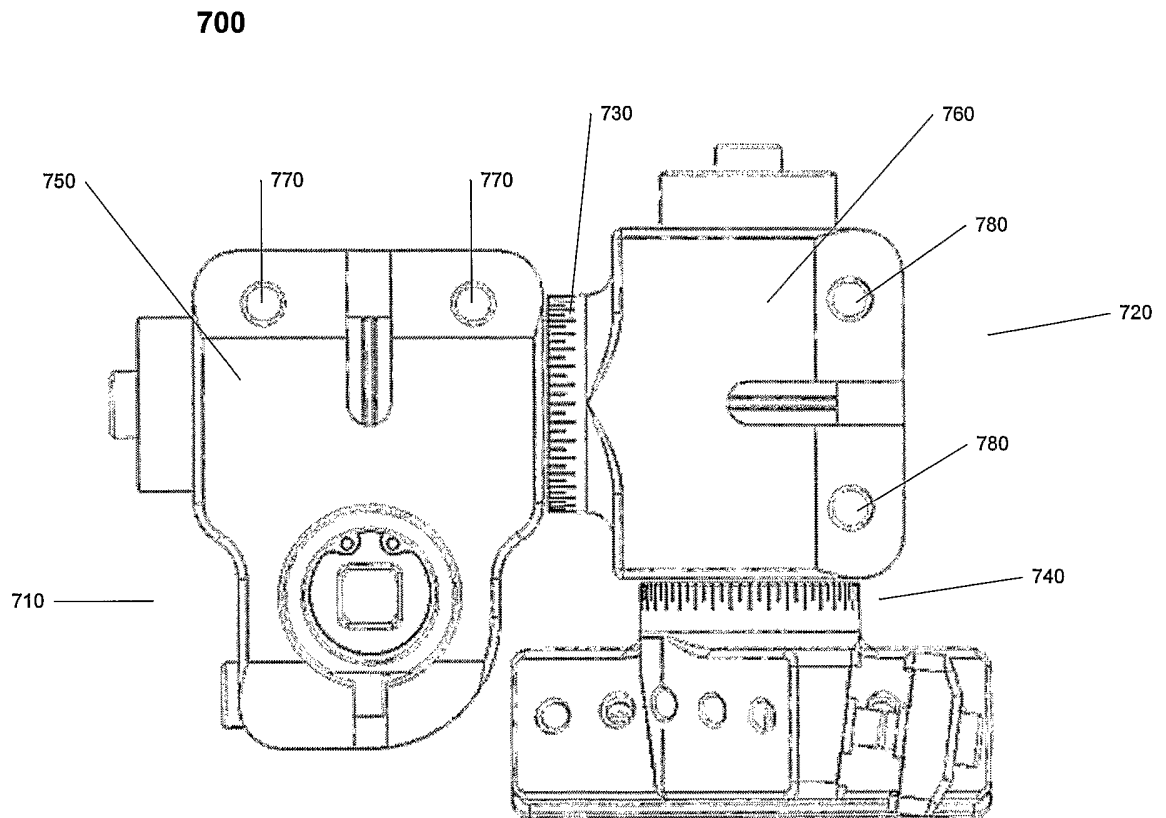


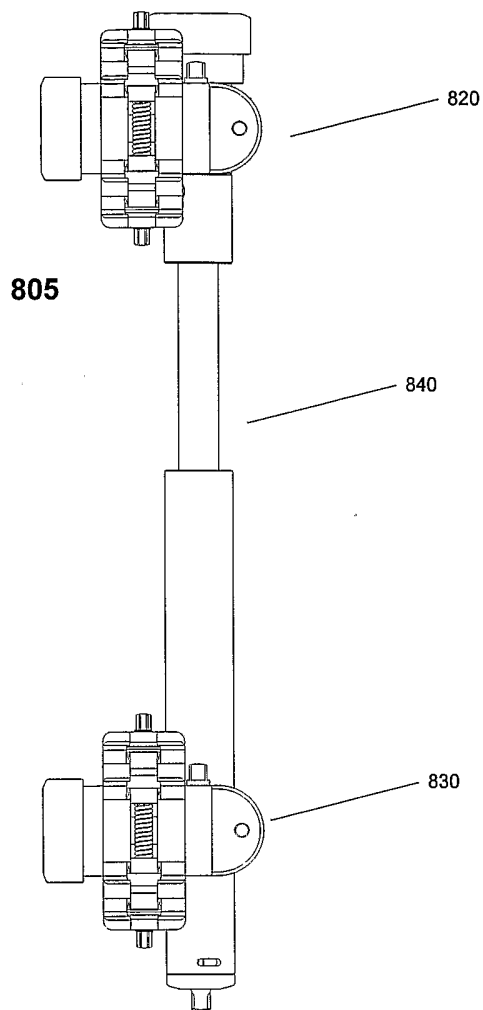
Fig. 6

SECTION C-C

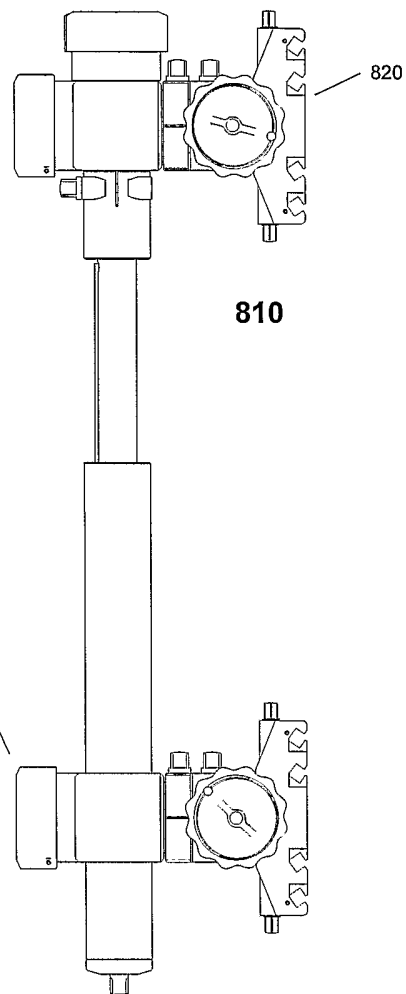


**Fig. 7**

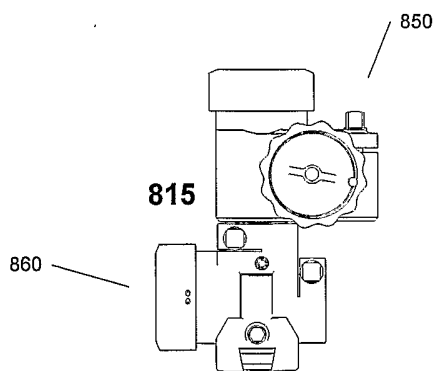
