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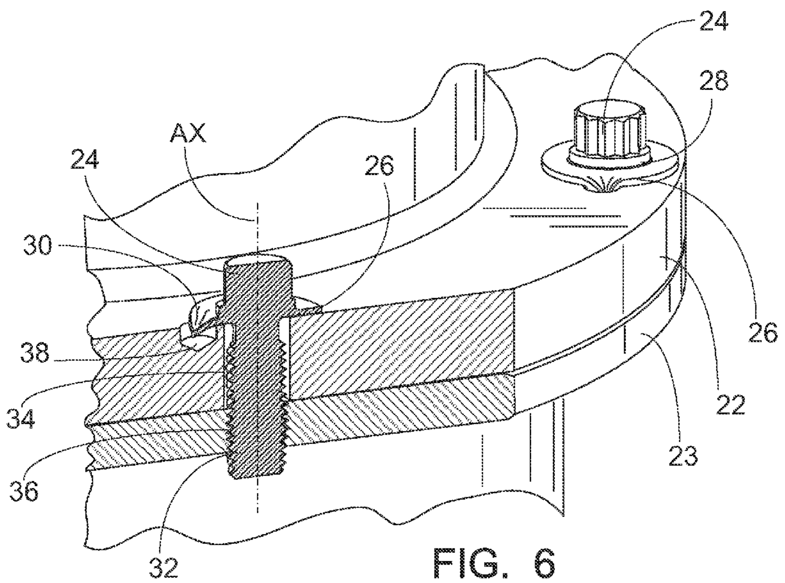

FIG. 6

(57) Abstract: A threaded fastener includes a head, a threaded shank extending from a bottom face of the head along a longitudinal axis of the fastener, and an annular flange oriented transverse to the longitudinal axis and surrounding the bottom face of the head. A surface has a receiving hole in which the shank of the threaded fastener is disposed with the bottom face of the head contacting the surface. The surface further has a crimping recess spaced apart from the receiving hole. A portion of the annular flange overlaps and is deformed into the crimping recess. The fastener may be a screw or bolt. In the case of a bolt, a nut engages the distal end of the threaded shank. The nut also includes an annular flange that is deformed into a crimping recess on a surface proximate to the nut.

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LOCKING FASTENER FOR SECURING COMPONENTS IN A NUCLEAR REACTOR

[0001] This application claims the benefit of U.S. Provisional Application No. 61/635,054 filed April 18, 2012. U.S. Provisional Application No. 61/635,054 filed April 18, 2012 is incorporated herein by reference in its entirety.

BACKGROUND

[0001] The following relates to the fastener arts, nuclear reactor arts, nuclear power generation arts, nuclear fuel arts, and related arts.

[0002] In environments such as nuclear reactors, ultra-high vacuum (UHV) processing systems, and the like, installed components are not readily accessible. In such environments, a threaded fastener that works itself loose over time due to exposure to chronic vibration, thermal cycling, or other environmental factors presents a serious difficulty. Numerous fastener locking schemes are known for preventing a threaded fastener from working itself out. Some fastener locking schemes include additional locking hardware, such as a locking washer, cotter pin, lock wire, locking cup or lock plate to secure the fastener. Other fastener locking schemes require specialized modification of the surface of the flange or other component secured by the fastener. For example, some locking schemes rely on friction or deformation of the mating surfaces for the locking action while others require a modified opening (e.g., counter-sinked well) into which the fastener head is crimped to lock the fastener. Lock washers, pins, castellated nuts, and lock wire are problematic for securing components inside a nuclear reactor as these components are subjected to long term exposure (e.g., on the order of decades) to flow induced vibration, seismic loads, etc. Loosening or failure of a single fastener in an operating nuclear reactor can require reactor shutdown and unscheduled maintenance.

[0003] Similarly, in a UHV system, pump down to operating pressures of around 10^{-9} Torr or lower typically employs applying a sequence of different pumps (e.g., mechanical, cryogenic, diffusion, ion pumps) in a prescribed sequence over a period of days or weeks. A single fastener failure can require opening the UHV system and consequent unscheduled downtime for pump down on the order of weeks.

[0004] The following discloses improved locked fastener arrangements and fastening methods.

SUMMARY

[0005] In one embodiment, an apparatus comprises: a threaded fastener including a head shaped to engage a driving tool, a threaded shank extending from a bottom face of the head along a longitudinal axis of the fastener, and an annular flange oriented transverse to the longitudinal axis of the fastener and surrounding the bottom face of the head; and a proximate surface having a receiving hole in which the shank of the threaded fastener is disposed with the bottom face of the head contacting the proximate surface, the proximate surface further having a crimping recess spaced apart from the receiving hole, a portion of the annular flange overlapping the crimping recess being deformed into the crimping recess. In some embodiments the apparatus further includes a proximate member defining the proximate surface, the receiving hole being a through-hole passing through the proximate member, the shank of the threaded fastener passing through the receiving hole; and a distal member having a hole through which the shank of the threaded fastener also at least partially passes. In some such embodiments the hole in the distal member is a tapped hole and the threaded fastener is a screw whose threaded shank engages with threading of the tapped hole. In some such embodiments the hole in the distal member is a through-hole, the threaded fastener is a bolt, and the apparatus further comprises a nut engaging with an end of the threaded shank of the bolt that protrudes out of the through-hole in the distal member, the nut including an annular flange oriented transverse to the longitudinal axis of the bolt and deformed into a crimping recess on a surface of the distal member contacting the nut.

[0006] In accordance with another aspect, a method comprises installing a threaded shank of a threaded fastener in a receiving hole formed in a proximate surface, and locking the installed threaded fastener by deforming a portion of a flange of the threaded fastener that overlaps a crimping recess formed in the proximate surface into the crimping recess. In some such embodiments the flange of the threaded fastener is an annular flange and a portion of the annular flange overlaps the crimping recess for any angular position of the installed threaded fastener.

[0007] In accordance with another aspect, an apparatus comprises: a bolt including a bolt head and a threaded shank extending from a bottom face of the bolt head along a longitudinal axis of the bolt; first and second members each having a through-hole through which the threaded shaft of the bolt passes, the bolt head being in contact with the first member and a distal end of the threaded shank protruding out of the through-hole of the second member; and a nut threaded onto the distal end of the threaded shank protruding out of the through-hole of the second member such that the bolt and nut form a bolt-and-nut fastener combination securing the first and second members together; wherein the bolt is locked to the first member and the nut is locked to the second member. In some such embodiments the bolt and the nut each have an annular flange, the annular flange of the bolt being deformed into a crimping recess formed in the first member and the annular flange of the nut being deformed into a crimping recess formed in the second member.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The invention may take form in various components and arrangements of components, and in various process operations and arrangements of process operations. The drawings are only for purposes of illustrating preferred embodiments and are not to be construed as limiting the invention.

