



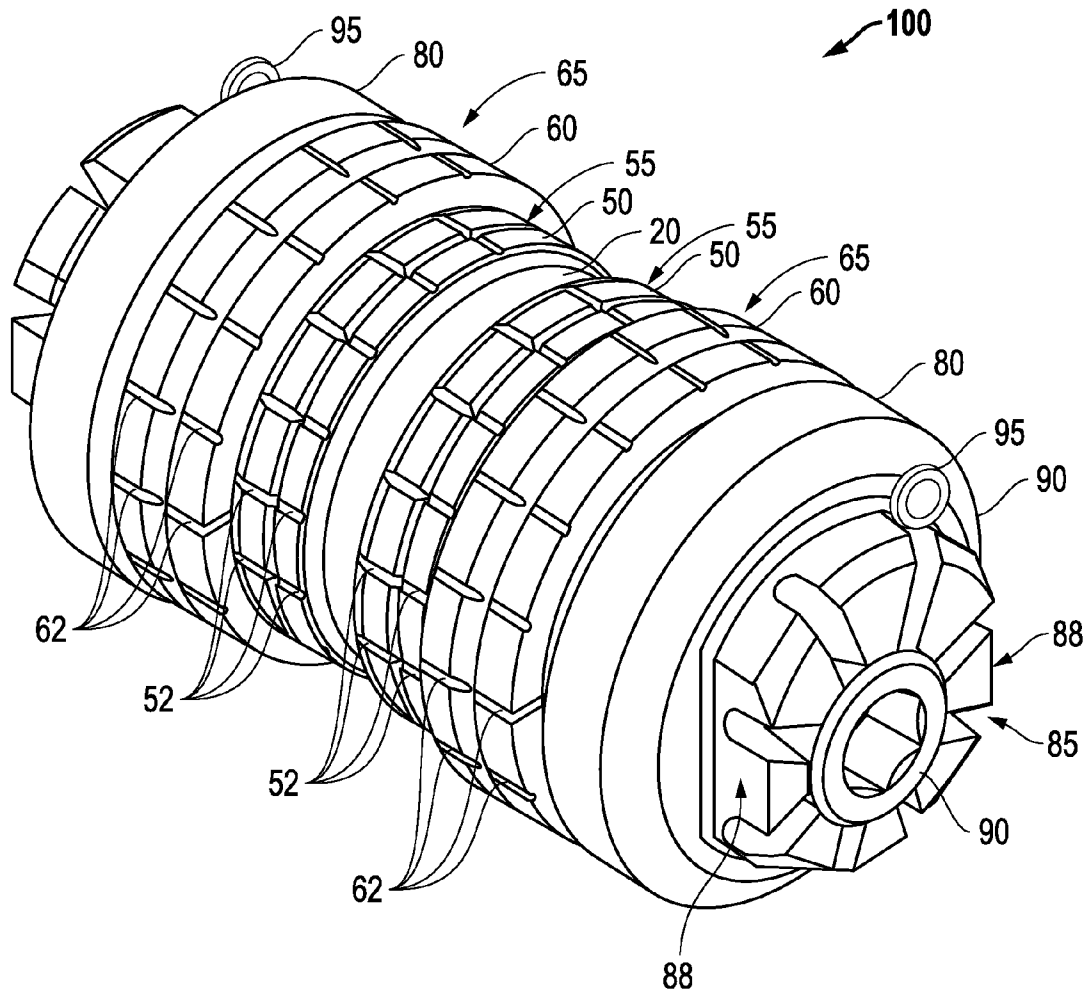
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(19) **United States**(12) **Patent Application Publication**
Orgeron et al.(10) **Pub. No.: US 2014/0314467 A1**(43) **Pub. Date: Oct. 23, 2014**(54) **5 DEGREES OF FREEDOM
ALIGNMENT-CORRECTING PRELOADED
BEARING CONNECTION SYSTEM****Publication Classification**

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INC.**, Tomball, TX (US)(21) Appl. No.: **14/216,546**(22) Filed: **Mar. 17, 2014****Related U.S. Application Data**(60) Provisional application No. 61/800,895, filed on Mar.
15, 2013, provisional application No. 61/821,617,
filed on May 9, 2013.(57) **ABSTRACT**

Exemplary embodiments provide a rotary misalignment-compensation bushing connection system that may be used in large-scale operations where several components are mounted in alignment on a single pin. For example, the misalignment-compensation system may be used in preloaded connection of a male lug rotatably mounted between a first lug and a second lug, on heavy equipment, for example, oil field exploration and production equipment. The misalignment-compensation system includes tapered cone bushings and surrounding counter-tapered cup bushings that expand in diameter and align the connection system as it is torqued together assembling the components to the pin.