8/29



Front  
Fig. 8a



Side  
Fig. 8b



Top  
Fig. 8c

9/29

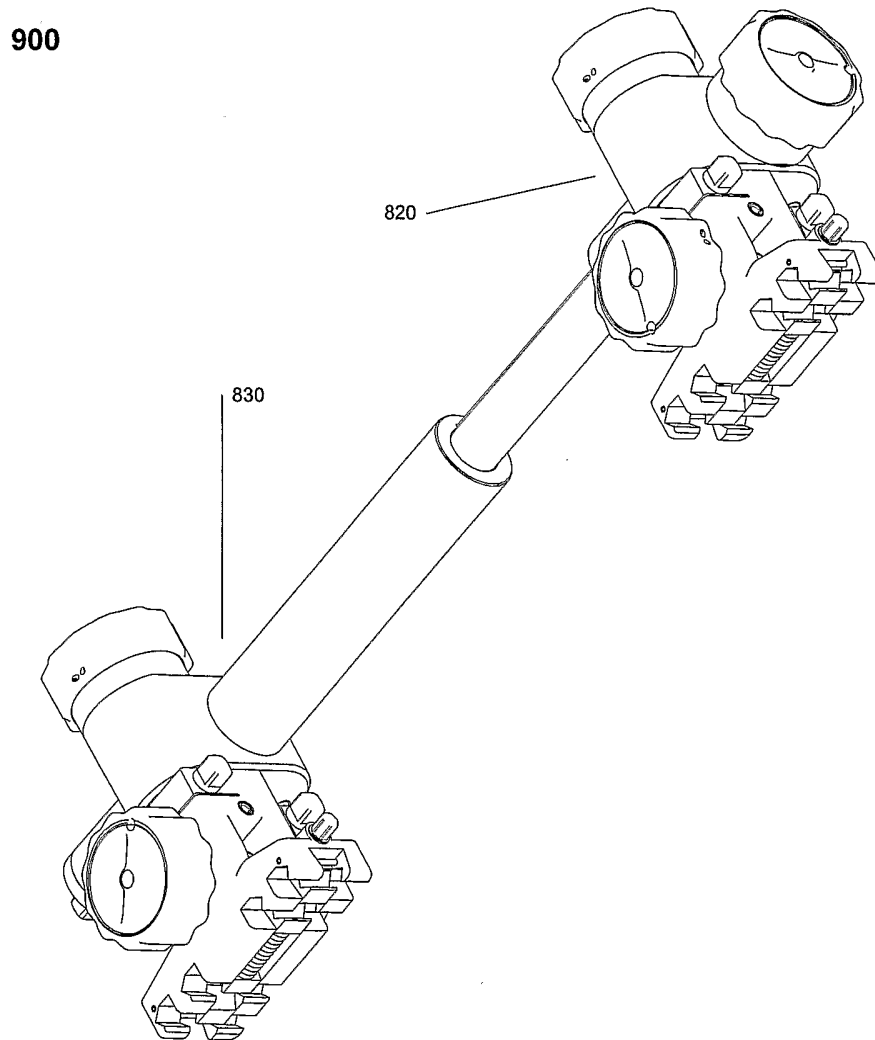
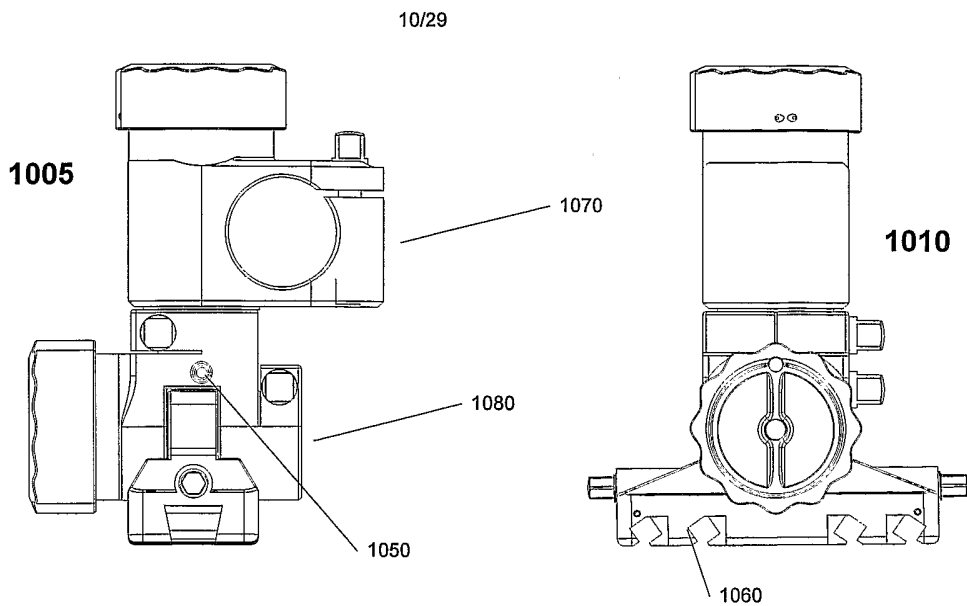
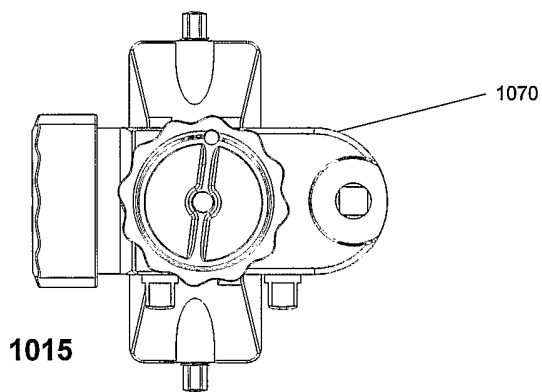