[0009] FIGURES 1 and 2 diagrammatically show perspective and perspective partial sectional views, respectively, of an illustrative nuclear reactor of the pressurized water reactor (PWR) variety with internal steam generators (integral PWR).

[0010] FIGURE 3 is a perspective view of a control rod drive mechanism (CRDM) standoff and support plate suitably used in the reactor of FIGURES 1 and 2.

[0011] FIGURE 4 is a perspective view of a portion of a CRDM mounted on the standoff and support plate of FIGURE 3.

[0012] FIGURE 5 is perspective view of a flanged connection suitably used for the CRDM/standoff coupling of FIGURE 4.

[0013] FIGURE 6 is a cut-away view of one of the fasteners of the flanged connection of FIGURE 5.

[0014] FIGURE 7 is a view of the crimping hole and receiving hole of FIGURE 5 with the fastener omitted.

[0015] FIGURES 8 and 9 show side and perspective views, respectively of a screw including a deformable flange for use in locked fastener approaches disclosed herein.

[0016] FIGURE 10 is a detail of the head of the fastener of FIGURES 8 and 9.

[0017] FIGURES 11-13 show alternative perspective views of a nut including a deformable flange for use in locked fastener approaches disclosed herein.

[0018] FIGURE 14 is a perspective view of a bolt including a deformable flange for use in combination with the nut of FIGURES 11-13 in locked fastener approaches disclosed herein.

[0019] FIGURE 15 is a perspective view of the nut of FIGURES 11-13 installed on the threaded end of the bolt of FIGURE 14 in accordance with locked fastener approaches disclosed herein.

[0020] FIGURE 16 diagrammatically shows suitable positions of a receiving hole, a crimping hole and a flange for use in locked fastener approaches disclosed herein.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0021] With reference to FIGURES 1 and 2, an illustrative nuclear reactor **1** of the pressurized water reactor (PWR) variety is shown. The illustrative PWR **1** employs internal steam generators **2** (see FIGURE 2) located inside the pressure vessel (i.e., integral PWR **1**), but embodiments with the steam generators located outside the pressure vessel (i.e., a PWR with external steam generators) are also contemplated. The illustrative PWR **1** includes an integral pressurizer **4**, but a separate external pressurizer may instead be employed. Fuel rods comprising fissile material (e.g., containing ^{235}U) make up the nuclear reactor core **6** seen in FIGURE 2. The illustrative PWR includes internal control rod drive mechanisms (internal CRDMs) **7**; however, external CRDMs are also contemplated. Circulation of primary coolant in the illustrative PWR **1** is upward through the reactor core **6** and through a central riser **8** (i.e., the “hot leg”), and back down to below the reactor core **6** via a downcomer annulus defined between the central riser **8** and the pressure vessel (i.e., the “cold leg”). The primary coolant circulation is assisted or driven by reactor coolant pumps (RCPs) **9** which are externally mounted near the pressurizer **4** in the illustrative PWR **1**, but which may be more generally located elsewhere, or may be canned internal RCPs located inside the pressure vessel. It is also contemplated to omit the RCPs entirely and to rely upon natural circulation of primary coolant driven by heating from the reactor core.

[0022] The PWR of FIGURES 1 and 2 include numerous components internal to the pressure vessel of the PWR that may be fastened using threaded fasteners (e.g., screws engaging threaded blind holes or threaded through-holes; nut/bolt combinations secured in through-holes, threaded rods, or so forth). Such components may include, for example: fasteners securing control rod guide frames; fasteners securing internal CRDMs **7**, fasteners securing internal canned pumps; and so forth. Such components, including the fasteners, should be reliable against failure for long periods, e.g. on the order of years or decades in some cases. Additionally, the PWR may include components mounted at vessel penetrations using threaded fasteners, such as the RCPs **9**. These fasteners also should be reliable to avoid primary coolant leakage requiring reactor shutdown and unscheduled maintenance. It will also be understood that the PWR of FIGURES 1 and 2 is merely an illustrative example. Similar considerations apply to fasteners employed in nuclear reactors of other types, such as boiling water reactor (BWR) designs, as well as in other applications such as ultra-high vacuum (UHV) systems where fastener reliability is desirable. For illustrative purposes, the locked fasteners and fastening methods disclosed herein are described with illustrative reference to securing the CRDMs **7** inside the reactor vessel.

[0023] FIGURE 3 shows an illustrative support plate **12** to which a CRDM is to be mounted via a standoff **14**. The standoff **14** has mounting flange **16** with an upper surface to which the CRDM is to mount. The flange **16** has holes (two of which are labeled **17)** for mounting the CRDM. Threaded fasteners are also used to secure the bottom flange of the standoff **14** to the support plate **12**.

[0024] FIGURE 4 illustrates the lower portion of a CRDM **18** including a stepper motor **19** for precisely adjusting the control rod position respective to the reactor core **6** (i.e., “gray rod” control). The CRDM **18** is suitably of a type having a separate scram mechanism **20** located above the motor **19** as described in U.S. Pub. No. 2011/0222640 A1 filed March 12, 2010 and U.S. Pub. No. 2010-0316177 A1 filed March 12, 2010, both of which are incorporated herein by reference in their entireties; alternatively, the CRDM can employ a motor with separable ball nut, or can be a dedicated shutdown rod, or can have some other suitable configuration. The lower end of the CRDM **18** is mounted to the standoff **14** via the upper flange **16.** Further illustrative holes are provided in a flange connecting the scram mechanism **20** with the motor **19**. It will be noted that these connections involve a blind hole in the casing of the CRDM motor **19**. Accordingly, a suitable threaded fastening arrangement is for the blind hole to be threaded and to employ a screw to secure flange **16** to the casing of the motor **19**, and similarly for the connection of the scram mechanism **20** to the motor casing. Similarly, if the mounting surface is “thinner”, e.g. a flange or plate (possibly support plate 14 of FIGURE 3), then the threaded hole with which the screw engages may be a through-hole rather than a blind hole.