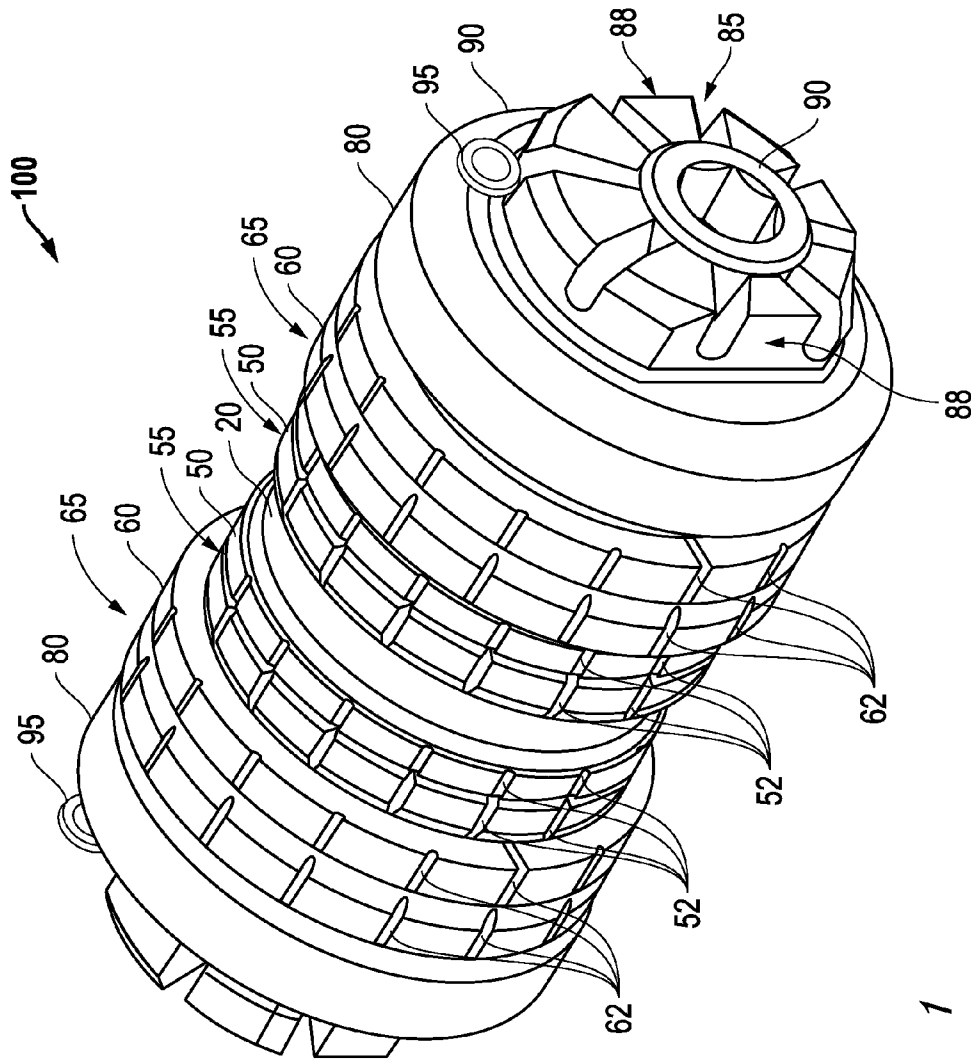


FIG. 1

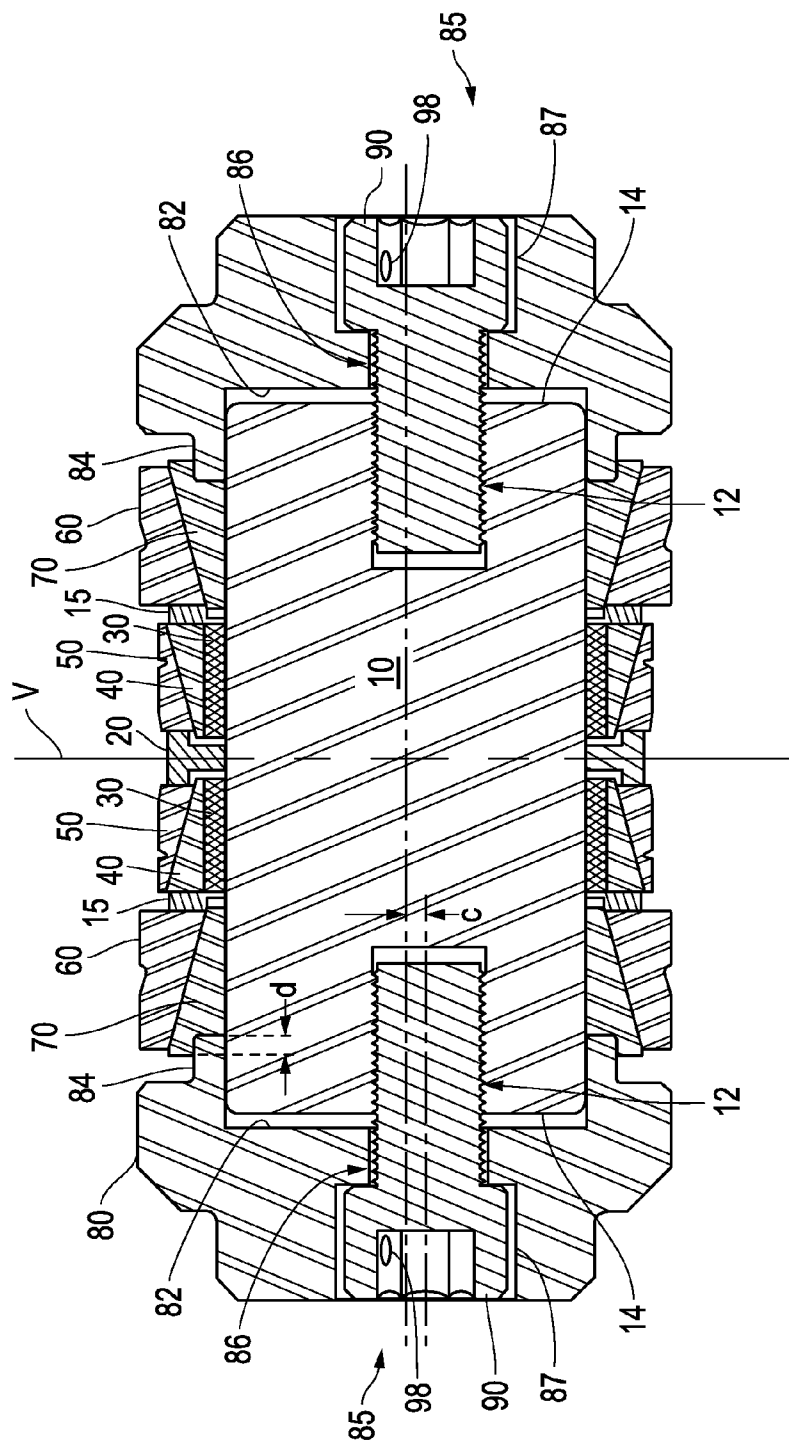


FIG. 2

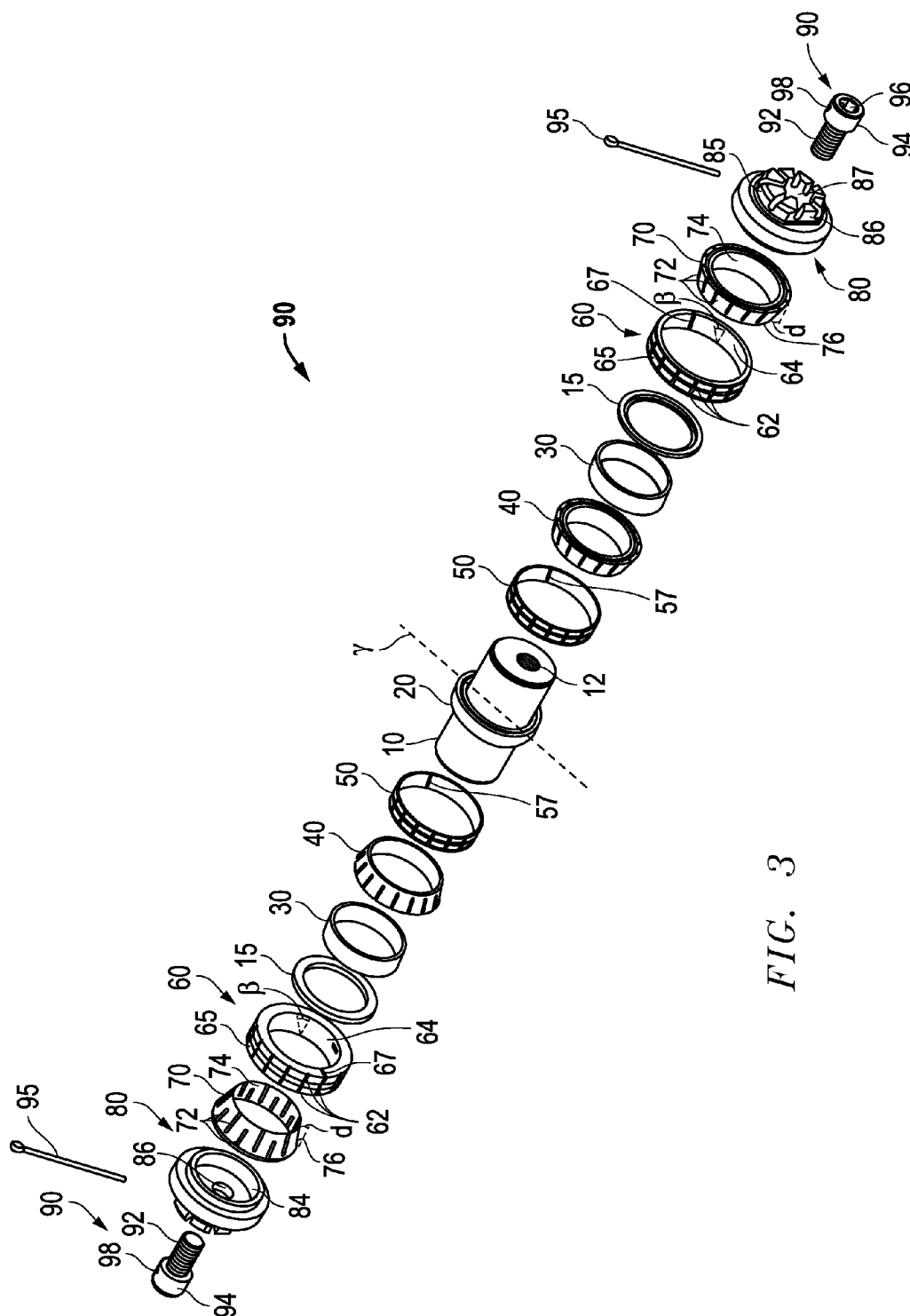


FIG. 3

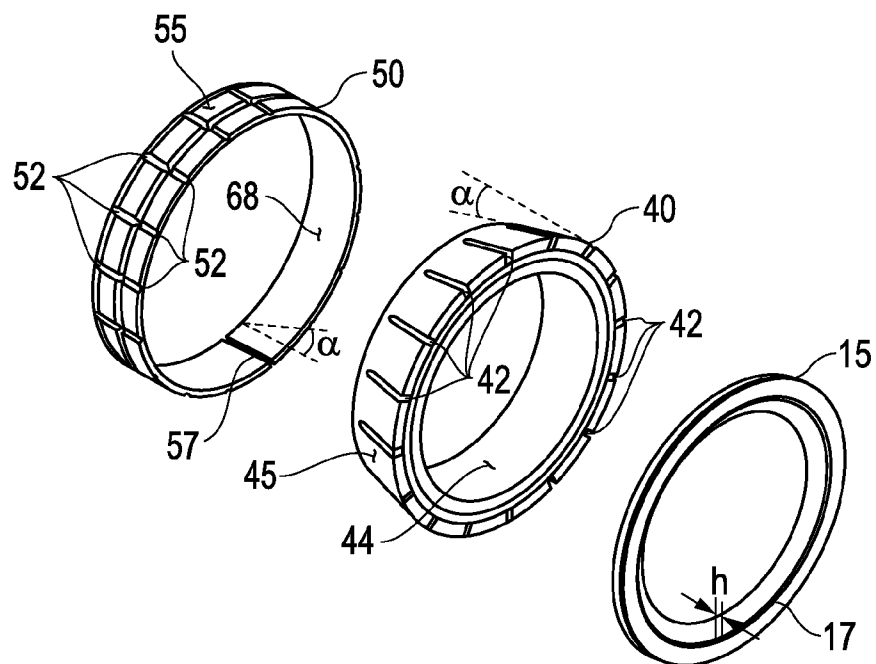


FIG. 3A

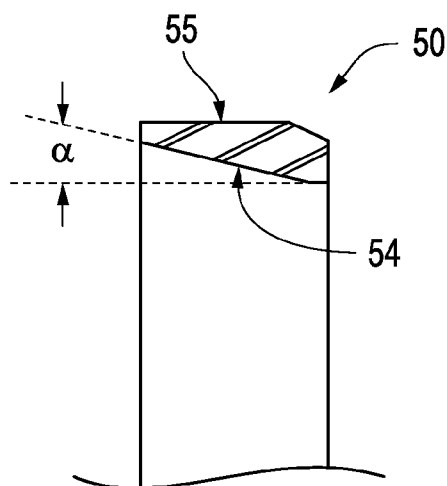


FIG. 3B

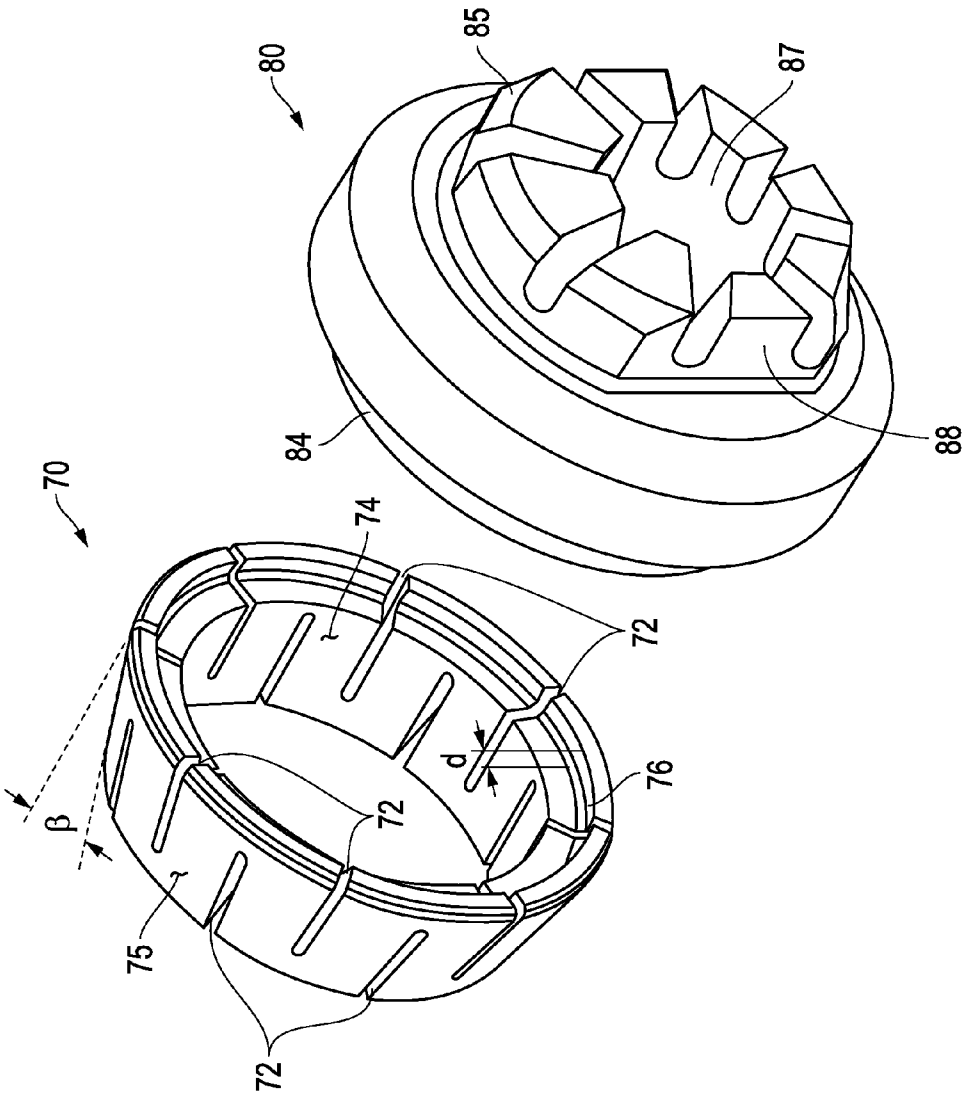


FIG. 3C