Fig. 9

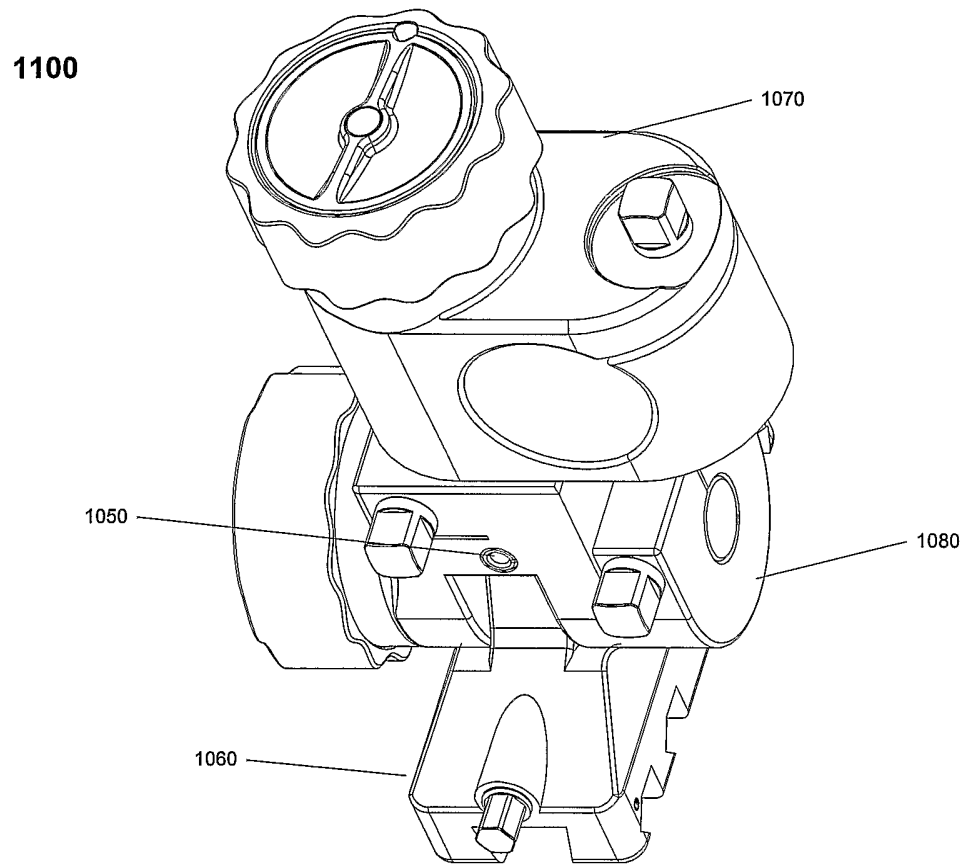


Front  
**Fig. 10a**

Side  
**Fig. 10b**

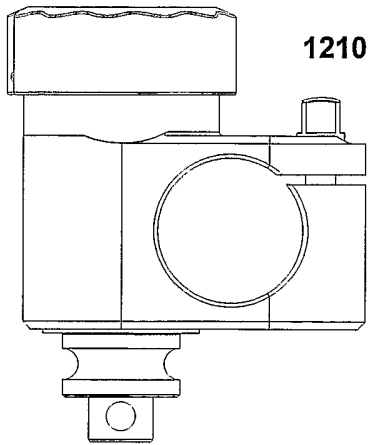


Top  
**Fig. 10c**



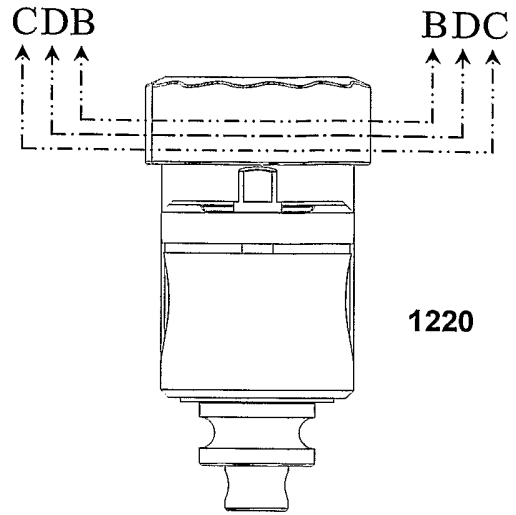
Isometric

**Fig. 11**



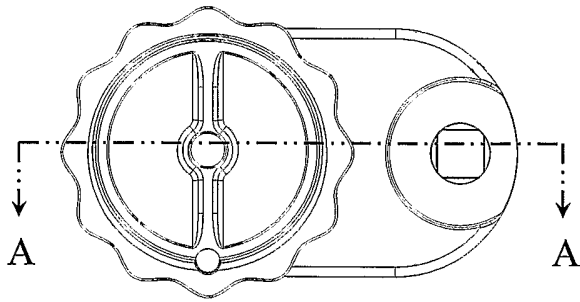
Front