[0025] With reference to FIGURES 5-10, a suitable locked fastener embodiment employing a screw engaging a threaded through-hole is illustrated and described. It will be appreciated that the through-hole can be replaced by a blind hole deep enough to receive the screw, e.g. as in the illustrative cases of FIGURE 4. In the example of FIGURES 5-7, the application is securing two flanges **22**, **23** using a screw **25** having a head **24**. The flange closest to the head **24** is referred to herein as the proximate flange **22**, while the flange furthest from the head **24** is referred to herein as the distal flange.

[0026] FIGURE 5 illustrates screws (one of which is labeled **25)** with twelve-point heads **24**. The screws **25** secure upper (i.e., proximate) flange **22** and lower (i.e. distal) flange **23**, which is a typical application. Each screw head **24** has a deformable flange **26** that rests on the top (i.e., proximate) surface of the proximate flange **22** when the screw **25** is fully inserted, and a portion of the annular flange **26** is crimped to lock the screw head **24** in place, preventing the screw **25** from backing out (i.e., loosening). The annular flange **26** of the screw head **24** has an integral stiffening ring **28** machined (or otherwise manufactured) just below the twelve-point screw head **24.** The stiffening ring **28** is located around the circumference of the head **24** at a junction between the head **24** and the annular flange **26**, and reduces the likelihood of a crack generated during the deformation of the flange **26** propagating into the head **24**. However, the thickness and lateral extent of the annular flange **26**, and the deformation force applied, are designed to make the formation of such a crack an unlikely event, and so the stiffening ring **28** is optionally omitted. In the illustrative embodiment, the lower (i.e., distal) flange **23** includes a through-hole and the shank of the screw **25** is long enough to extend completely through the hole in the lower flange **23**, as shown by the slightly visible shank **32** in FIGURE 5. Again, however, it is to be understood that the screw **25** may alternatively engage a blind hole, or as another variant the distal flange **23** can have a through-hole as shown but the screw **25** may be too short to extend all the way through the distal through-hole.

[0027] Although two flanges **22**, **23** are shown, the screw **25** may be used to attach other types of structural members, such as connecting the standoff **14** with the support plate **12** (see FIGURE 3).

[0028] The screw **25** is installed in the usual way, i.e. by threading it into the receiving threaded hole (which may be a blind hole or through-hole). After threading the screw into the hole, the annular flange **26** is crimped into a hole in the flange that is spaced apart from the receiving threaded hole to form a crimp region **30**. The crimp region **30** acts as a lock to prevent the screw **25** from backing out (i.e., loosening). The force for the crimp is applied axially, that is, parallel to the axis of the screw or bolt, and orthogonally to the direction of rotation of the screw **25**. Because the force is applied axially, the risk of loss of preload of the fastener is lessened. The axial crimping of each fastener into a crimping recess or hole eliminates the need for a separate locking piece. The crimp prevents rotation and backing out (i.e., loosening) of the fastener.

[0029] A twelve-point head is shown in FIGURES 5-10, but the crimp lock will work with a variety of fastener heads, such as but not limited to twelve- or eight-point heads, hex heads, Phillips or flat-heads, allen heads, or star (Torx™) heads. While a screw is shown in FIGURES 5-10, the deformable flange and crimp can be used with a screw, bolt, nut, threaded shaft, or other threaded fastener. In the case of a nut, the deformable flange is suitably on the nut itself (see FIGURES 11-13 and related discussion).

[0030] FIGURE 6 shows a cross-section through one of the screws **25** and its annular flange **26** with deformation or crimp **30**. The screw **25** has the head **24** and a threaded shank **32** extending from a bottom face of the head **24** along a longitudinal axis **AX** of the fastener **25**. The annular flange **26** is oriented transverse to the longitudinal axis **AX** of the fastener **25** and surrounds the bottom face of the head **24**. The shank **32** passes through a through-hole **34** in the proximate flange **22** (that is, the flange closest to the head **24**) and that passes at least partway into (and in the illustrative example all the way through) an opening or hole **36** in the distal flange **23** (that is, the flange furthest away from the head **24**). In cutaway, it can be seen that the hole **34** in the upper flange **22** is unthreaded and the hole **36** in the lower flange **23** is threaded (tapped). The distal opening or hole **36** is threaded (i.e., tapped) to engage threading on the shank **32** of the screw **25**. When securing two flanges **22**, **23** together using screw **25**, the hole or opening **34** in the proximate flange **22** is a through-hole so that the shank **32** can pass completely through and into the hole or opening **36** in the distal flange **23**. The distal hole or opening **36** is tapped and may be a through-hole (as shown), or a blind hole.

[0031] The crimp **30** is a deformation of the annular flange **26** of the screw head **24** into a crimping hole or recess **38** formed in the proximate surface **39** of the proximate flange **22** (i.e., in the surface **39** contacting the head **24** of the inserted screw **25**). Laterally, the crimping recess **38** is located on the proximate surface **39** “next to” the opening **34** into which the screw **25** is inserted. More precisely, the lateral location of the crimping recess **38** can be specified as follows: When the screw **25** is installed in the openings **34**, **36**, the outside diameter of the flange **26** is centered on crimping recess **38**. The centering need not be perfect, but should be close enough so that a portion of the recess **38** is covered by the flange **26**. This ensures that there is a portion of the annular flange **26** that overlaps the crimping recess **38** and hence can be crimped into the recess **38** to form the crimp **30**.

[0032] Additionally, it is preferable to have the lateral location of the crimping recess **38** far enough away from the opening **34** so that a portion of the recess **38** remains visible when the screw **25** is fully inserted into the openings **34**, **36**. The visible portion of the crimping recess **38** serves as an alignment aid for aligning the awl or other instrument used to form the crimp **30**. This alignment aspect may be less important if a robotic apparatus is employed to install the screw **25** and form the crimp **30**. However, having a portion of the crimping recess **38** remain uncovered by the annular flange **26** also makes the crimping easier by providing a mechanical guide for centering the awl or punch, and the resulting crimp **30** expected to be more reliable as compared with a crimp formed with the annular flange **26** completely overlapping the crimping recess **38**. As seen in FIGURES 5 and 6, when a portion of the crimping recess **38** remains uncovered by the annular flange **26**, the resulting crimp **30** is a wedge-shaped deformation of the free edge (i.e., the outer periphery) of the annular flange **26**. In contrast, if the crimping recess is completely covered by the annular flange then the resulting crimp is a "dimple" formed in the interior of the annular flange. Deforming the free edge of the annular flange **26**, as in the example of FIGURES 5 and 6, is easier than punching a dimple into the interior of the flange, and the latter operation is more likely to puncture the flange and/or to generate stress-induced cracking of the flange.