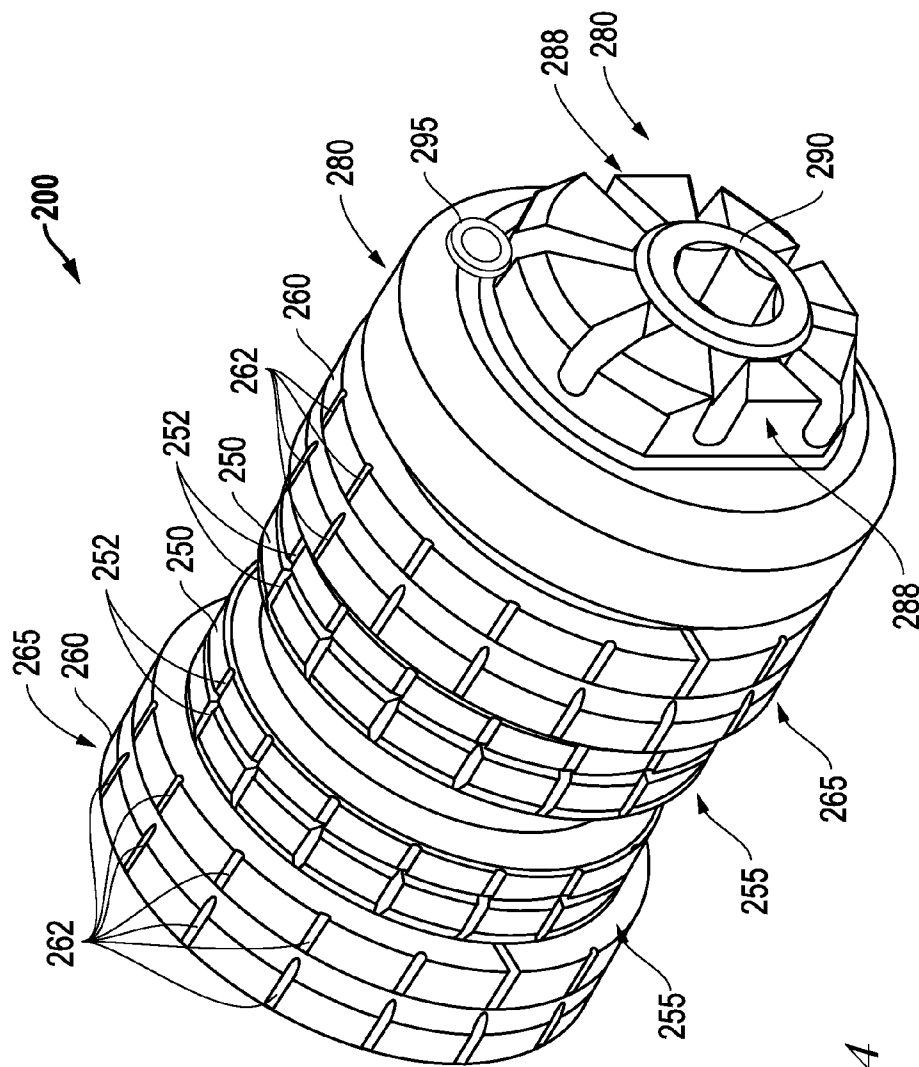


FIG. 4

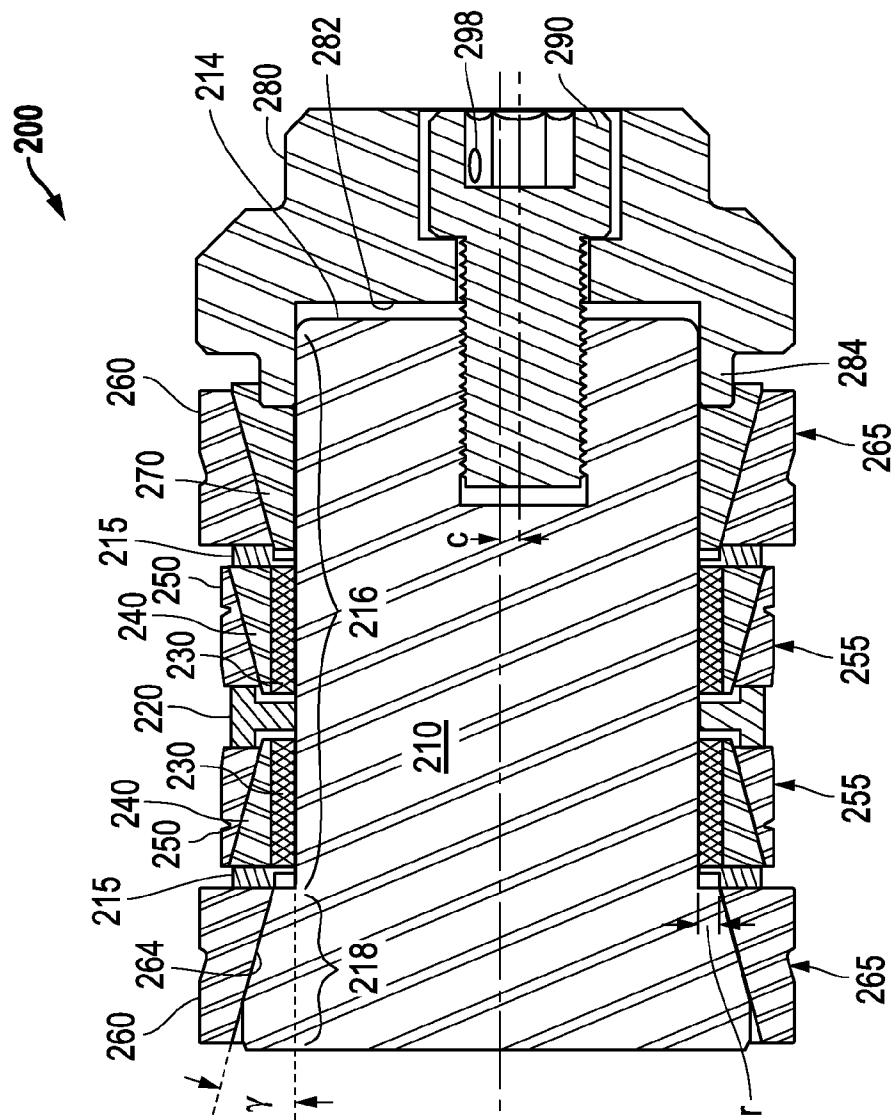


FIG. 5

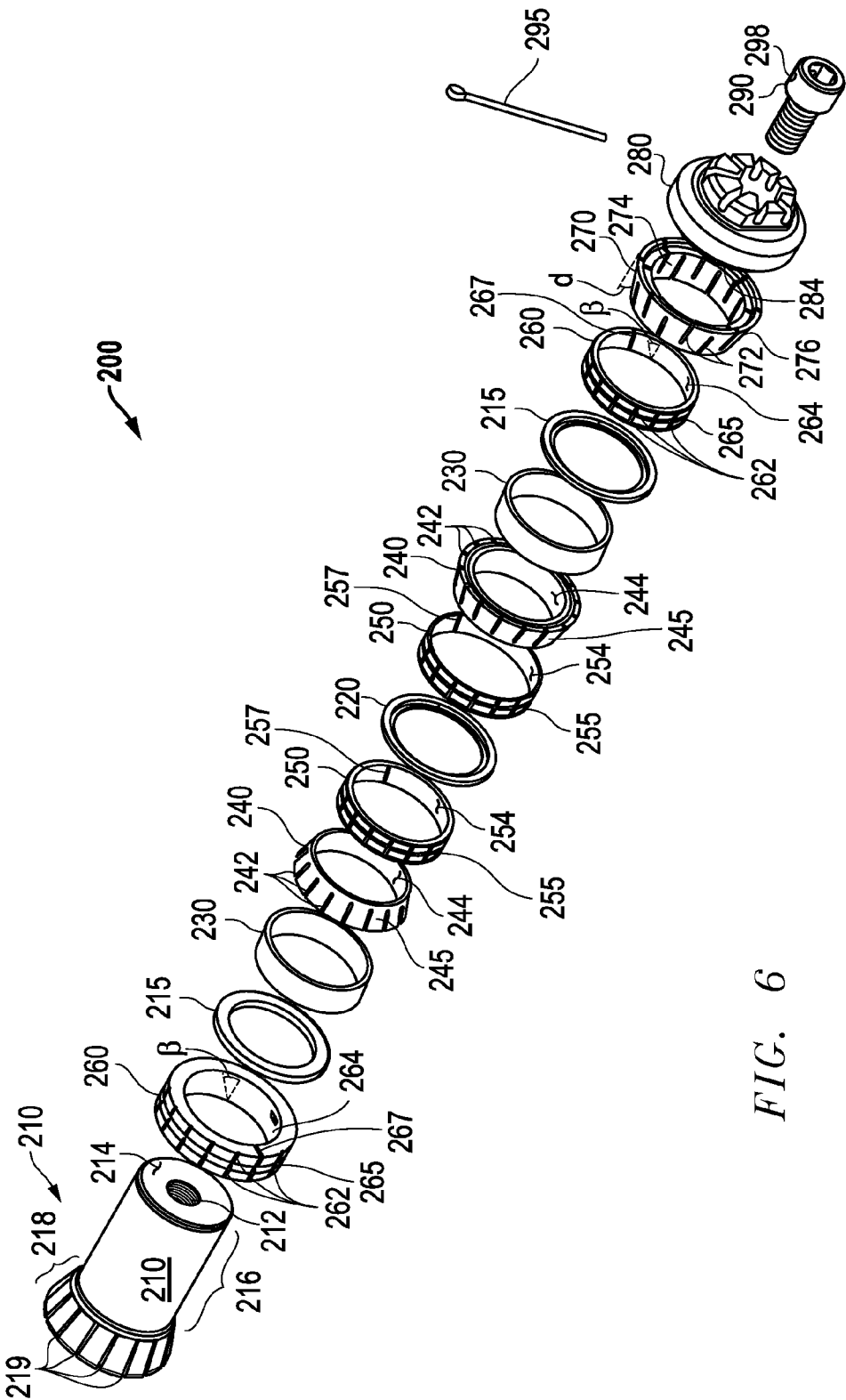


FIG. 6

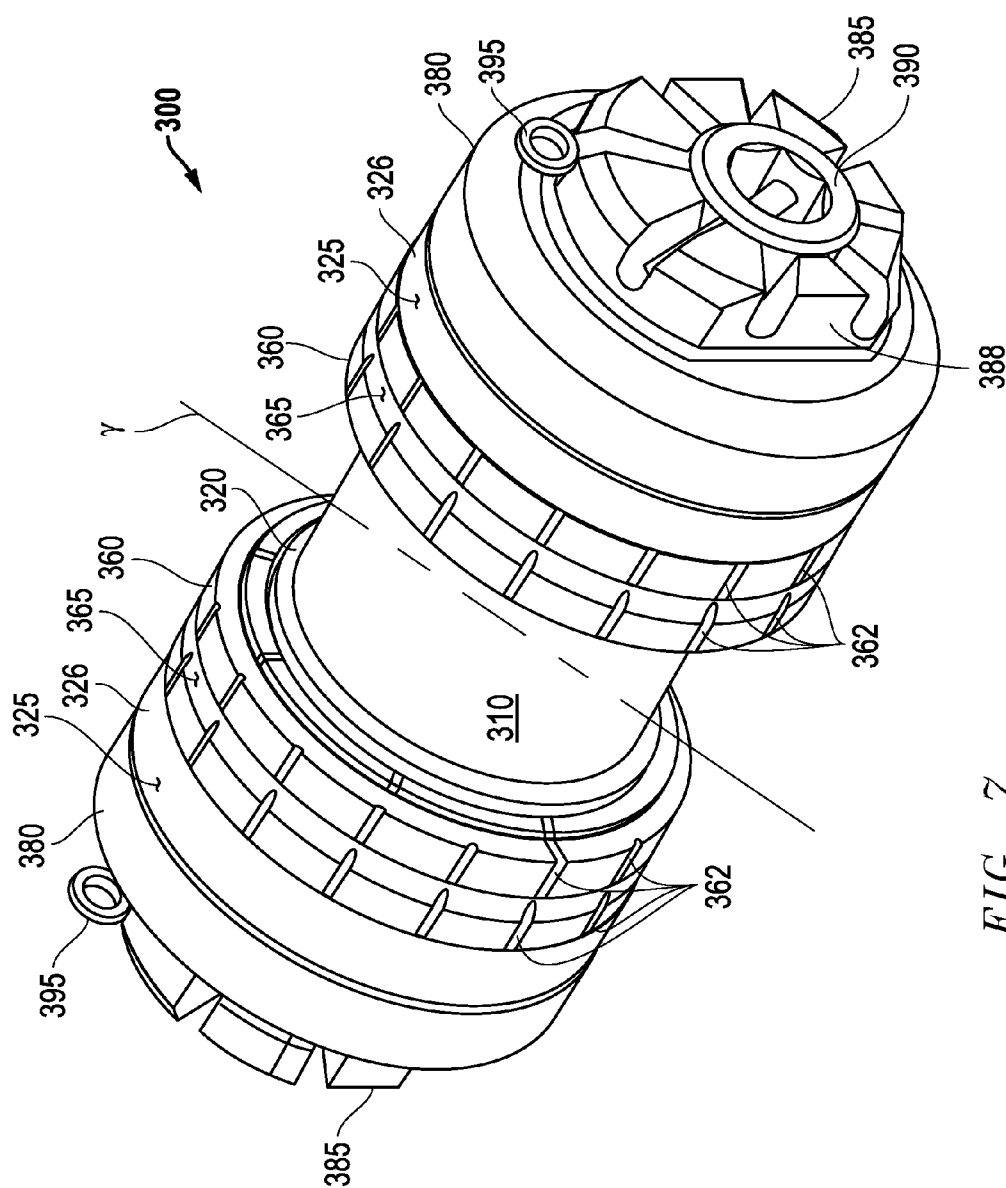


FIG. 7

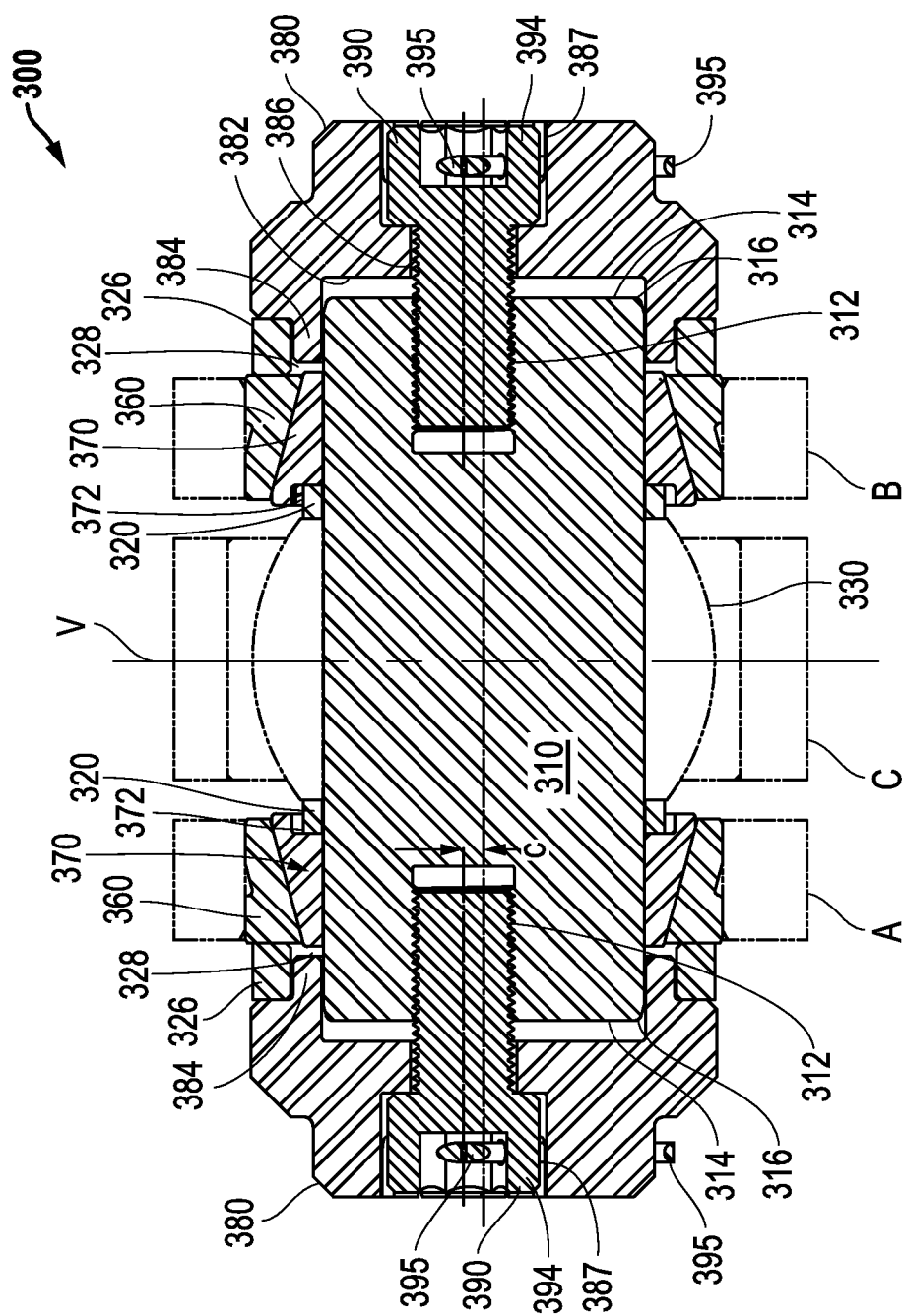


FIG. 8

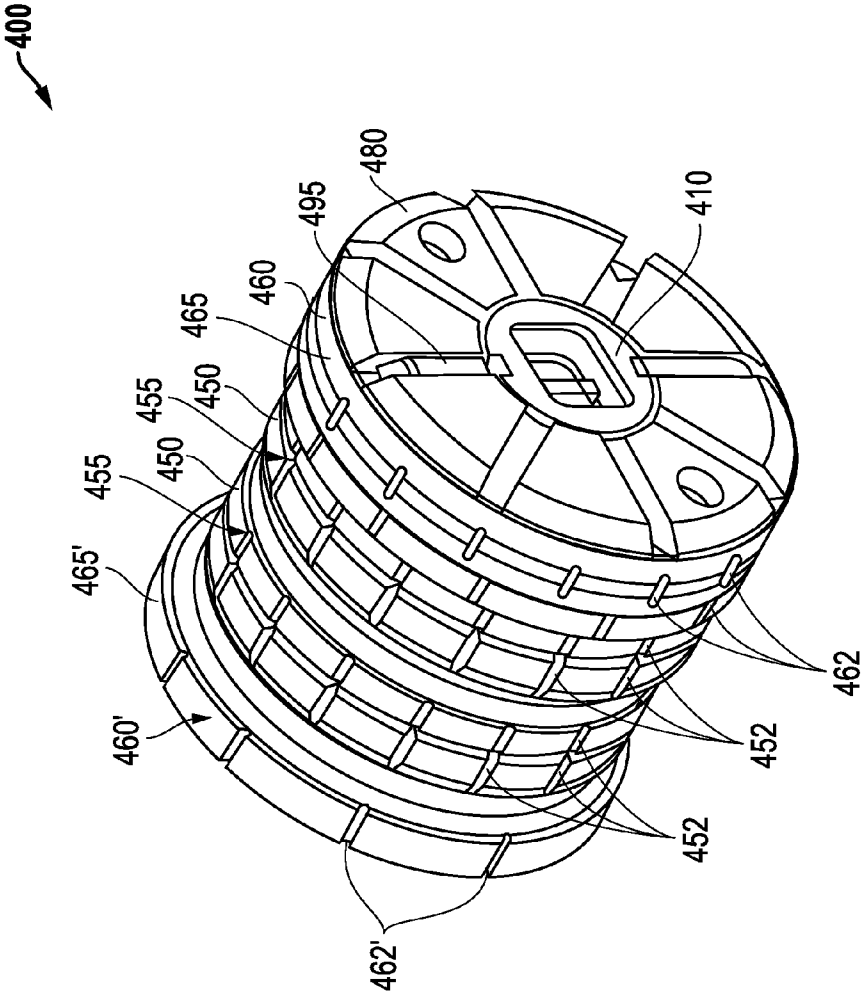
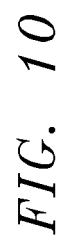