**Fig. 12a**



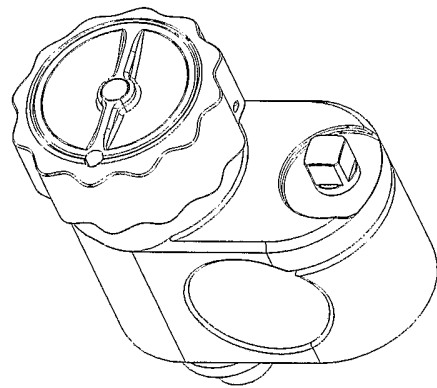
Side

**Fig. 12b**



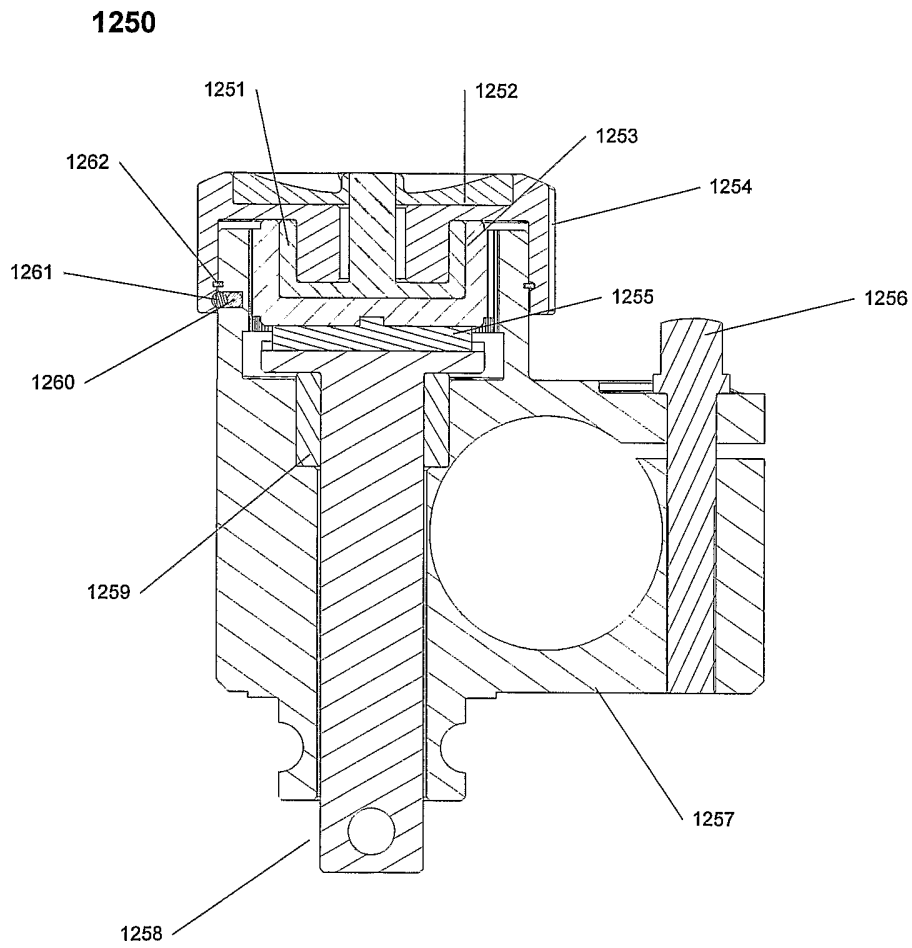
Top

**Fig. 12c**



Isometric

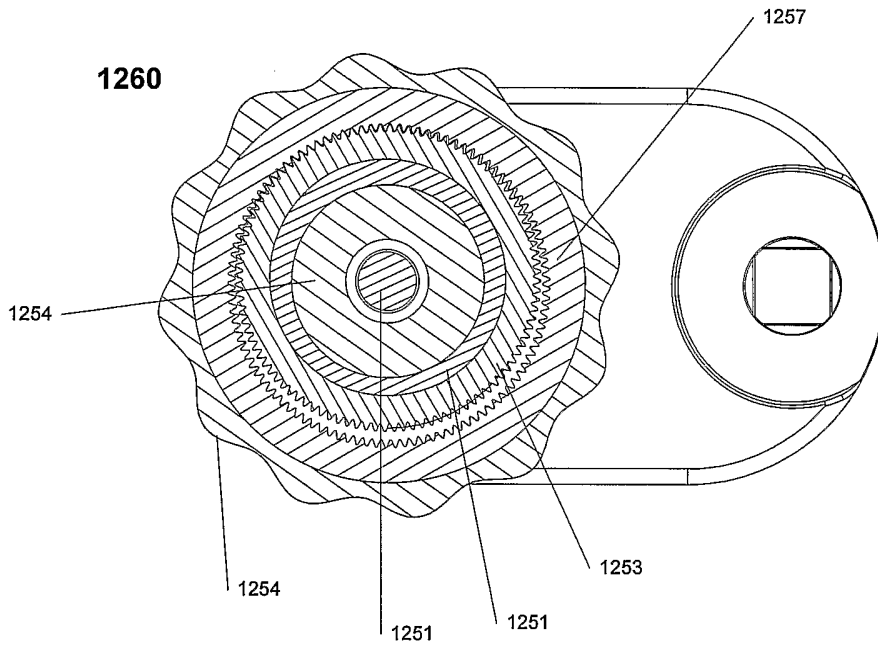
**Fig. 12d**



Section A-A

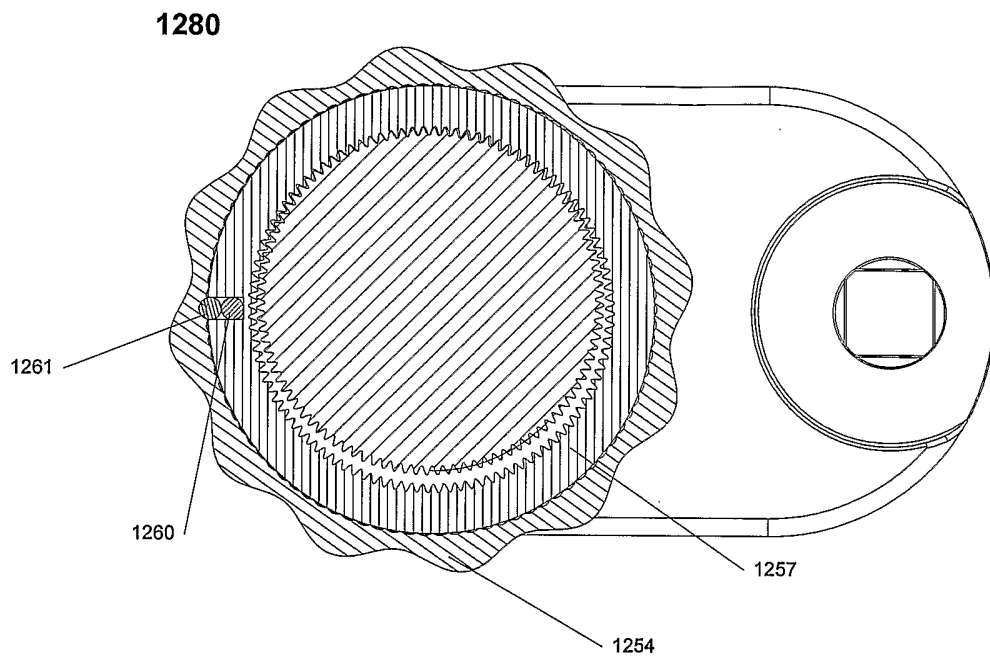
**Fig. 12e**





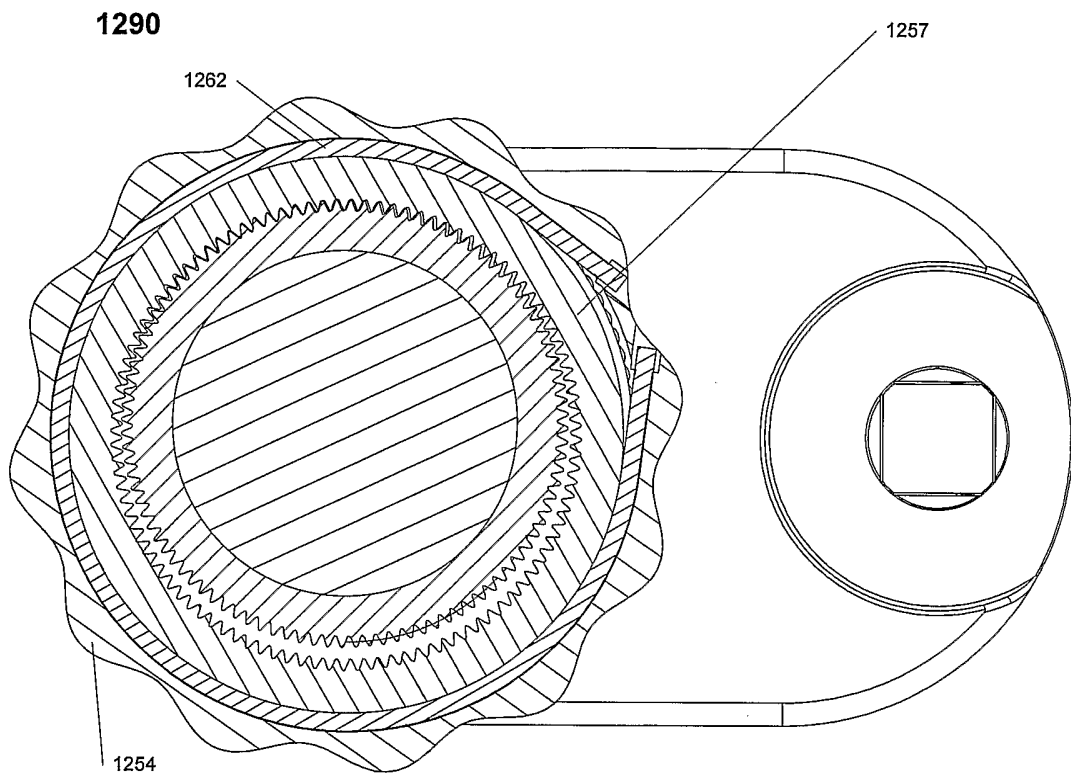