[0033] In general, the crimp **30** should be a plastic deformation of the annular flange **26**, but the crimping operation should not induce cracking or puncturing of the flange **26**. Cracking or puncturing of the flange can produce particulates that can contaminate the primary coolant flowing through the nuclear reactor, and/or sharp edges that can abrade neighboring components or injure maintenance personnel, and crack propagation from the flange **26** can, in extreme cases, damage the screw head **24**. (Again, the integral stiffening ring **28** helps to reduce the possibility of a crack propagating into the head **24**).

[0034] In general, the rotation of the screw **25** during installation stops when the screw head **24** comes into contact with the proximate surface **39** of the proximate flange **22**. Alternatively, the distal hole in the distal flange **23** can serve as an insertion stop, either through a finite depth in the case of a blind hole, or by terminating the tap, tapering the hole, or so forth. In any of these stopping mechanisms, it is difficult or impossible to predict the angular position of the rotating screw **25** at the point of complete insertion. However, because the annular flange **26** has continuous rotational symmetry, the angular position of the rotating screw **25** at the point of complete insertion does not affect the subsequent crimping operation.

[0035] The crimped region **30** of the deformable flange **26** is crimped into crimping recess **38**. In the embodiment of FIGURE 6, the crimping recess **38** is a blind hole; however, the crimping recess can also be a through-hole. Moreover, the crimping recess **38** can have a shape other than that of a round hole, although sharp geometries (e.g., a square hole) may have a disadvantage in increasing the likelihood of cracking or puncturing the flange **26** during crimping.

[0036] FIGURE 7 shows the arrangement for the receiving hole **34** and crimping recess **38** on the proximate surface **39**. The arrangement consists of the main screw hole **34** with a (typically though not necessarily) smaller crimping recess **38** off to the side. In some embodiments, the crimping recess **38** may be machined completely through the flange (i.e., a through-hole). The illustration shows only a single crimping recess **38** for each receiving hole **34**; however, two, three, four, or more crimping recesses may be provided to provide multiple crimps for more locking force. A symmetric arrangement of two, three, or more crimping recesses around the receiving hole may be advantageous to ensure symmetry of the fastening.

[0037] In general, the closer the crimping recess **38** is to the receiving hole **34,** the smaller the diameter of the annular flange **26** of the screw head **24** can be made. A smaller-diameter annular flange increases manufacturing part yield (since the relatively thin deformable flange **26** is a likely feature to be damaged during manufacturing or transport) and footprint of the locked fastener. In one contemplated embodiment having the geometry of FIGURE 7, the edge break for the main screw hole **34** is limited to .005 inch maximum thereby allowing the crimping hole to be located closer to the main screw hole. As a result, the diameter of the deformable flange **26** of the fastener can be minimized. The depth of crimp **30** should be sufficient to provide the desired locking force, but a deeper crimp increases the likelihood of cracking or puncturing of the flange **26**. In some embodiments having the geometry of FIGURES 5-7, the crimp depth is specified to be 2.5 times the thickness of the flange. For example, in one contemplated embodiment the thickness of the flange **26** away from the head **24** (that is, the portion of the flange **26** to be crimped) is nominally.025-inch thick which allows for a significant crimp that will prevent loosening of the fastener. Ductile material, such as 316 Stainless Steel, is used for the fastener **25** to reduce the likelihood of cracking during the crimping process. In some embodiments a crimp depth of about 2.5 times the flange thickness is contemplated (e.g., about 0.06 inch crimp depth for a flange thickness of 0.025 inch). For a given screw size and a given specified locking force (e.g., measured by the breakaway torque needed to overcome the crimp **30** and back out the screw **25**), test runs for flanges of different thickness and for different crimping forces can be performed to optimize the annular flange **26** and the crimping operation to maximize yield and minimize or eliminate cracking or puncturing.

[0038] FIGURES 8-10 are details of the screw **25**. The illustrative screw **25** incorporates fillets into the head design. As best seen in FIGURE 10, the screw shank **32** is undercut at **40** to allow for a fillet **42** under the screw head **24**. This, along with the integral stiffening ring **28**, helps to reduce the possibility of a crack propagating into the head **24** and to improve fatigue capability in service. By undercutting the screw shank **32**, the fillet **42** under the screw head **24** clears the small edge break on the hole.

[0039] In the locked fastener approaches disclosed, the modification to the proximate surface **39** (i.e., the mounting surface contacting the head **24** of the fastener **25**) is modified only in the formation of the crimping recess **38**, which can be a blind hole or a through-hole. Since this surface **39** is already being machined or otherwise processed to form the receiving hole **34**, the additional machining or processing is not different in kind from that already performed on the flange **22**. Indeed, the proximate surface **39** can be a planar surface with no countersunk features. In contrast, formation of a countersunk feature into which a fastener is crimped to lock the fastener may entail an additional or different countersink machining operation. The annular flange **26** is an integral part of the screw **25**, and thus does not constitute an additional part that can be lost (as compared with a locking washer or the like which is an additional component). If the screw **25** is a die-cast component then the annular flange **26** is straightforwardly incorporated into the die. Another advantage is that the crimp **30** is readily observable during assembled component inspection prior to final installation and close-up of the reactor vessel (or UHV chamber or other restricted-access location).

[0040] The locking strength is also readily tailored to specific situations. For example, a single crimping recess **38** can be used in most applications, but for components or environments that experience particularly aggressive vibrations, thermal cycling, or so forth additional crimping recesses can be added to the surface **39** to allow for additional crimps to provide greater locking strength.

[0041] The crimping operation employs axial force, in the direction of the fastener axis, which is unlikely to release any preload, as no torque is being applied in the rotational direction of the fastener **25** during crimping. The locked fastening process can be performed manually, e.g. using an awl, punch (e.g., spherical punch), or other handheld instrument to crimp the flange **26** into the crimping recess **38** to form the crimp **30**. Alternatively, the locked fastening process can be automated, e.g. being performed using a robotic apparatus employing a rotary drive tool to install the screw **25** and an axial punch tool to form the crimp **30**. Robotic processing can employ a virtual part model (e.g. CAD model) to identify the location of the crimping recess **38**. Alternatively, a machine vision sub-system can be employed to identify the crimping recess **38** partially covered by the annular flange

26 after the screw is threaded in. Other automated processing techniques can also be employed.