FIG. 9



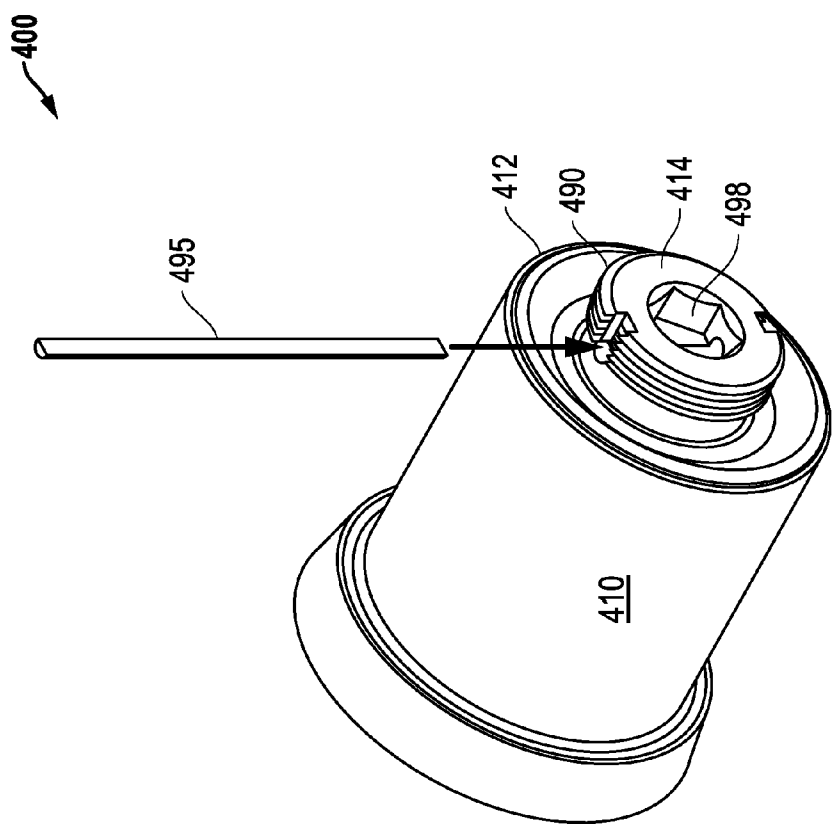


FIG. 11A

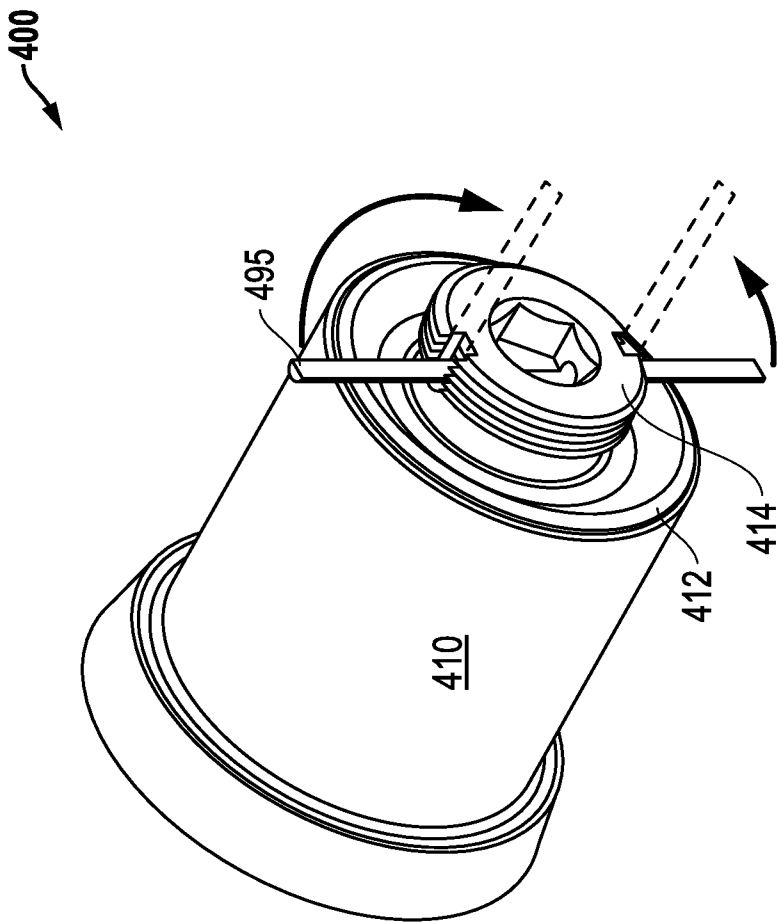


FIG. 11B

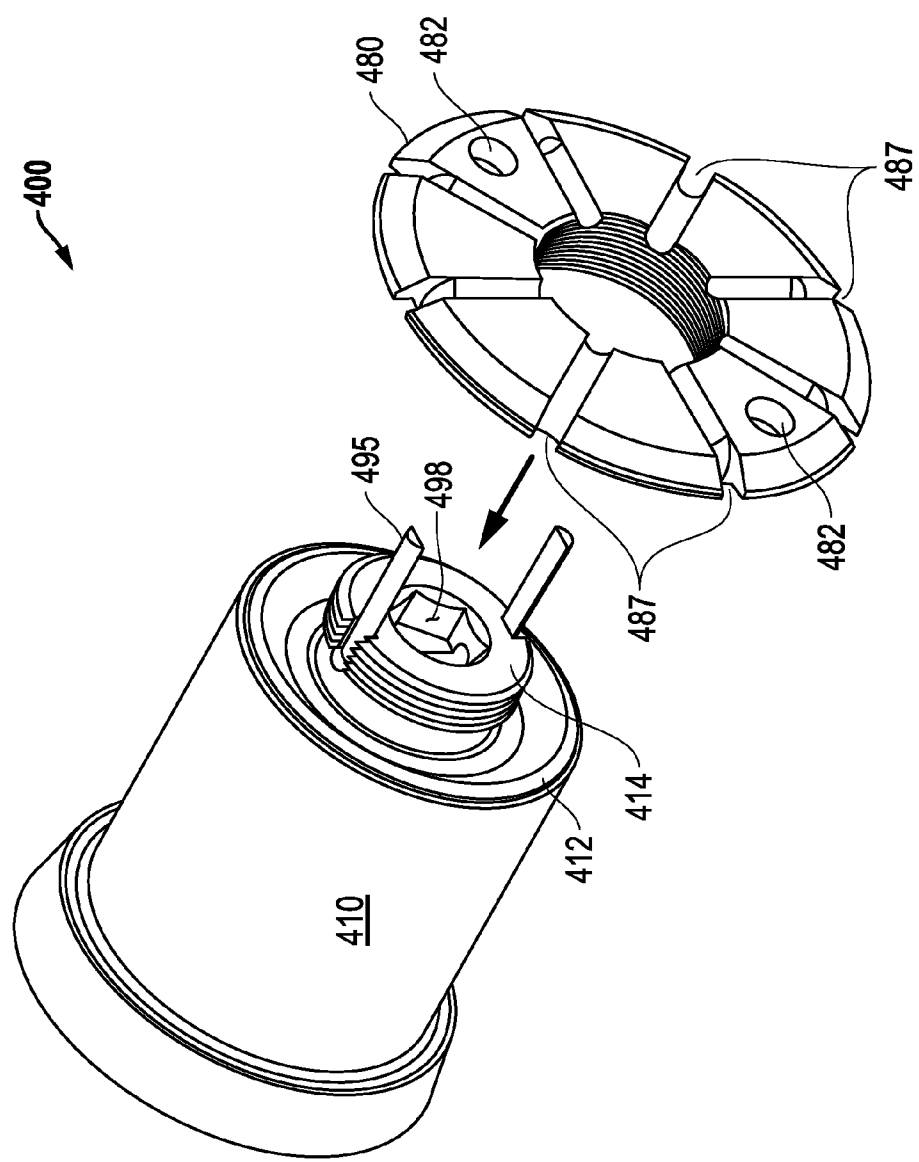


FIG. 11C

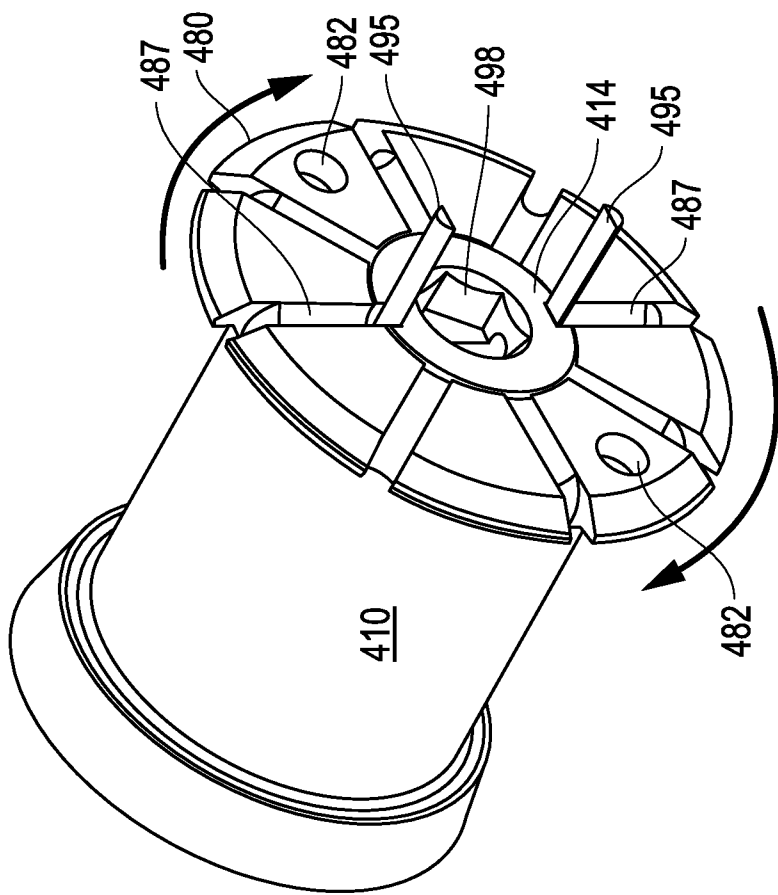


FIG. 11D

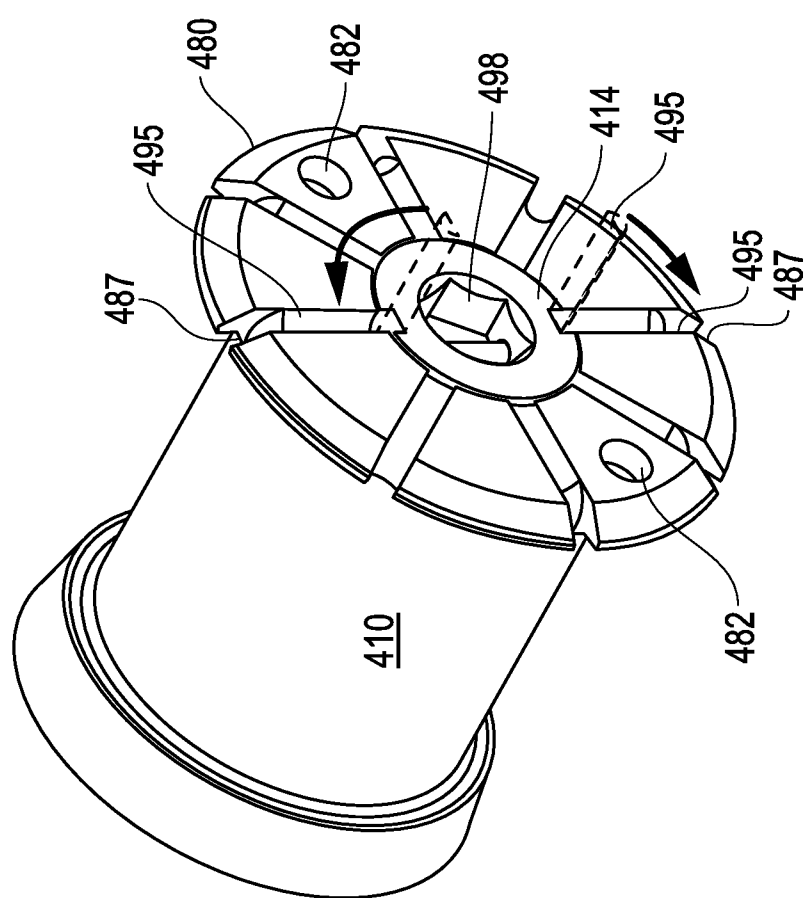
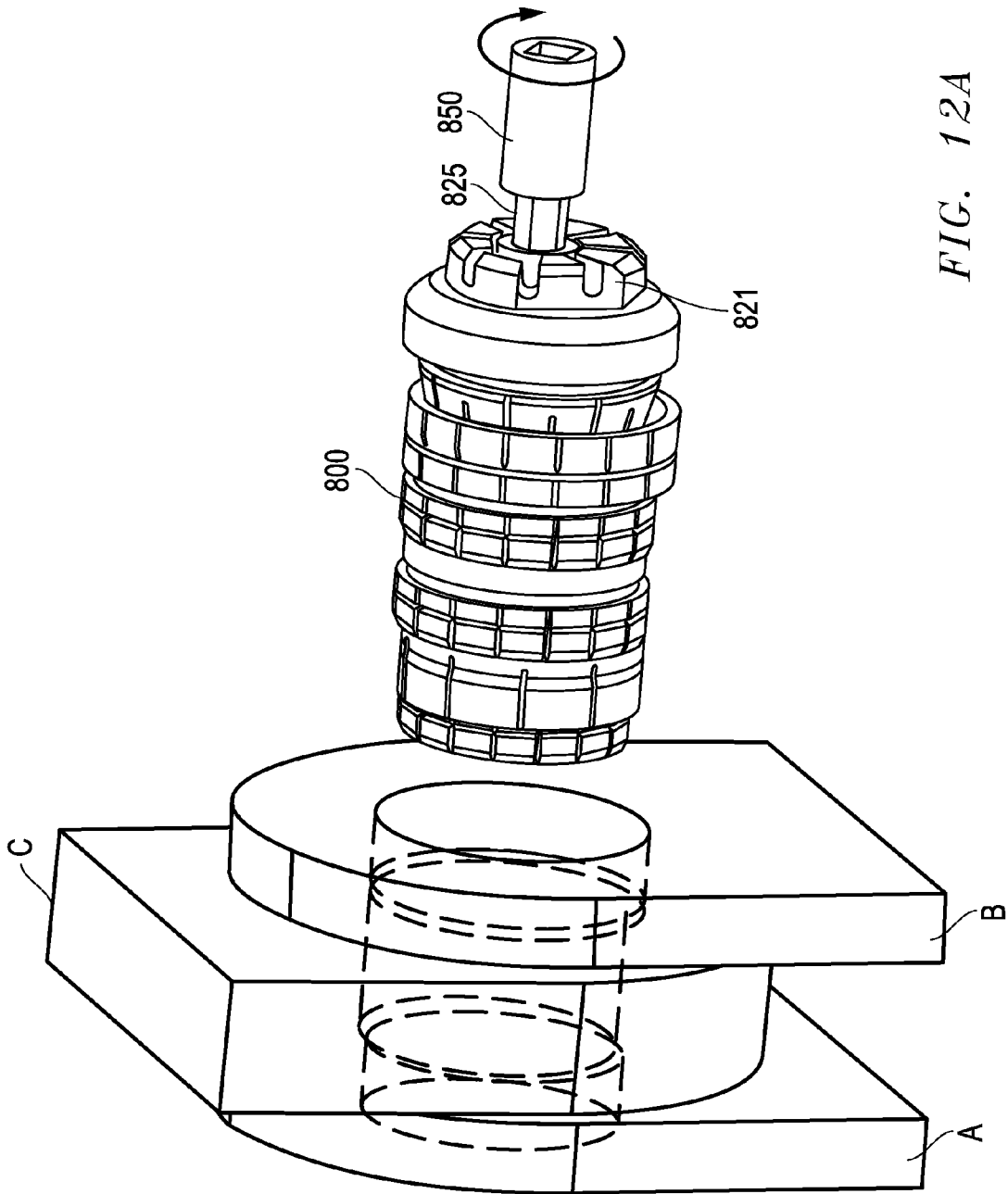


FIG. 11E



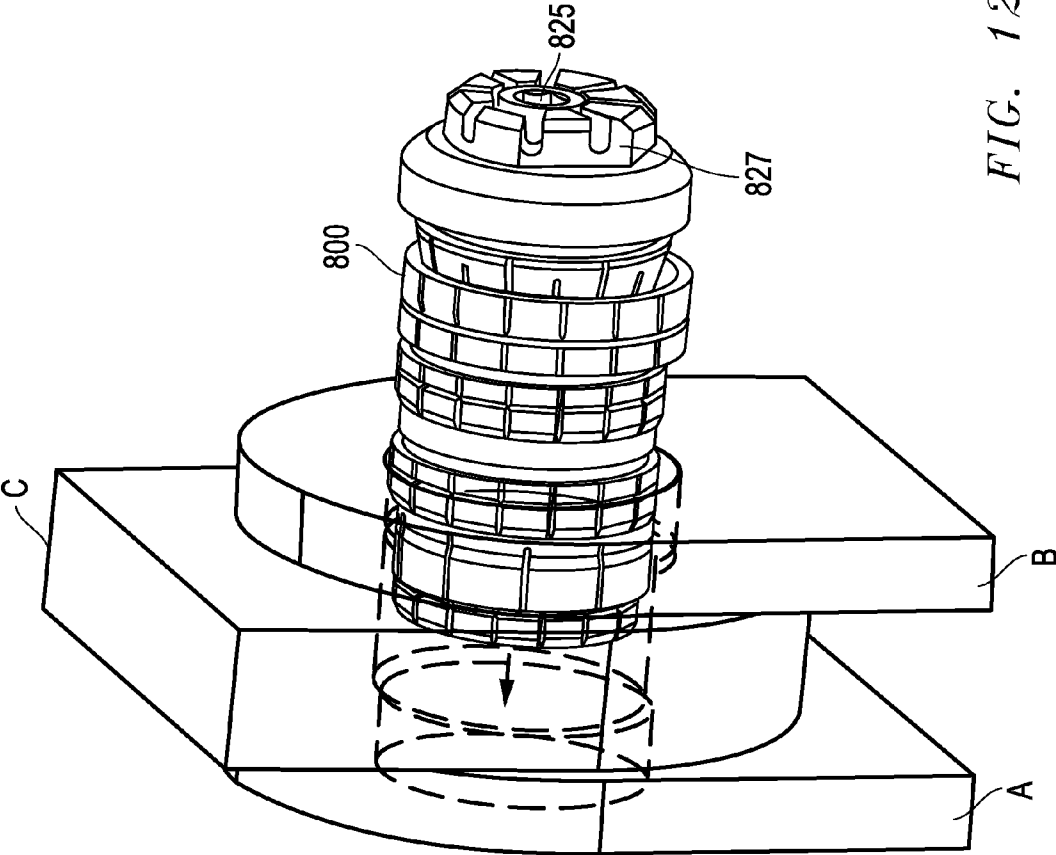
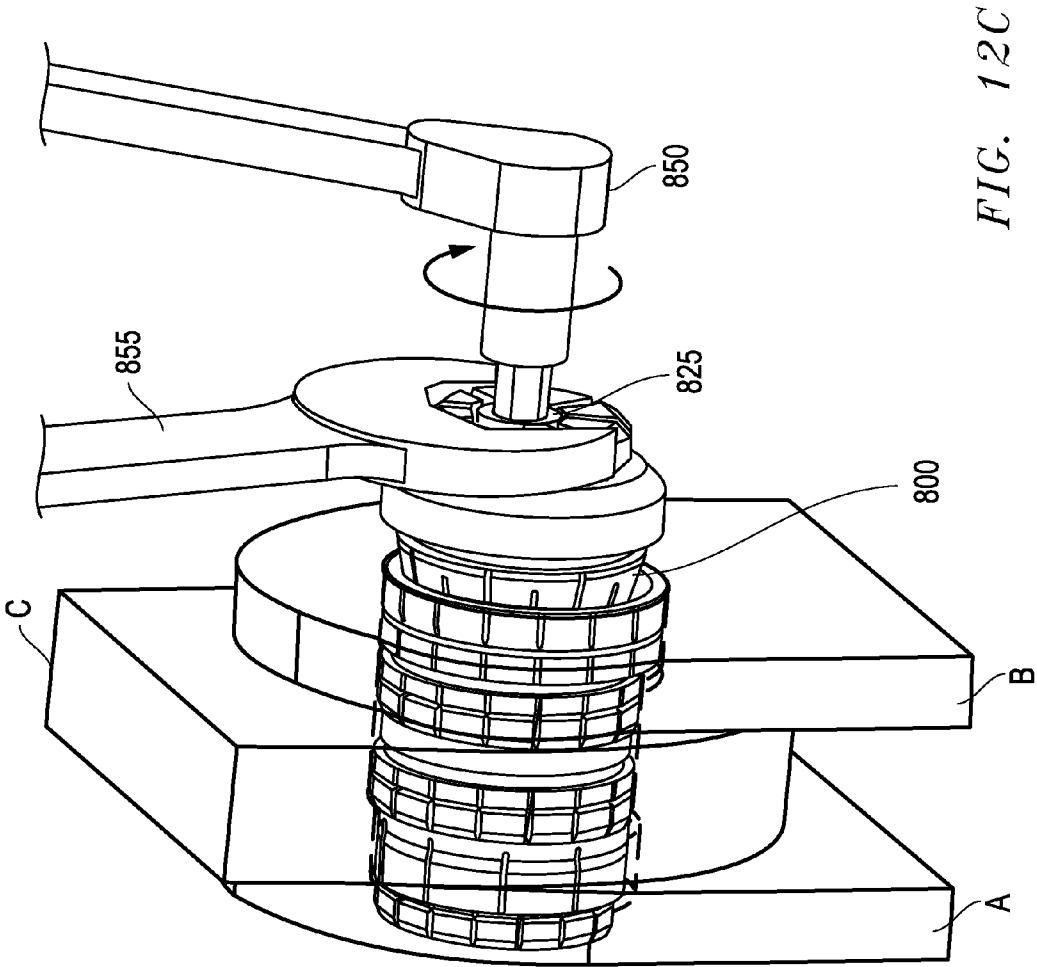


FIG. 12B



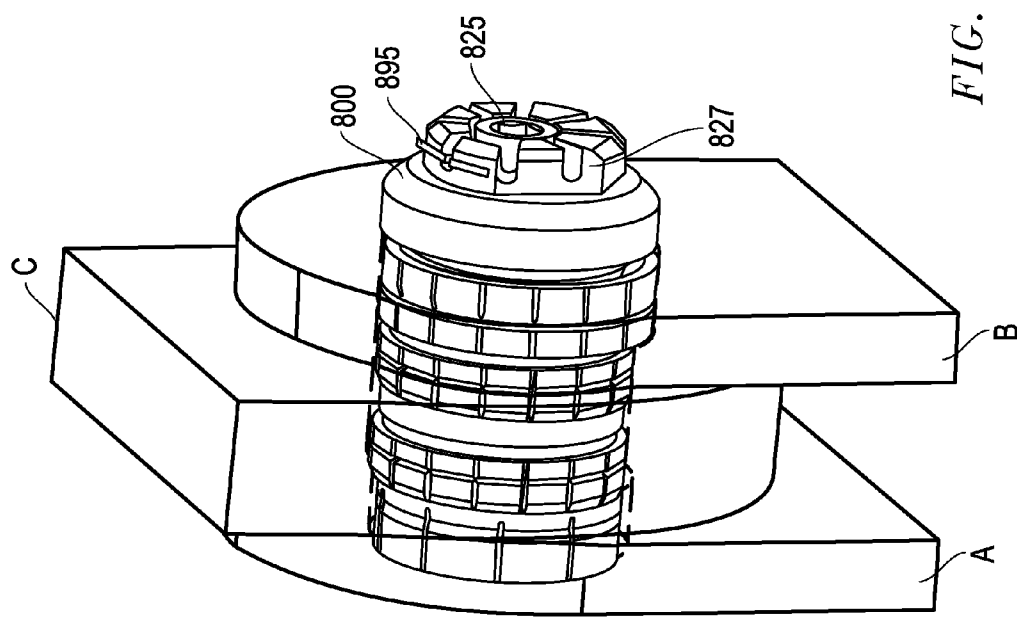


FIG. 12D

5 DEGREES OF FREEDOM ALIGNMENT-CORRECTING PRELOADED BEARING CONNECTION SYSTEM

TECHNICAL FIELD OF INVENTION

[0001] The present invention relates to a misalignment-compensating bushing system for use in apparatus for subterranean exploration. The present invention may be retrofitted to an existing large scale apparatus, such as the equipment used in connection with oil field operations. In particular, the invention provides misalignment compensation in an apparatus that has several large scale components, such as lugs, mounted side-by-side to a single pin where one lug rotates about the pin while others are immobile on the pin.