Section B-B

**Fig. 12f**



Section C-C

**Fig. 12g**



Section D-D

**Fig. 12h**

17/29

1300

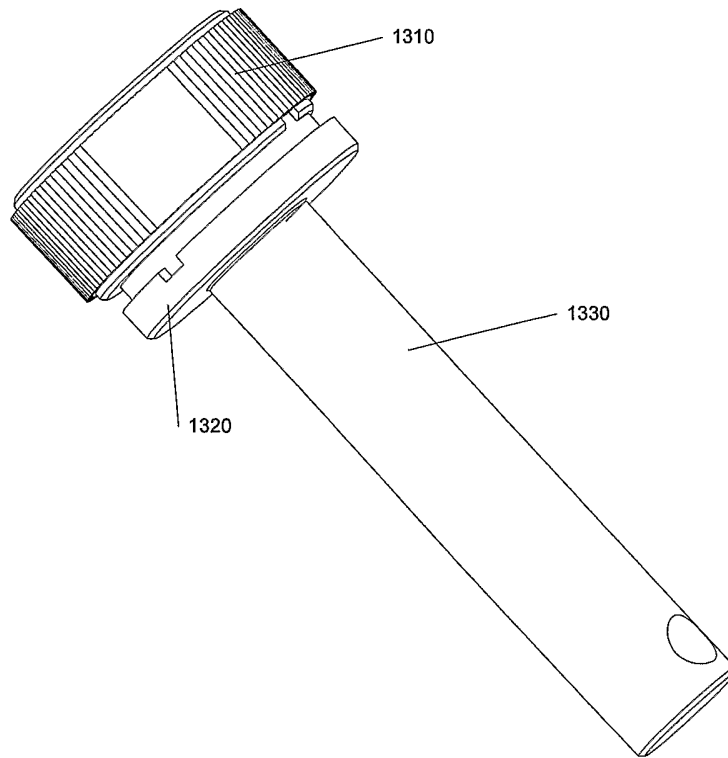
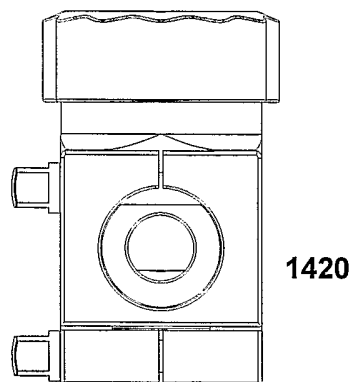
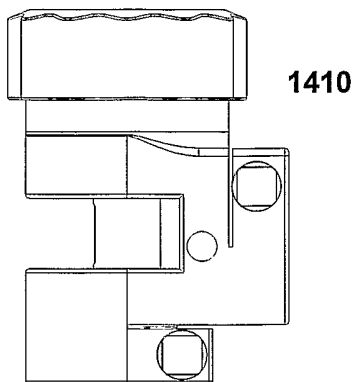
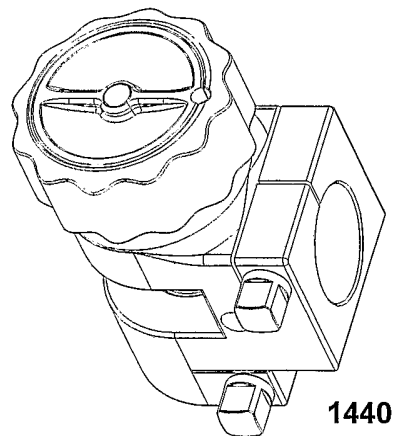
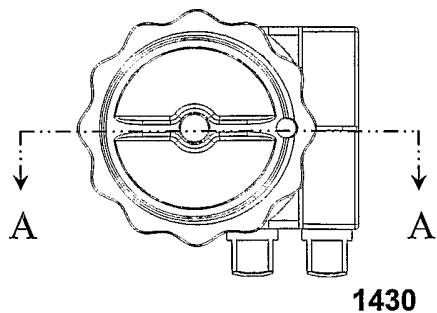