[0042] The illustrative example of FIGURES 5-10 pertains to a threaded fastener in the form of the illustrative screw **25**. More generally, the disclosed locking approach is applicable to substantially any type of threaded fastener. With reference to FIGURES 11-15, an example of a bolt-and-nut threaded fastener combination is described. The illustrative nut (FIGURES 11-13) employs a hex-head, while the illustrative bolt (FIGURE 14) employs a twelve-point head. In the bolt-and-nut threaded fastener combination, the bolt threads into the nut, or viewed in the alternative the nut threads onto the bolt. Consequentially, it is possible for the bolt to back out of the nut, or for the nut to back off of the bolt. To lock against both possibilities, both the nut and the bolt include the disclosed annular flange deformed into a crimping recess.

[0043] With reference to FIGURES 11-13, a nut **46** is shown in isolation. The nut **46** includes a “head” **47** and an annular flange **48**. (The term “head” is not normally used in conjunction with a nut, but as used herein the head is the part of the threaded fastener that is engaged by a ratchet or other tool used to rotate the fastener or to hold the fastener against rotation during installation.) FIGURE 11 shows the face of the nut **46** which contacts with the fastened component or member. This face includes the annular flange **48** that serves the same function (and optionally has the same thickness, ductility, and composition) as the annular flange **26** of the screw **25** of FIGURES 8-10. In the embodiment shown, the engagement face of the nut **46** (FIGURE 11) is smooth, but it is contemplated that the face may be serrated or scalloped to better grip the surface of the fastened component. The deformable flange **48** extends around the circumference of the face of the nut which contacts with a member to be fastened. As best seen in FIGURE 13, the head **47** of the illustrative nut **46** is a hex head; however, a twelve-point head or other type of head can also be used. The nut **46** has a stiffening ring **49** at the base of the head **47** which is analogous in shape and function to the stiffening ring **28** at the base of the head **24** of the screw **25**.

[0044] FIGURE 14 shows a shoulder bolt **52** with twelve-point head **24**, which is compatible with the nut **46** of FIGURES 11-13. The bolt **52** includes the same head **24** with annular flange **26** as the screw **25** of FIGURES 8-10. However, the threaded shank **32** of the screw **25** is replaced in the bolt **52** by a threaded shank **54**

with threading **56** at a distal end of the shank **54**. The threading **56** is sized and shaped to engage the threads of the nut **46**. Alternatively, the threading can extend further up the shank or even all the way up to the head **24**, optionally with space left for a fillet as in the screw **25** of FIGURES 8-10. The bolt **52** has the head **24** and the threaded shank **54** extending from a bottom face of the head **24** along longitudinal axis **AX** of the bolt **52**. The annular flange **26** is oriented transverse to the longitudinal axis **AX** of the bolt **52** and surrounds the bottom face of the head **24**.

[0045] FIGURE 15 shows a typical installation of nuts **46** onto the distal ends **56** of bolts **52**. In FIGURE 15, the nuts **46** contact a proximate surface **60** which is proximate to the heads **47** of the nuts **46**. (The surface **60** is distal from the bolt heads). The surface **60** includes a crimping recess **62** corresponding to each receiving hole that receives a bolt-and-nut combination. The portion of the annular flange **48** of the nut **46** overlapping the crimping recess **62** is deformed into the recess **62** to form crimp **64**.

[0046] The crimp **64** locks the nut **46** against rotation. However, this, by itself, is not sufficient to prevent the bolt **52** from backing out of the nut **46**. Although not shown, on the opposite side of the assembly of FIGURE 15, where the head **24** of the bolt **52** is located, the annular flange **26** of the bolt **52** is similarly crimped into a crimping recess to lock the bolt against rotation. (Not shown for bolt **52**, but analogous to the crimp **30** of the flange **26** shown for the screw **25** in FIGURES 5-6). By crimping both the flange **48** of the nut **46** and the flange **26** of the bolt **52**, both backing of the bolt out of the nut and backing of the nut off the bolt are prevented, thus providing locking of the bolt-and-nut fastener combination. Note that for the bolt-and-nut fastener combination, the flange (or other element) that serves as the proximate flange for the nut is the distal flange for the bolt, and the flange (or other element) that serves as the proximate flange for the bolt is the distal flange for the nut.

[0047] The use of hex nuts and twelve-point bolts in the example of FIGURES 11-15 is merely illustrative, and various head combinations (e.g., twelve-point bolts and twelve-point nuts; twelve-point bolts and hex nuts as illustrated; hex-head bolts and twelve-point nuts; hex nuts and hex-head bolts; various other types of heads; and so forth) are contemplated.

[0048] FIGURE 16 diagrammatically shows the relationship between receiving hole **34**, crimping recess **38** (which may be a blind hole or a through hole), and the circumference **54** of the deformable flange (shown in outline by a dashed line). FIGURE 16 is an overhead diagram of upper (i.e., proximate) flange **22** of FIGURES 5-7. The radius of the deformable flange is labeled **F**. The radius of the receiving hole **34** is labeled R. The radius of the crimping hole **38** is labeled **S**. The distance from the center of the receiving hole **34** to the center of the crimping hole **38** is labeled **X**. (In other words, **X** is the center-to-center separation between the crimping hole **38** and the receiving hole **34**). The shortest distance (along a line connecting the centers) from the edge of the receiving hole **34** to the edge of the crimping hole **38** is labeled **Y**. It is contemplated that the crimping hole **38** and receiving hole **34** could overlap, meaning that **Y** is zero, but, in the embodiment shown, **Y** has a positive value**.** Given that the radii **R** and **S** are the distances from the centers of their respective circles to their edges, and **Y** is the distance between the edges of the circles, X=R+Y+S.

[0049] The deformable flange radius **F** must be at least greater than **R**, or the fastener would not have any surface mating with the top member to be fastened (e.g. the upper flange **22**)**.** In order for the deformable flange to overlap the crimping hole **38,** the deformable flange radius **F** must also extend farther than the separation **Y** (plus the radius **R**) between the receiving hole **34** and the crimping hole **38**. That is, **F** must be greater than R+Y. If the deformable flange circumference **54** passes through the exact center of the crimping hole **38**, then **F** will equal X, that is: F=X=R+Y+S. In the embodiment shown, F is slightly greater the X, mainly for illustration.