BACKGROUND OF THE INVENTION

[0002] In engineering machinery, it is often useful to mount components to a common pin, where one rotates relative to other stationary components mounted to the common pin. Such pins are frequently used in heavy engineering structural machines, such as mechanical structures used in exploration for oil, gas and geothermal energy, drilling operations, pipe handling equipment, and the like. In heavy engineering equipment, the alignment of multiple large and heavy components on a single common pin, presents several design issues. For example, it is readily apparent that an angular misalignment at the pin that might be within an expected tolerance, when traced along a length of a structure extending several meters (or feet) from the pin may result in the far end of the component extending several inches out of its intended position. This might be sufficient to interfere with other components aligned on the same pin and may cause excessive wear on mechanical components due to cyclical uneven loads, or may even cause a catastrophic collision with other equipment or workers.

[0003] It is desirable from the standpoint of mechanical reliability to ensure that all heavy mechanical components mounted to a pin are aligned as near perfectly on the pin as possible. One approach to improving alignment is to alter the shape of the pin to use its shape to assist in alignment. However, such multi-shaped pins are more expensive to manufacture with precision, and present additional engineering challenges of their own. More commonly, large cylindrical pins are used as being easier to control dimensionally, and less expensive to make and to inventory. Accordingly, other technologies are needed that may be used with a cylindrical pin. Desirably, these technologies should also minimize or compensate for misalignment of components mounted on the pin.

[0004] In some circumstances, once components are mounted to a load bearing pin, the components and the bushing assembly have to be tightened at both ends of the pin to lock all the component parts together. However, in many situations, one side of the assembly may not be readily accessible. Accordingly, there is a need for a rotatable bushing connection system that permits tightening from one side only and that also minimizes or compensates for any misalignment of components mounted on the pin. Still further, there is a need for a rotatable bushing connection system that does not require any modification to the components being mounted.

SUMMARY

[0005] The following is a summary of some aspects and exemplary embodiments of the present technology, of which

a more detailed explanation is provided under the Detailed Description section, here below.

[0006] The invention provides a rotary misalignment-compensation bushing connection system that may be used in large scale operation where several components must be mounted side-by-side in alignment on a single pin, and where one of the components rotates about the pin. For example, the misalignment-compensation system may be used in preloaded connection of a male lug rotatably mounted between stationary first and second lugs, on heavy equipment, for example, oil field exploration and production equipment or other heavy machinery.

[0007] In an exemplary embodiment, the misalignment-compensating rotary bushing connection system has a second threaded hole in the second end of the pin. A center spacer is located over the pin and is substantially centered along the length of the pin. The system also includes a pair of sleeve bearings, one located on each side of the center spacer and surrounding at least a portion of the pin. An inner cone bushing is located on each sleeve bearing, and an inner cup bushing is located on each inner cone bushing. The system has a pair of thrust bearings located on the pin, and extending at least partially circumferentially around the pin, each of the thrust bearings positioned adjacent to a sleeve bearing on an outboard side of the inner cone bushings. In addition, the exemplary misalignment-compensating rotary bushing connection system has a pair of outer cone bushings located on and surrounding the pin. The second outer cone bushings are each adjacent to an outboard side of a thrust bearing. An outer cup bushing is located on top of and is located on each outer cone bushing. Further, the connection system includes a first and a second retainer cap, each having an internal side and an external side, and a connecting passage from the internal to the external side. The internal side of each cap has a compression boss, and a relief receivable of one of the ends of the pin. The external side of the cap is configured to engage a fastening tool, and has a radial slot or bore receivable of a locking pin.

[0008] In the above exemplary embodiment, each of the pairs of inner cup bushings and inner cone bushings have a first complementary counter-taper, and each of the pairs of the outer cup bushings and the outer cone bushings have a second complementary counter-taper. Accordingly, when the connection system is assembled, and tightened with a fastening tool, the first and second complementary counter-tapers, respectively, permit sliding engagement and expand the diameter of the exemplary embodiment. As the diameter expands during tightening, the bores of the lugs are engaged, and the lugs are urged into proper alignment.

[0009] In exemplary embodiments, grooves may be applied to outer surfaces of any one or more of the inner cone bushing, the inner cup bushing, the outer cone bushing and the outer cup bushing. Moreover, in other exemplary embodiments, slots shorter than an axial length of the cone bushing may be provided, for example, extending axially through a thickness of the outer cone bushings, and extending from opposite ends of the outer cone bushings.

[0010] In exemplary embodiments, low friction coatings may be applied selectively to certain of the inner and outer bores of the cones and the inner bores of the cups; these coatings, in combination with the utilization of higher friction surfaces on some elements, can be utilized to ensure full

makeup of all elements of the assembly without requiring excessive axial force applied through the tightening mechanism.

[0011] In an alternate embodiment, the pin may have a first portion and a second portion. The first portion may be substantially cylindrical, and the second portion may be substantially frusto-conical in shape, with cone diameter increasing with distance from the first portion. The outer surface of the second portion edge is separated from the outer surface of the first portion by a ledge having a radial depth. The frusto-conical second portion replaces one of the outer cone bearings of the embodiment described. Further this embodiment only requires a single retainer cap.

[0012] In other exemplary embodiments, the retainer cap may be configured in a variety of different ways to prevent rotation of the retainer cap relative to the center pin when a fastener is torqued into the threaded bore of the pin.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The foregoing aspects, and many of the attendant advantages, of the present technology will become more readily appreciated by reference to the following Detailed Description, when taken in conjunction with the accompanying simplified drawings of exemplary embodiments. The drawings, briefly described here below, are not to scale, are presented for ease of explanation and do not limit the scope of the inventions recited in the accompanying patent claims.

[0014] FIG. 1 is an illustration depicting a first exemplary embodiment of the misalignment-compensating rotary bushing connection system.

[0015] FIG. 2 is a cross sectional view of the first embodiment.

[0016] FIG. 3 is an exploded view showing detail of the components of the first embodiment.

[0017] FIG. 3A is an exploded view showing detail of certain components (shown on the right-hand side in FIG. 3) of the first embodiment.

[0018] FIG. 3B is a cross section through a portion of an exemplary inner cup bushing (shown on the right-hand side in FIG. 3) of the first embodiment showing the internal taper angle.

[0019] FIG. 3C is an illustration of an exemplary outer cone bushing of the first embodiment showing the external taper angle.

[0020] FIG. 4 is an illustration depicting a second exemplary embodiment of the misalignment-compensating rotary bushing connection system.

[0021] FIG. 5 is a cross sectional view of the second embodiment.

[0022] FIG. 6 is an exploded view showing detail of the components of the second embodiment.

[0023] FIG. 7 is an illustration depicting a third exemplary embodiment of the misalignment-compensating rotary bushing connection system.

[0024] FIG. 8 is a cross sectional view of the third embodiment.

[0025] FIG. 9 is an illustration depicting a fourth exemplary embodiment of the misalignment-compensating rotary bushing connection system.

[0026] FIG. 10 is a cross sectional view of the fourth exemplary embodiment.

[0027] FIGS. 11A-11E illustrate in more detail the assembly of a retainer cap of the fourth embodiment.

[0028] FIGS. 12A-12D illustrate in more detail an exemplary embodiment of the misalignment-compensating rotary bushing connection system being inserted from one end of a series of lugs and tightened from one end to affix the embodiment in position.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0029] The following non-limiting detailed descriptions of examples of embodiments of the invention may refer to appended Figure drawings, but are not limited to the drawings, which are merely presented for enhancing explanations of features and aspects of the inventive technology. In addition, the detailed descriptions may refer to particular terms of art, some of which are defined herein, as appropriate and necessary for clarity.

[0030] In exemplary embodiments of the misalignment-compensating rotary bushing connection system there are generally a pair of inner cup-and-cone bushings that are nested together and are located axially side-by-side, each on a sleeve bearing that is located on either side of a center of the central pin of the connection system. A spacer is also located on the pin, between each set of inner cup-and-cone bushings. The inner cup-and-cone bushings bear on a lug (or pair of lugs) that rotates around the pin, and the inner cup-and-cone bushings (and the sleeve bearings) rotate with the lug around the pin. Accordingly, structure and surfaces are utilized to promote this motion, and to maximize slippage with respect to the pin, for the sake of efficiency. In contrast, the exemplary embodiments also have a pair of outer cone-and-cup bushings (or cup-on flared-pin-end) combinations that bear on lugs that are immobile. Thus, for these components, slippage is minimized between the pin and these components. The non-rotating components are axially separated from the rotating components by a pair of thrust bearings, thus minimizing slippage between the rotating and non-rotating components, i.e., the inner cup-and-cone bushings and the outer cup-and-cone bushings.

[0031] A first exemplary embodiment 100 of the misalignment-compensating rotary bushing connection system is shown in FIGS. 1, 2, 3, and 3A-C. The first embodiment is symmetrical about the vertical axis V. Accordingly, the description that follows may focus at times on only one side of V, but applies to the other side as well. In addition, locations closer to the vertical axis V are termed “inboard” relative to those farther from the axis V, which are termed “outboard.” The first embodiment is configured for preloaded connection of a male lug that is rotatably mounted between a first immobile lug and a second immobile lug (also called female lugs). In embodiment 100, there is a central, substantially-cylindrical pin 10 configured to fit within a bore in a series of male and female lugs, such that the central male lug only rotates about the pin. Pin 10 has a threaded hole 12 in each of its two ends 14. These threaded holes 12 are off center, in this embodiment, by a distance c, as depicted. The distance c is approximately 3 to 10% of the diameter of pin 10. The offset c permits the entire assembly 100 to be immobilized from one end to allow a fastener to be screwed into the threaded hole 12. In addition, the circumferential edges of ends 14 are chamfered, for example, at an angle of about 45 degrees or a larger or smaller angle.

[0032] As best seen in the illustrated embodiment in FIG. 3, an annular central spacer 20 is located on the pin 10. Spacer 20 has a T-shaped cross. In other embodiments, a spacer may

be omitted or have a different cross-sectional shape to accommodate the particular bore characteristics of a lug being mounted. Spacer 20 is flanked on each side by a sleeve bearing 30 that is located on the surface of pin 10 and rotates about the pin. An annular inner cone bushing 40, seen in more detail in FIG. 3A, is located on the outer surface of each of the sleeve bearings 30. Referring to FIG. 3A (showing components located on the right-hand side of FIG. 3), the inner surface 44 of cone bushing 40 is substantially cylindrical, allowing it to fit in complementary engagement onto the outer cylindrical surface of sleeve bearing 30. The outer surface 45 of the inner cone bushing 40 is frusto-conical and tapers along its axial length, from the outboard side to the inboard side. Thus, the inner cone bushing 40 has a greater thickness on one side than on the axially opposite side. The taper of cone bushing 40 is α degrees, which may vary from 5 to 25, and desirably 15 degrees, in some embodiments, but may be more or less. Inner cup bushing 50 has a substantially cylindrical outer surface 55 and an inner surface 54 having a taper complementary to that of the outer surface 45 of inner cone bushing 40. Thus, it has an inner taper of α degrees, and has a complementary counter-taper to the outer surface 55 of inner cup bushing 50, as seen in FIGS. 3A and 3B. Outer surface 55 may be equipped with grooves 52 to increase friction with the bore of a lug that is mounted to the first embodiment. During fastening, by torquing a fastener 90 at each end of the assembly, as explained later, the complementary counter-tapers of inner cone bushing 40 and inner cup bushing 50 are urged into engagement. As they are urged into engagement, the inner cone bushing is forced under the inner cup bushing, thus expanding the diameter of the inner cup bushing, which allows it to grip the bore of an attached lug. Inner cup bushing 50 may further have an expansion joint 57 for this purpose.

[0033] On the outer (outboard) sides of each of the inner cone bushings 40 and inner cup bushings 50 is a thrust bearing 15, that has a substantially annular shape and that extends around the outer circumference of pin 10. As seen more clearly in FIG. 3A, each of the pair of thrust bearings 15 has a notch 17 of depth h that runs all around one of its circular side surfaces, and that is configured and sized to avoid contact with outer cone bushing 70, thereby minimizing frictional drag on the outer cone-and-cup assembly (discussed below), which is immobile, when the inner cup-and-cone bushing assembly rotates along with sleeve bearing 30 as the male lug rotates. Thrust bearing 15 also interfaces with inner cone bushing 40, and rotates in concert with it. Accordingly, the face of thrust bearing 15 that contacts inner cone bushing 40 may be treated to increase friction and enhance grip between these two components. Annular outer cone bushing 70 is located on the outer surface of pin 10, outboard of the sleeve bearing 30 and the thrust bearing 15, and it is located on the pin's outer surface. Also, because the thrust bearing 15 only interfaces with the outer cup bearing 60, thrust loads are transmitted to the female lug through the shortest and stiffest load path, thus reducing the loads transmitted through the remainder of the outboard assembly which would tend to reduce the clamping friction of the outer cone bushing 70 in the outer cup bearing 60. The outer frusto-conical shaped cone bushing 70 is an annulus that has an inner surface 74 that is cylindrical and sized and configured to fit over the outer surface of pin 10. The inner surface 74 may be treated to increase friction between it and the pin to prevent pin 10 from rotating freely beneath the inner surface 74. As shown in more detail in FIG. 3C, the outer cone bushing 70 has a frusto-

conical taper at an angle of β , of between 5 and 25 degrees or more. The outer surface 75 is oriented with the narrow end of the taper inboard from the thicker end of the taper. As shown, the outer cone bushing 70 may include a series of axially extending slots 72, shorter than the axial length of the bushing 70, and extending through the thickness of the bushing and alternating by extending axially from one end, then from the other end of the bushing. In addition, the inner surface 74 of the bushing is offset from the outer surface and the outboard (or thicker) edge of the bushing to form a ring-shaped depression 76 that has an (axial) depth d . The depression 76, of depth d , is sized and configured to receive at least a portion of a leading end 84 of retainer cap 80. When torquing the fastener, the leading edge 84 engages within the depression 76, and the outer cone bushing is locked into place.