Fig. 13



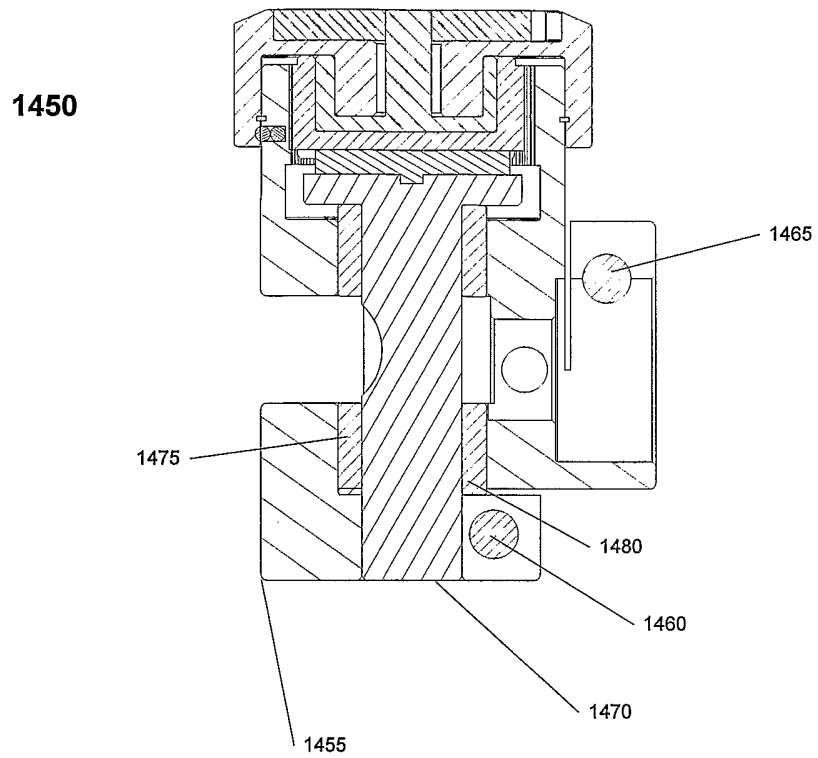
**Fig. 14a**

**Fig. 14b**



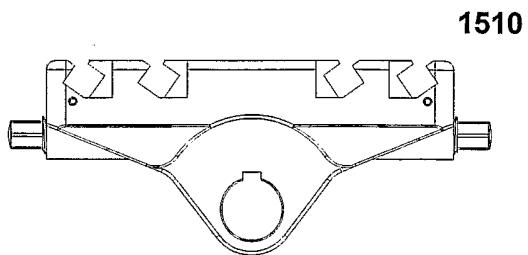
**Fig. 14c**

**Fig. 14d**



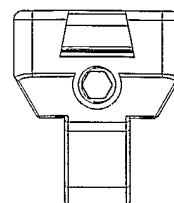
Section A-A

**Fig. 14e**



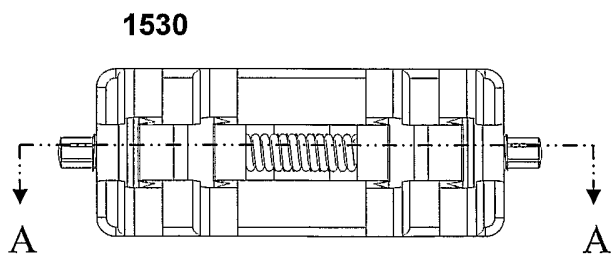
Front

**Fig. 15a**



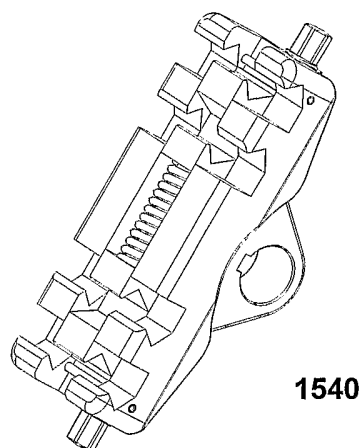
Side

**Fig. 15b**



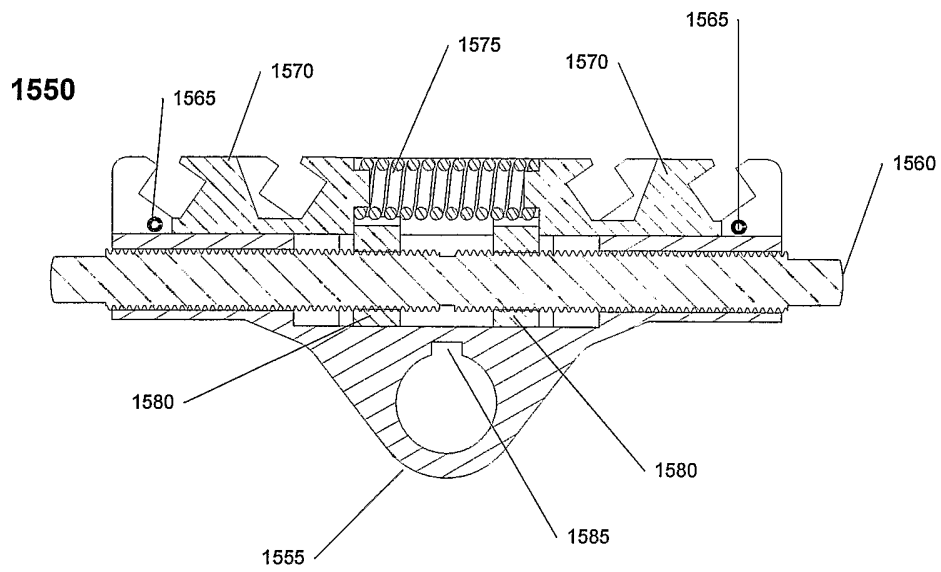
Top

**Fig. 15c**



Isometric

**Fig. 15d**

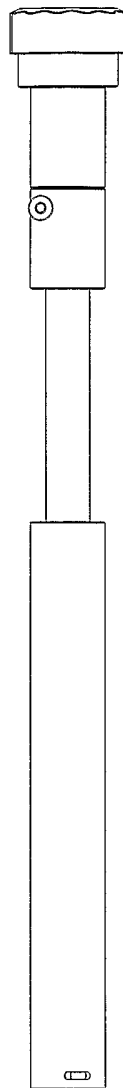


Section A-A

Fig. 15e

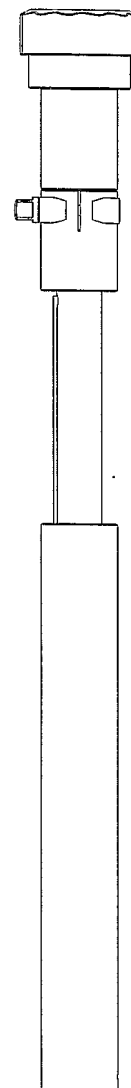


1610



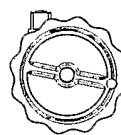
Front  
**Fig. 16a**

1620

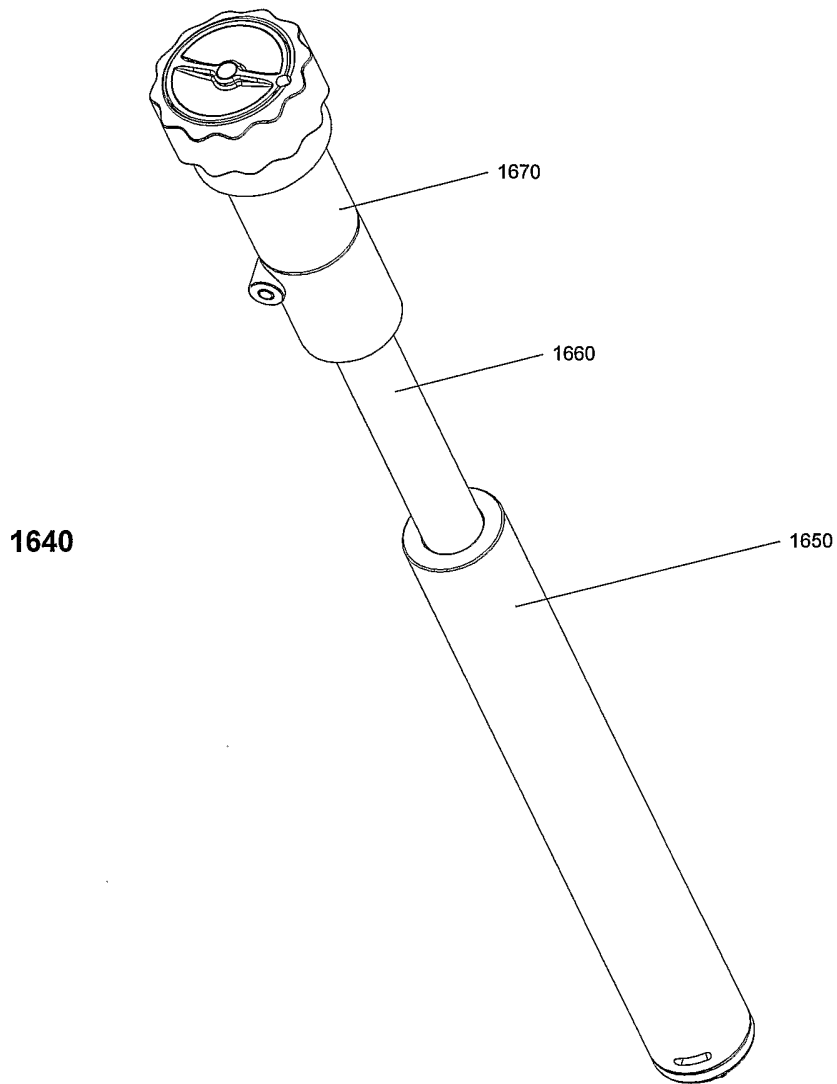


Side  
**Fig. 16b**

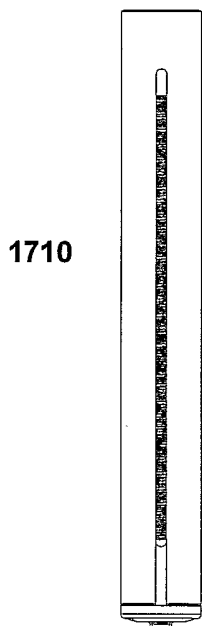
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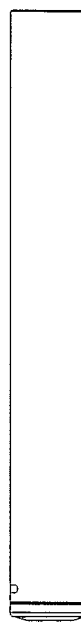
Top  
**Fig. 16c**