[0050] If the radius of the deformable flange extends farther than the crimping hole **38** (i.e., F>X+S), then the flange completely covers the crimping recess. In this case, the crimp is a punch into the interior of the flange. As previously pointed out, such a crimp is difficult to form manually due to inability to see where to crimp, but could be done robotically, albeit requiring more force than a crimp where the deformable flange is not supported by the upper flange around the entire circumference of the crimping hole. A manual crimp could also be performed if, for example, markings indicating the position of the crimping hole are provided on the proximate surface, or a special alignment tool is employed.

[0051] In embodiments in which the deformable flange only partially covers crimping hole **38** (e.g., as in FIGURE 16), it follows that F is less than X+S and F is greater than X-S. In other words, (X-S)<F<(X+S). (In an alternative formulation, F is between R+Y and R+Y+2×S. As mentioned above, it is contemplated that other shapes besides a circle may be used, in which the preferred flange width could be based on a circle which circumscribes the shape of the crimping recess.

[0052] The preferred embodiments have been illustrated and described. Obviously, modifications and alterations will occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

CLAIMS

We Claim:

1. An apparatus comprising:

a threaded fastener including a head shaped to engage a driving tool, a threaded shank extending from a bottom face of the head along a longitudinal axis of the fastener, and an annular flange oriented transverse to the longitudinal axis of the fastener and surrounding the bottom face of the head; and

a proximate surface having a receiving hole in which the shank of the threaded fastener is disposed with the bottom face of the head contacting the proximate surface, the proximate surface further having a crimping recess spaced apart from the receiving hole, a portion of the annular flange overlapping the crimping recess being deformed into the crimping recess.

2. The apparatus of claim 1 wherein the annular flange does not completely overlap the crimping recess.

3. The apparatus of claim 1 wherein a portion of the edge of the annular flange is deformed into the crimping recess.

4. The apparatus of claim 1 wherein the annular flange has a circular perimeter of radius F where $(X-S)<F<(X+S)$ and X is the center-to-center separation between the receiving hole and a circle of radius S circumscribing the crimping recess.

5. The apparatus of claim 4 wherein the crimping recess is circular with radius S.

6. The apparatus of claim 1 wherein the annular flange has a circular perimeter with radius equal to the center-to-center separation between the receiving hole and the crimping recess.

7. The apparatus of claim 1 further comprising:

a proximate member defining the proximate surface, the receiving hole being a through-hole passing through the proximate member, the shank of the threaded fastener passing through the receiving hole; and

a distal member having a hole through which the shank of the threaded fastener also at least partially passes.

8. The apparatus of claim 7 wherein the hole in the distal member is a tapped hole and the threaded fastener is a screw whose threaded shank engages with threading of the tapped hole.

9. The apparatus of claim 8 wherein the tapped hole in the distal member is one of a tapped blind hole and a tapped through-hole.

10. The apparatus of claim 7 wherein the hole in the distal member is a through-hole, the threaded fastener is a bolt, and the apparatus further comprises:

a nut engaging with an end of the threaded shank of the bolt that protrudes out of the through-hole in the distal member, the nut including an annular flange oriented transverse to the longitudinal axis of the bolt and deformed into a crimping recess on a surface of the distal member contacting the nut.

11. The apparatus of claim 7 wherein one of the proximate and distal members is a control rod drive mechanism (CRDM).

12. The apparatus of claim 1 wherein the fastener further includes a stiffening ring around the circumference of the head at a junction between the head and the annular flange.

13. The apparatus of claim 1 wherein the head of the fastener is one of a hex head, an eight-point head, a twelve-point head, a Phillips head, an allen head, and a star head.

14. The apparatus of claim 1 wherein the proximate surface is a planar surface with no countersunk features.

15. The apparatus of claim 1 wherein the crimping recess is one of a blind hole and a through-hole.

16. The apparatus of claim 1 further comprising:

a nuclear reactor including a nuclear reactor core comprising fissile material and a pressure vessel containing the nuclear reactor core, the threaded fastener, and the proximate surface.

17. A method comprising:

installing a threaded shank of a threaded fastener in a receiving hole formed in a proximate surface; and

locking the installed threaded fastener by deforming a portion of a flange of the threaded fastener that overlaps a crimping recess formed in the proximate surface into the crimping recess.

18. The method of claim 17, wherein the flange of the threaded fastener is an annular flange and a portion of the annular flange overlaps the crimping recess for any angular position of the installed threaded fastener

19. The method of claim 18, wherein the installing and the locking do not include aligning a rotational position of the installed threaded fastener with the crimping recess.

20. The method of claim 18, wherein the annular flange does not completely overlap the crimping recess and the locking includes deforming a portion of the edge of the annular flange that overlaps the crimping recess into the crimping recess.

21. The method of claim 18, wherein the deforming comprises applying an axial force oriented parallel with the shank of the installed threaded fastener.

22. The method of claim 17 wherein the threaded fastener is a bolt and the installing includes engaging a nut onto a distal end of the bolt, and the method further comprises:

locking the nut by deforming a portion of a flange of the nut that overlaps a crimping recess formed in the surface contacted by the nut into the crimping recess formed in the surface contacted by the nut.

23. An apparatus comprising:

a bolt including a bolt head and a threaded shank extending from a bottom face of the bolt head along a longitudinal axis of the bolt;

first and second members each having a through-hole through which the threaded shaft of the bolt passes, the bolt head being in contact with the first member and a distal end of the threaded shank protruding out of the through-hole of the second member; and

a nut threaded onto the distal end of the threaded shank protruding out of the through-hole of the second member such that the bolt and nut form a bolt-and-nut fastener combination securing the first and second members together;

wherein the bolt is locked to the first member and the nut is locked to the second member.

24. The apparatus of claim 23 wherein the bolt and the nut each have an annular flange, the annular flange of the bolt being deformed into a crimping recess formed in the first member and the annular flange of the nut being deformed into a crimping recess formed in the second member.