[0034] An annular outer cup bushing 60 is located on the outer cone bushing 70 and interfaces with the thrust bearing 15. As shown, in the example, the outer cup bushing 60 has a tapered inner surface 64 at an angle β , selected to match the taper of the outer surface 75 of the outer cone bushing 70. Thus, as in the case of inner bushings 40 and 50, the tapers are complementary and serve the same function of correcting any misalignment as they are urged into engagement by torquing fastener 90 during assembly. The outer surface 65 of outer cup bushing 60 may include a series of grooves 62, both axial and circumferential, to minimize slippage the bore of a lug. Outer cup bushing 60 may further have an expansion joint 67 to allow for it to expand in diameter and engage the bore of an attached lug.

[0035] A retainer cap 80 is fitted onto each of the ends 14 of pin 10. Referring back to FIG. 2, retainer caps 80 are substantially cylindrical and each has an internal surface 82 that is sized and configured to receive one end 14 of the pin 10. Leading edges 84 of cap 80 extend beyond edges 14 of pin 10. Thus, retainer cap 80 receives and encapsulates ends 14 of pin 10. The outer surface 85 of cap 80 includes a through bore 86 forming a connecting passage from the internal to the external side. The through bore 86 has a countersunk head 87 at the outboard end to receive the head of a fastener 90. Moreover, in the example shown, the outer surface 85 is configured to engage a tool, while the fastener 90 is being torqued, to prevent rotation of the entire assembly 100 and permit threadingly driving the fastener 90 into the threaded bore 12 of pin 10 and thereby urging all components into aligned position. Thus, for example, the outer surface 85 has a pair of spaced apart flats 88 that can be gripped by a wrench so that the retainer cap is held immobile, while the fastener 90 is driven by another tool inserted into its socket 96 so that its threaded shank 92 enters the threaded bore 12 of the pin, and the head 94 enters the countersunk portion 87. During torquing, the inner surface 84 of cap 80 functions as a compression boss urging all the components of the bushing connection system 100 axially. The urging drives the inner cone-and-cup bushings into complementary counter-tapered engagement, and the outer cone-and-cup bushings into complementary counter-tapered engagement. As the cone-and-cup bushings are urged into alignment, their external diameters increase thereby gripping the bores of the lugs that are being mounted. Torquing (and urging) is continued until the rotary bushing connection system is fully aligned and secured in place. At that stage, a locking pin 95 is inserted through a radially extending bore in cap 80 (not shown) and through a bore 98 in fastener 90, when these bores are lined up into registration with each other.

[0036] A second exemplary embodiment **200** of the misalignment-compensating rotary bushing connection system, one having only a single retainer cap, and thus allowing use in situations where both sides of the assembly cannot be reached, is shown in FIGS. 4, 5, and 6. In the second embodiment **200**, a central rotatable lug or lugs may be mounted to surfaces **255**, while immobile lugs may be mounted to surfaces **265**. The second embodiment **200** has a pin **210** that has a threaded bore **212** at only one end **214**. The pin **210** has a substantially cylindrical first section **216** and a second section **218** that is substantially frusto-conical. The second section **218** has a cross sectional diameter increasing with distance from the first section **216**. The taper angle of the outer surface γ may be from 5 to 25 degrees, and preferably 15 degrees, but may be greater or less. And, the second section **218** is separated from the first section **216** by a ledge having a radial depth r . The radial depth r , in the example shown, approximates the thickness of the sleeve bearings **230**. The outer surface of the second section **218** may be supplied with grooves **219**. The end **214** of the first section **216** has a threaded bore **212** that may be off-center by an amount c as shown. In addition, the circumferential edges at end **214** of pin **210** are chamfered, for example, at an angle of about 45 degrees, or a larger or smaller angle.

[0037] In the illustrated embodiment, an annular central spacer **220** is located on the first section **216** of pin **210**, and is located on the circumference of pin **210**. Spacer **220** is flanked on each side by an annular sleeve bearing **230** that is located on the surface of pin **210**, and is located on the circumference of pin **210**. Annular sleeve bearing **230** rotates about the pin **210**. An annular inner cone bushing **240** is located on the outer surface of each of the sleeve bearings **230**, and fits snugly on the outer surface of the sleeve bearings **230**. The inner surface **244** of cone bushing **240** is substantially cylindrical to fit tightly onto the outer cylindrical surface of sleeve bearing **230**. But, the outer surface **245** of the inner cone bushing **240** tapers from the outboard side of the annular shape to the inboard side, so that the inner cone bushing **240** has a greater thickness on one side than on the axially opposite side. The taper of cone bushing **240** is α degrees, which may vary from 5 to 25, and desirably 15 degrees, in some examples, but may be more or less. Inner cup bushing **250** is substantially annular in shape and has an inner surface **254** that has a taper complementary to that of inner cone bushing **240**. Thus, it has an inner taper of α degrees. The outer surface **245** of inner cup bushing **240** is substantially cylindrical in shape and may be equipped with axial and circumferential grooves **242** to increase friction with an attached lug. During fastening, by torqueing a fastener **290**, the complementary counter-tapers of the inner cone and inner cup bushings are urged into engagement and this engagement facilitates correcting for any misalignment by re-aligning components. Inner cup bushing **250** may further have an expansion joint **257** to allow its diameter to expand and engage the bore of an attached lug during assembly.

[0038] On each side of the inner cone bushings **240** and inner cup bushings **250** is a thrust bearing **215** that has a substantially annular shape that extends around the outer circumference of the first section **216** of pin **210**. Each thrust bearing has a notch that runs all around one of its circular side surfaces, and that is configured to avoid contact with outer cone bushing **260** or the second section **218** of pin **210**, thereby minimizing frictional drag on the outer assemblies, which are immobile, when the inner cup-and-cone bushing

assembly rotates along with sleeve bearing **230** about the pin. Thrust bearing **215** also interfaces with inner cone bushing **240**, and rotates in concert with it. Accordingly, the interface of thrust bearing **215** with inner cone bushing **240** may be treated to increase friction and enhance grip between these two components. Similarly, the interface between thrust bearings **215** and outer cup bushings **260** may be treated to reduce friction and increase slippage to reduce drag from the rotating components. Also, because the thrust bearing **215** only interfaces with the outer cup bearing **260**, thrust loads are transmitted to the female lug through the shortest and stiffest load path, thus reducing the loads transmitted through the remainder of the outboard assembly which would tend to reduce the clamping friction of the outer cone bushing **270** in the outer cup bearing **260**.

[0039] Unlike the first embodiment **100**, the second embodiment **200** only requires a single annular outer cone bearing **270** because the frusto-conical section **218** of pin **210** performs the function of a second outer cone bearing. As such, only a single outer cone bushing **270** is located on the outboard side of the thrust bearing **215** that is farthest from section **218**. Outer cone bushing **270** is located on the pin's outer surface and may be treated to maximize friction with the pin's surface to prevent the pin from sliding freely, so that an attached lug remains immobile. The outer cone bushing **270** is a frusto-conical-shaped annulus that has an inner surface **274** that is cylindrical and sized and configured to fit over the outer surface of pin **210**. The outer surface **275** of outer cone bushing **270** has a taper at an angle of β , of between 5 and 25 degrees or more. The outer surface **275** is oriented with the thicker end of the taper nearer to the end **214** of pin **210**. As shown, the outer cone bushing **270** may include a series of slots **272** extending through the thickness of the bushing and alternating by extending axially from one end, then from the other end of the bushing. The slots **272** are shorter than the axial length of the bushing **270**. In addition, the inner surface **274** of the bushing is offset from the outer surface **275** at the thicker edge of the bushing by a circumferentially extending ring-shaped depression **276** that has an (axial) depth d . The depression **276** of depth d is sized and configured to receive at least a portion of a leading end **284** of retainer cap **280**. When torqueing the fastener **290**, the leading edge **284** engages within the depression **276**.

[0040] On the side of the inner cone bushing **240** that is located farthest from end **214** of the pin, and nearest to the second section **218** of the pin, as indicated above, is a thrust bearing **215**, which is separated from the ledge that separates the first section **216** from the second section **218** of pin **210**. The second section **218** of pin **210** has an outer surface that tapers at an angle γ and it is surrounded by an annular outer cup bushing **260** that has an inner surface **264** tapered at a like angle. The outer surface **265** of the outer cup bushing **260** may be cylindrical, and may be supplied with grooves **262** to increase friction with the bore of a lug. The inner surface **264** of the outer cup bushing may also be treated to increase friction and decrease slippage. Outer cup bushing **260** may further have an expansion joint **267** to allow for it to expand in diameter and engage the bore of an attached lug.

[0041] A retainer cap **280**, like that described for the above exemplary embodiment, or one of a different design, may be fitted onto end **214** of pin **210**. During torqueing, the inner surface **284** of cap **280** functions as a compression boss urging all the components of the bushing assembly **200** axially toward the farther end of second section **218**. The urging

forces the inner cone-and-cup bushings into complementary tapered engagement, and the outer cone-and-cup bushings into complementary tapered engagement. This causes the cone-and-cup bushings' diameters to increase. Torqueing (and urging) is continued until the rotary bushing assembly is fully aligned and secured in place. At that stage, a locking pin 295 is inserted through a radially extending bore in cap 280 (not shown) and through a bore 298 in fastener 290, when these bores are lined up into registration with each other.

[0042] A third exemplary two-ended embodiment 300 of the misalignment-compensating rotary bushing connection system is illustrated in FIGS. 7 and 8. The embodiment is symmetrical about a central vertical axis V. In this exemplary embodiment of the rotary misalignment-compensation bushing connection system 300, a central pin 310 passes through a first outer lug A, and a second outer lug B, as well as a central lug C, that is equipped with a bearing 330, in this example shown as a spherical bearing. The exemplary embodiment compensates for any misalignment and provides appropriate alignment between the three lugs, A, B and C. Lugs A and B are immobile relative to the pin, while lug C moves about the pin. The central cylindrical pin 310 has a pair of ends 314, that each has a chamfered circumferential edge, and a threaded off-center hole 312 for receiving a threaded shank of a fastener 390. The bearing 330 is centered along the axis of pin 310 and is flanked by annular spacers 320 located on the pin 310. Each of the spacers 320 is in turn flanked on the outboard side by an axially-tapered annular cone bushing 370. The cone bushings 370 have tapered exterior surfaces. Interior surfaces of the cone bushings 370 may be treated to increase friction and prevent slippage with the surface of the pin such that the pin rotates in concert with the attached lugs A and B. The cone bushings 370 are oriented with the thicker end of the taper inboard. The thicker end has a circumferentially extending notch 372 that is configured and sized to receive a portion of spacer 320 when the bushing connection system is assembled, but is able to slip over the surface of spacer 320. An annular cup bushing 360 is located on each of the cone bushings 370. The cup bushings 360 have interior surfaces that are tapered at a counter-taper to that of the outer surfaces of the cone bushings 370. During torqueing of the fastener 390, as in other embodiments described above, the surface 384 of cap 380 functions as a compression boss urging all the components of the bushing assembly 300 axially together such that the complimentary counter-tapers of the cone and cup bushings 360 and 370 become engaged and thereby correct for any component misalignment. The cup bushing (similar to the above described outer cup bushings) may have an expansion joint to allow its diameter to expand during assembly and thereby urge against the bore of an attached lug. The angle of taper α of the bushings may range from 5 to 25, and desirably 15 degrees, but may be more or less. The outer surface 365 of each cup bushing 360 may be provided with grooves 362, depicted as axial and radial grooves in this example. A pair of outer spacers 326 are located outboard of each of the cup bearings 360. These annular spacers 326 have an inner diameter less than that of the compression boss 384, but greater than that of pin 310 such that it does not interface with cone bearing 370. As such, the spacer 326 is sized and configured to receive the leading edge 384 of the retainer cap 380, when the assembly 300 is urged together by torqueing the fastener 390, and to transfer forces axially along the assembly of components.

[0043] A retainer cap 380, like that described for the above exemplary embodiment, or one of a different design, may be fitted onto ends 314 of pin 310. During torqueing, the inner surfaces 384 of caps 380 function as a compression boss urging all the components of the bushing assembly 300 axially toward the axis V. As explained above, the retainer cap 380 may be gripped by a wrench or other tool at opposed flats 388 such that a fastener 390 can be threaded into end hole 312 and the head 394 of the fastener is drawn into the countersunk bore 387 of the retainer cap. The offset c in the threaded bore 312 permits the bushing assembly 300 to be immobilized in such a manner. Torqueing (and urging) is continued until the rotary bushing assembly 300 is fully aligned and secure in place. At that stage, a locking pin 395 is inserted through a radially extending bore in cap 380 (not shown) and through a bore 398 in fastener 390, when these bores are lined up into registration with each other.

[0044] A fourth exemplary embodiment 400 of the misalignment-compensating rotary bushing connection system is illustrated in FIGS. 9, 10, and 11A-11E. Reference to "inboard" and "outboard" with regard to this embodiment refers to proximity to the spacer 420.

[0045] The fourth embodiment 400 compensates for any misalignment and provides appropriate alignment between the three lugs, A, B and C. Lugs A and B are immobile with respect to pin 410, while lug C rotates about pin 410. The central pin 410 has a first section 416 and a second section 418. Section 416 is cylindrical, and section 418 is frusto-conical, tapered at an angle β , with a larger diameter end being outboard. At the intersection of the first and second sections 416 and 418 is a ledge of radial depth l . As a result of the depth l of the ledge, thrust bearing 415 avoids contact with pin 410 at that point, as explained later. At the opposite end to end 415 of pin 410, there is a central boss 414 of smaller diameter than pin section 416, and that has external threading. In this embodiment, the central boss 414 of the pin extends farther out than the peripheral ends 412 of the pin. However, in alternate embodiments, the peripheral ends 412 may extend beyond the central boss 414 or to the same length as the central boss 414. The threaded boss 414 is used in assembling the connection system, as explained here below.