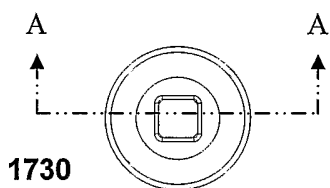
Isometric  
**Fig. 16d**



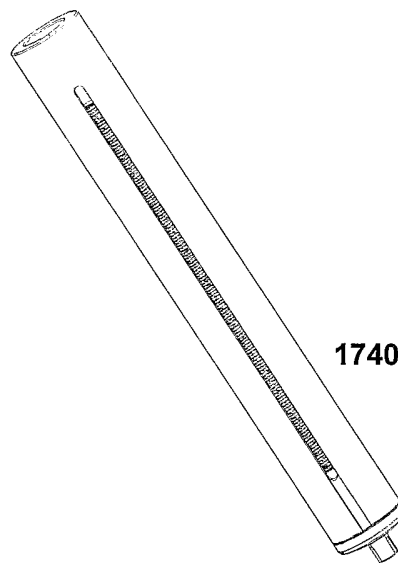
Front  
**Fig. 17a**



Side  
**Fig. 17b**



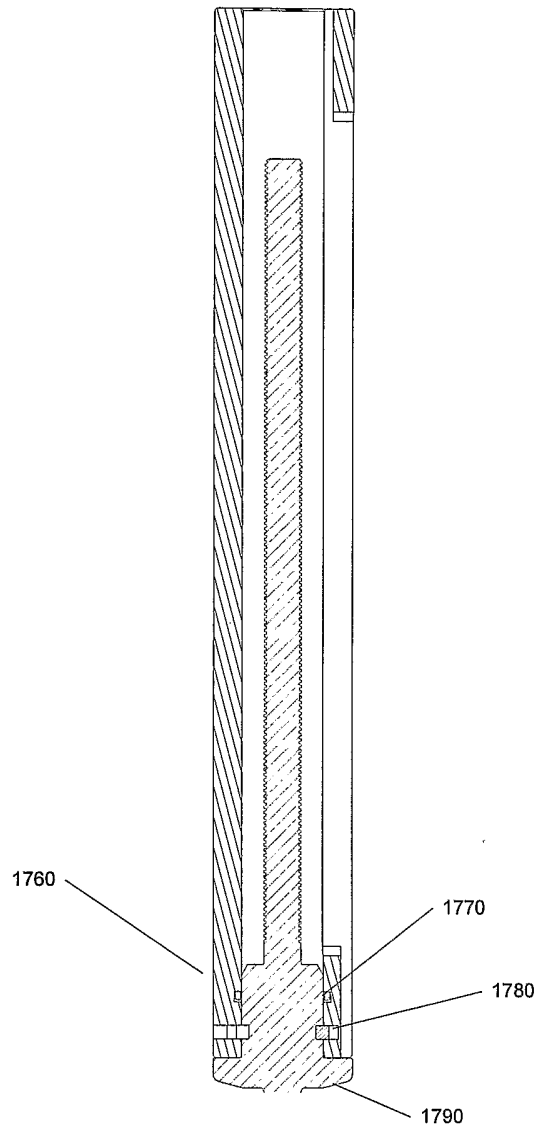
Bottom  
**Fig. 17c**



Isometric  
**Fig. 17d**

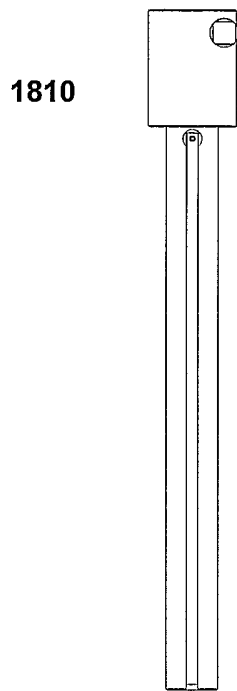
25/29

1750



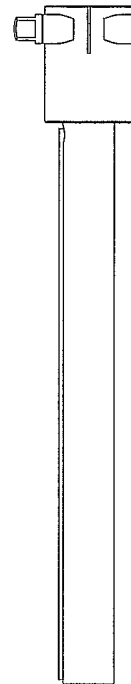
Section A-A

**Fig. 17e**



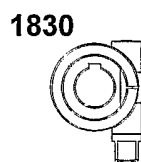
Front