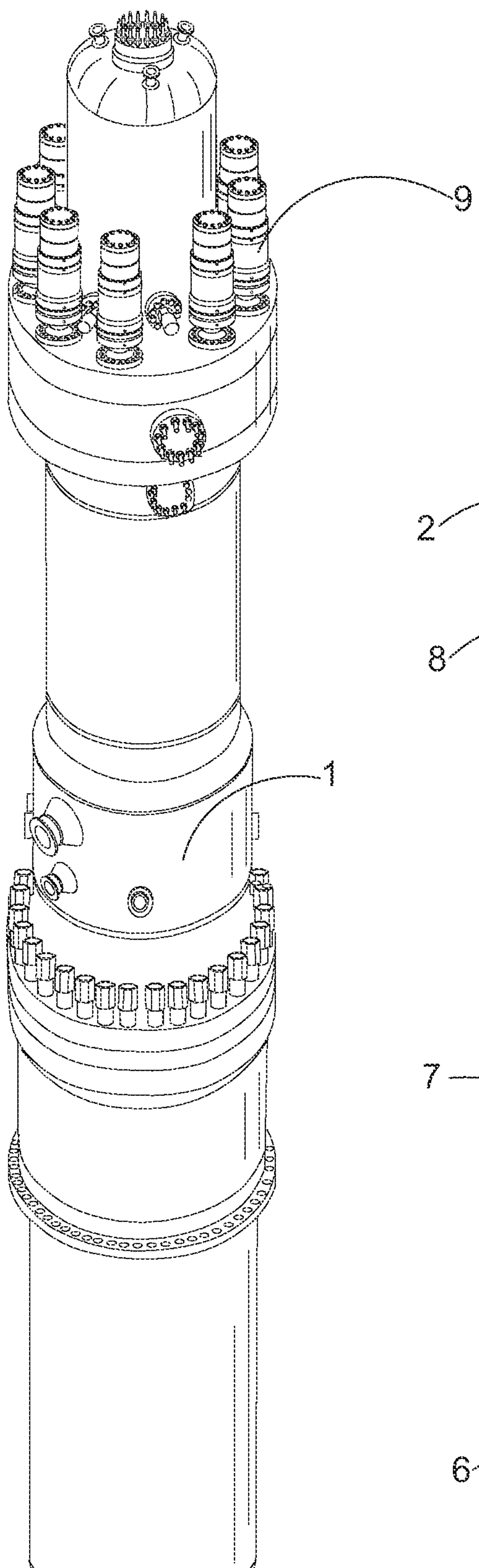

FIG. 1

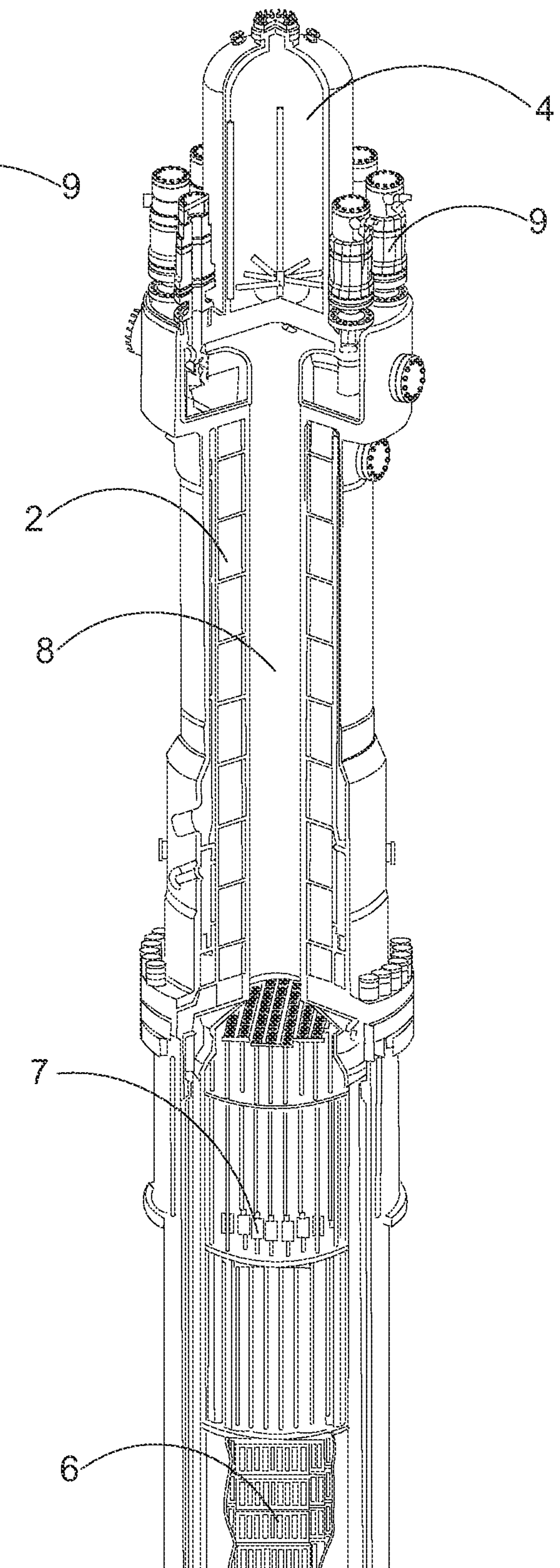

FIG. 2