[0046] Approximately at the axial center of the exemplary embodiment is a spacer 420. The spacer is flanked by a pair of sleeve bearings 430 that are located on the pin 410 and that rotate about the pin.

[0047] An annular inner cone bushing 440 is located on the outer surface of each of the sleeve bearings 430, and moves with the sleeve bearing. The inner surface of cone bushing 440 is substantially cylindrical allowing it to fit in complementary engagement onto the outer cylindrical surface of sleeve bearing 430, such that the two move in concert. The outer surface of the inner cone bushing 440 is frusto-conical and tapers along its axial length, from one side to the other side. Thus, the inner cone bushing 440 has a greater thickness on one side than on the axially opposite side. Inner cone bushing 440 has a taper of α degrees, which may vary from 5 to 25, and desirably 15 degrees, in some examples, but may be more or less. Inner cup bushing 450 has a cylindrical outer surface 455 and an inner surface having a taper complementary to that of the outer surface of inner cone bushing 440. Thus, it has an inner taper of α degrees. Outer surface 455 may be equipped with grooves 452 to minimize slippage across the surface. During assembly, as explained later, the complementary counter-tapers of inner cone bushing 440 and

inner cup bushing **450** are urged into engagement and the outer diameter expands and urges against the bore of attached lug C. Thereby, this engagement facilitates correcting for any misalignment by re-aligning components.

[0048] On each of the outboard sides of the inner cone bushings **440** is a thrust bearing **415**, that has a substantially annular shape and that extends around the outer circumference of the first section **416** of pin **410**. Each thrust bearing has a notch that runs all around one of its circular side surfaces, and that is configured and sized to receive therein a tapered end of an outer cone bushing **470**, and such that a smooth outboard face of the bearing slides against outer cup bushings **460** and **460'**.

[0049] An annular frusto-conical outer cone bushing **470** is located on the outer surface of the first section **416** of pin **410**, and has an inner surface that may maximize friction and prevent slippage with the pin. The outer cone bushing **470** has an inner surface that is cylindrical and sized and configured to fit onto the outer surface of pin **410**. The outer surface of outer cone bushing **470** has a taper at an angle of β , of between 5 and 25 degrees, desirably 15 degrees, but may be more or less. The outer surface **475** is oriented with the thicker end of the taper outboard. The outer cone bushing **470** may include a series of slots extending through the thickness of the bushing and alternating by extending axially from one end, then from the other end of the bushing. The slots are shorter than the axial length of the bushing.

[0050] An annular outer cup bushing **460** is located on the outer cone bushing **470**. The outer cup bushing **460** has a cylindrical outer surface **450** and an inner surface that tapers at an angle α that is complementary to the outer surface taper of outer cone bushing **470**. The outer cup bushing **460** may have an expansion joint to permit its diameter to expand during assembly.

[0051] Another annular outer cup bushing **460'** is located on the outer surface of section **418** of the pin **410**. The outer surface of pin section **418** may be grooved, and is tapered at an angle α . The inner surface of outer cup bushing **460'** matches that taper angle such that the two surfaces are in complementary engagement when the cup bushing **460'** is located on the pin section **418**. Taper angle β may vary from 5 to 25 degrees, desirably 15 degrees, but may be more or less. The outer surface **465'** of the cup bushing **460'** may be provided with grooves **462'**, as illustrated, to minimize slippage with an attached lug. The outer cup bushing **460'** may have an expansion joint to permit its diameter to expand during assembly.

[0052] FIGS. 11A-11E illustrate in more detail the steps of assembling the fourth embodiment **400**, in particular assembly of retainer cap **480**. First, inboard components are located onto pin **410** starting with the outer cup bushing **460'** and ending with outer cup bushing **460** and outer cone bushing **470** as shown in FIG. 10). These inboard components have been omitted from FIGS. 11A-E for clarity. Next, a cotter pin **495** is inserted into a bore **490** in the central boss **414** of pin **410** as shown by the arrow in FIG. 11A. The ends of the cotter pin **495** are bent at a 90 degree angle as shown in FIG. 11B by the arrows. Alternatively, the inboard components may be located onto the pin after the cotter pin has been bent. Next, a retainer cap **480** having an inner-threaded, central-through hole is threaded onto the central boss **414** of pin **410** (see FIG. 11C). The pair of ends of the cotter pin **495** extends outward through the central hole in retainer cap **380**.

[0053] During assembly, the retainer cap **480** is initially partially-threaded onto the boss **414** as is explained in more detail below. This can be done by hand. Then, the untightened, misalignment-compensation system **400** may be inserted into lugs A, B, and C. Then retainer cap **480** may be fully tightened by inserting a fastening tool into socket **498** of central boss **414** of the pin to torque pin **410** while retainer cap **480** may be gripped immovably using a tool (e.g., a spanner wrench) that inserts into holes **482** (see FIG. 11D). Alternatively, pin **410** may be gripped immovably while retainer cap **480** is torqued. During this torquing, the peripheral inner surface **486** of the retainer cap **480** acts as a compression boss to push axially against outer cone bushing **470** (see FIG. 10). This axial pushing urges the complementary tapers of the assembled cone-and-cup bushings into alignment, which cause their exterior diameters to expand and urge against the bores of the lugs A, B, and C. Once embodiment has been torqued such that the assembly is complete, the ends of cotter pin **495** are bent backward at 90 degrees to fit within any pair of opposed slots **487** on the exterior surface of retainer cap **480** as shown by the arrow in FIG. 11E. Thus, retainer cap **480**, which is threaded to central boss **414** of the pin, is secured and neither can rotate independently of the other. That is, retainer cap **480** is threaded to pin **410** and cannot be removed from the pin without first straightening the ends of cotter pin **495** and unthreading retainer cap **480**.

[0054] FIGS. 12A-12D depict an exemplary method for assembling an exemplary embodiment **800** of the rotary misalignment-compensation bushing connection system. Exemplary embodiment **800** depicted in FIGS. 12A-12D is substantially identical to the second embodiment **200** disclosed above. A fastening tool **850** is inserted into socket **825** of exemplary embodiment **800** and is used to partially fasten the exemplary embodiment (see FIG. 12A). In this position, the components of exemplary embodiment **800** are loosely engaged and have their smallest exterior diameter. It is clear that the largest diameter of embodiment **800** (when not fully-fastened) must be less than the smallest bore of the lugs when the exemplary embodiment **800** is being inserted. Next, the partially-tightened embodiment **800** is inserted into a series of lugs, A, B, and C, as illustrated in FIG. 12B. Once embodiment **800** is approximately in place, it may be fully-torqued from one side using a fastening tool **850** to torque the socket **825** while another tool (e.g., a wrench) engages the pair of spaced flats **827** of the retainer cap of the exemplary embodiment **800** (see FIG. 12C). Alternatively, in lieu of partially-tightening and inserting, the pin of embodiment **800** may first be inserted into the bore of the lugs, then the components may be placed on to the pin, and then the embodiment may be fully-tightened. Because the threaded hole of the pin of exemplary embodiment **800** is offset from center by a distance c (see FIG. 2), the pin may be rotationally immobilized by immobilizing the retainer cap using a tool as shown in FIG. 12C. As exemplary embodiment **800** is torqued, small errors in the alignment of the lugs (even up to $1/8^{th}$ inches in assemblies with pin diameters up to 4 inches, and more in larger sizes) are corrected as the various components are urged into their proper locations. During torquing of the socket, the components of exemplary embodiment **800** are urged together and the diameter of the embodiment **800** expands slightly, as axial components are brought into overlapping alignment and complementary tapers are engaged. This radial expansion is sufficient for the appropriate surfaces of embodiment **800** to engage the surfaces of the bores of the lugs and

prevent the exemplary embodiment and the lugs from disengaging. Finally, a locking pin **895** may be inserted to lock the embodiment (see FIG. **12D**). Similarly, the other embodiments of the rotary misalignment-compensation bushing connection system disclosed and claimed herein may be assembled and engaged as is apparent to one of ordinary skill in the art.

[0055] While examples of embodiments of the rotary misalignment-compensation bushing connection system have been presented and described in text and, in some examples, also by way of illustration, it will be appreciated that various changes and modifications may be made in the described rotary misalignment-compensation bushing connection system and its components without departing from the scope of the invention, which is set forth in, and only limited by, the scope of the appended patent claims, as properly interpreted and construed.

1. A rotary misalignment-compensation bushing connection system for preloaded connection of a male lug rotatably mounted between a first lug and a second lug, the bushing connection system comprising:

- a substantially cylindrical pin having opposed first and second ends, the pin configured to fit within an orifice in each of the first and second lugs and the male lug, such that the male lug rotates about the pin;
- a first axial threaded hole in the first end of the pin;
- a center spacer located substantially centered on the pin in a non-interfering fit;
- a pair of sleeve bearings, one each being located on the pin on each side of the center spacer;
- the sleeve bearings being located on the pin;
- an inner cone bushing located on each sleeve bearing in interference fit;
- an inner cup bushing located on each inner cone bushing;
- a pair of thrust bearings located on the pin, on an end of the bushing opposite to the center spacer;
- an outer cone bushing located on and surrounding the pin, the outer cone bushing adjacent to one of the thrust bearings;
- an outer cup bushing located on top of and surrounding the outer cone bushing;
- the center spacer being axially preloaded between the inner cup bushings;
- the thrust bearings being rotatable and axially preloaded against an outer cup bushing;
- a retainer cap having an internal side and an external side, and a connecting passage from the internal to the external side;
- the internal side having a compression boss engageable with the outer cone, and a relief receivable of the first end of the pin having the threaded hole; and,
- the external side configured to engage a fastening tool, and having a radial slot or bore receivable of a locking pin.

2. The bushing connection system of claim **1**, wherein the outer cup bushing is located at a portion of the pin closest to the first end.

3. The bushing connection system of claim **1**, wherein the pin comprises a first portion and a second portion, the second portion is substantially frusto-conical in shape, with cone diameter increasing with distance from the first portion, the second portion separated from the first portion by a ledge having a radial depth.

4. The bushing connection system of claim **3**, wherein an outer thrust bearing is located adjacent the ledge and adjacent one of the pair of sleeve bearings farthest from the first end of the pin.

5. The bushing connection system of claim **4**, further comprising an outer cone bushing located on the second end of the pin.

6. The bushing connection system of claim **1**, wherein the external side of the cap includes a countersink for receiving the head of a fastener.

7. The bushing connection system of claim **1**, wherein the relief on the external side of the retainer cap is further configured for gripping with a tool other than the fastening tool.

8. The bushing connection system of claim **1**, further comprising grooves on outer surfaces of any one or more of the inner cone bushing, the inner cup bushing, the outer cone bushing and the outer cup bushing.

9. The bushing connection system of claim **1**, further comprising slots extending axially through a thickness of the outer cone bushing, and extending from opposite ends of the outer cone bushing, the slots shorter than an axial length of the outer cone bushing.

10. The bushing connection system of claim **1**, wherein the inner cup bushing and the inner cone bushing have a first complementary counter-taper, and wherein the outer cup bushing and the outer cone bushing have a second complementary counter-taper, such that when the connection system is assembled, and tightened with a fastening tool, the first and second complementary tapers permit sliding engagement and alignment of the bushing connection system to compensate for misalignment.

11. The bushing connection system of claim **1**, comprising a second threaded hole in the second end of the pin.

12. The bushing connection system of claim **11**, further comprising a second outer cone bushing located on the pin, the second outer cone bushing adjacent to a thrust bearing; and a second outer cup bushing located on top of each outer cone bushing, the second outer cone bushing and the second outer cup bushing adjacent to the second end of the pin.

13. The bushing connection system of claim **11**, further comprising a second retainer cap having an internal side and an external side, and a connecting passage from the internal to the external side, the internal side of the cap having a compression boss, and a relief receivable of the second end of the pin, the external side of the cap configured to engage a fastening tool, and having a radial slot or bore receivable of a locking pin.

14. The bushing connection system of claim **11**, further comprising grooves on outer surfaces of any one or more of the inner cone bushing, the inner cup bushing, the outer cone bushing, and the outer cup bushing.

15. The bushing connection system of claim **11**, further comprising slots extending axially through a thickness of the outer cone bushing, and extending from opposite ends of the outer cone bushing, the slots shorter than an axial length of the outer cone bushing.

16. The bushing connection system of claim **11**, wherein the relief on the external side of the retainer cap is further configured for gripping with a tool other than the fastening tool.

17. The bushing connection system of claim **11**, wherein the inner cup bushing and the inner cone bushing have a first complementary counter-taper, and wherein the outer cup bushing and the outer cone bushing have a second comple-

mentary counter-taper, such that when the connection system is assembled, and tightened with a fastening tool, the first and second complementary tapers permit sliding engagement and alignment of the bushing connection system to compensate for misalignment.

18. The misalignment-compensation bushing connection system of claim **11**, wherein the external side of the cap includes a countersink for receiving the head of a fastener.

19. The misalignment-compensation bushing connection system of claim **1**, wherein the first threaded hole is offset from the center of the first end of the pin.

20. The misalignment-compensation bushing connection system of claim **11**, wherein the first and second threaded holes are off-set from centers of their respective ends of the pin.

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