**Fig. 18a**



Side

**Fig. 18b**



Top

**Fig. 18c**

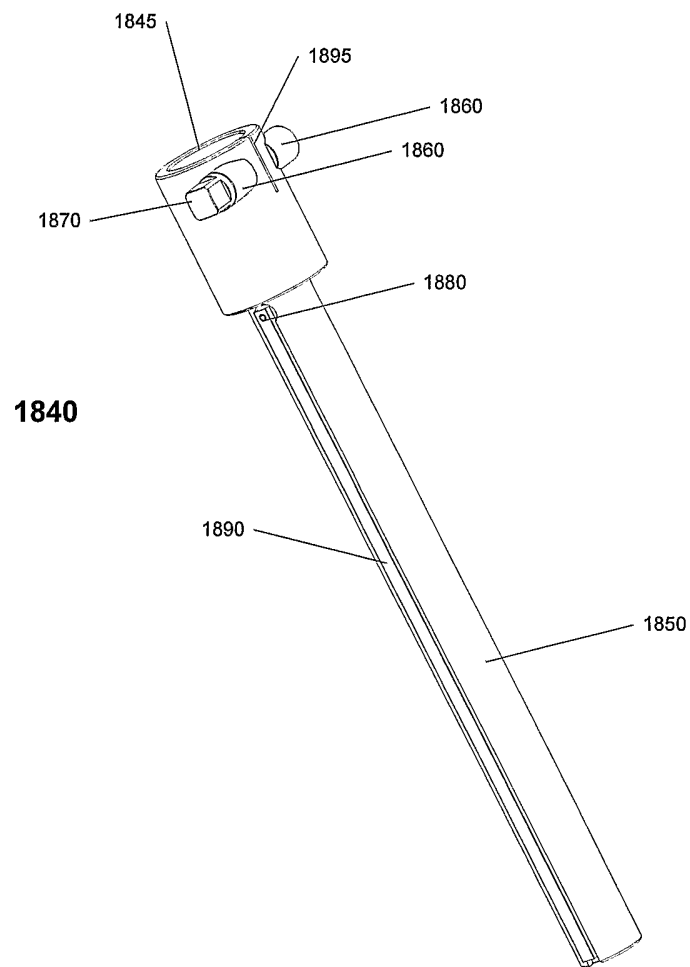
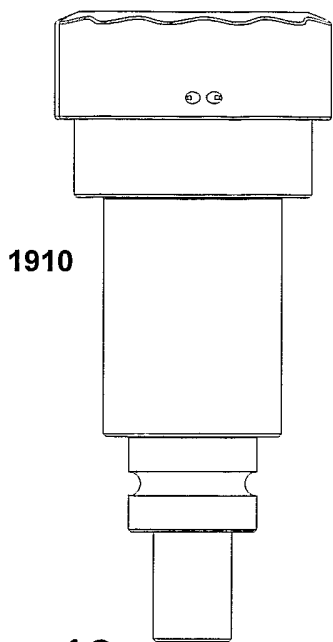
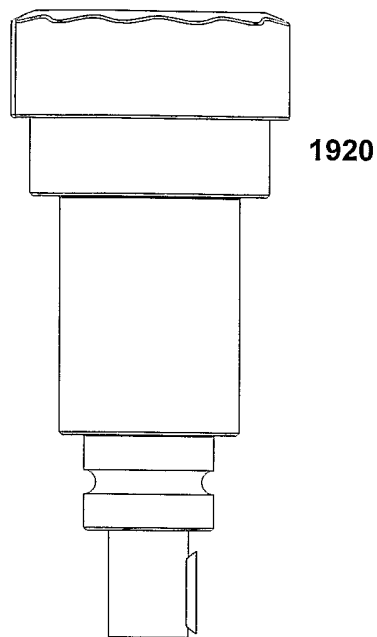


Fig. 18d



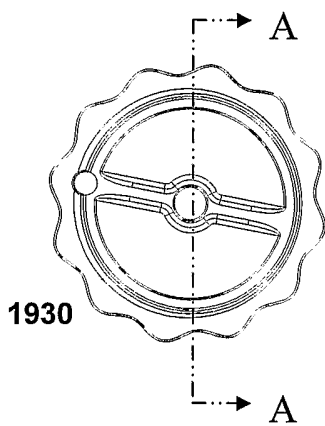
**Fig. 19a**

Front

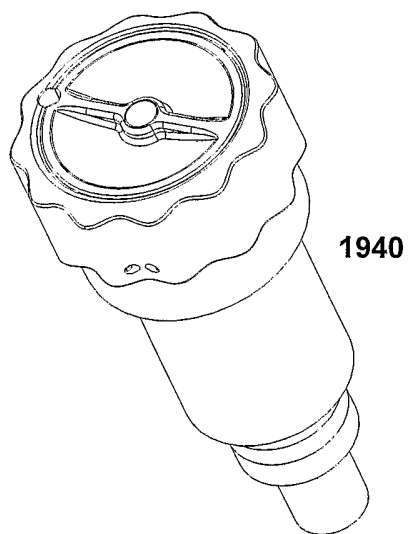


**Fig. 19b**

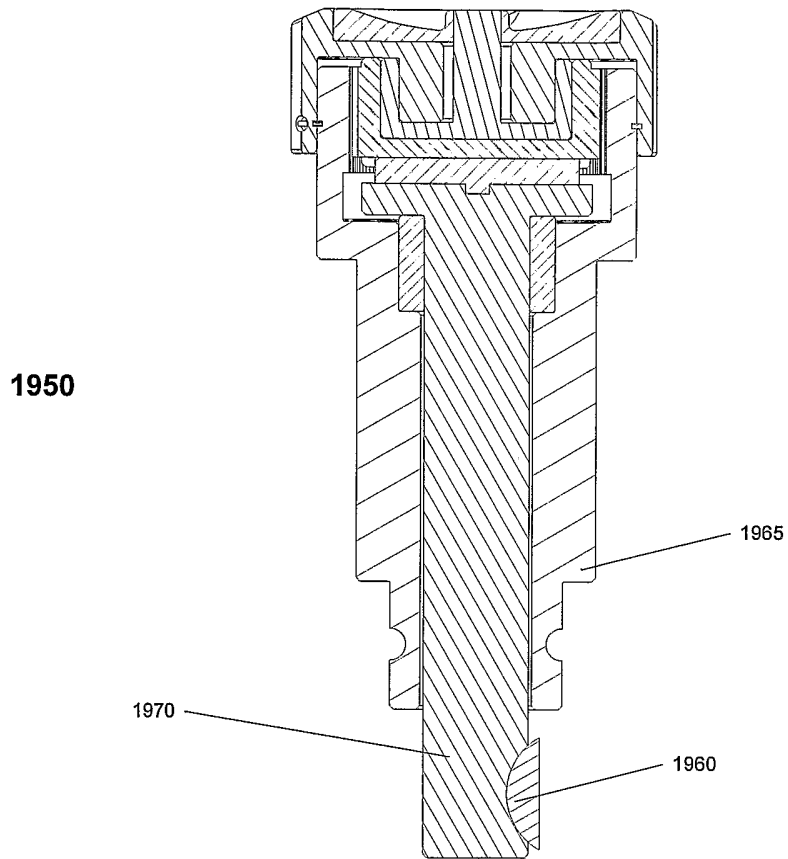
Side



Top  
**Fig. 19c**



Isometric  
**Fig. 19d**



Section A-A  
**Fig. 19e**