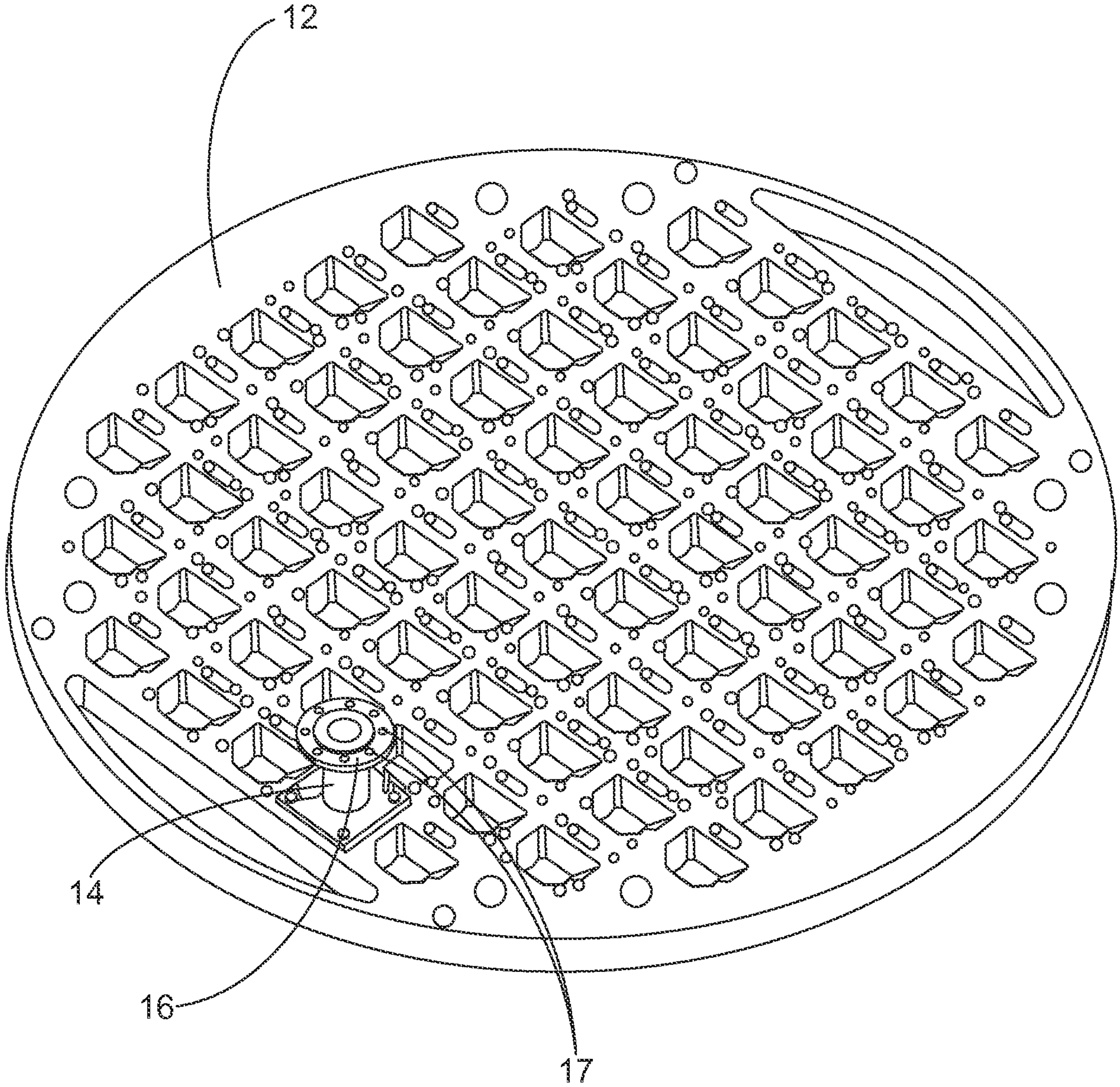

FIG. 3

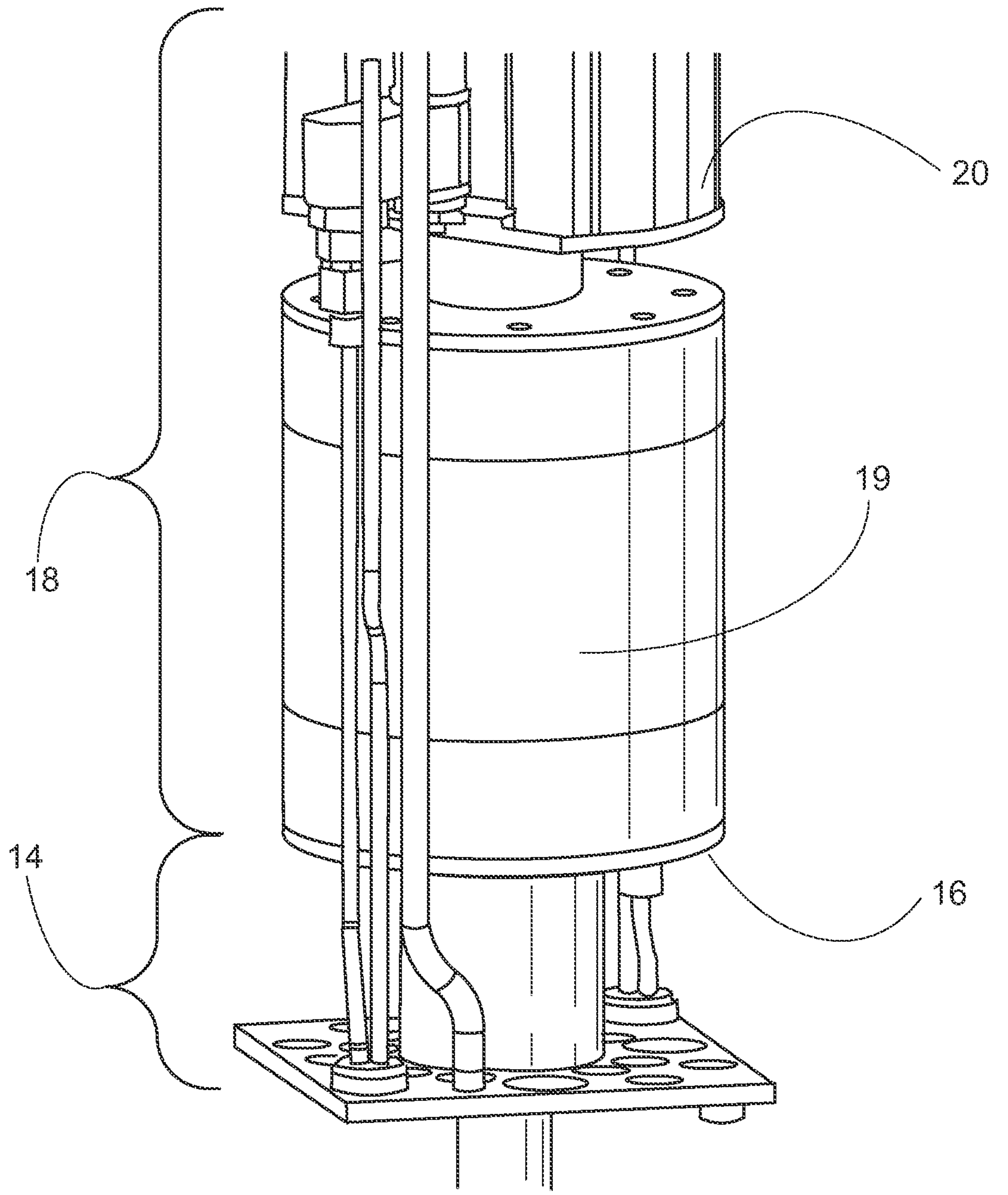

FIG. 4

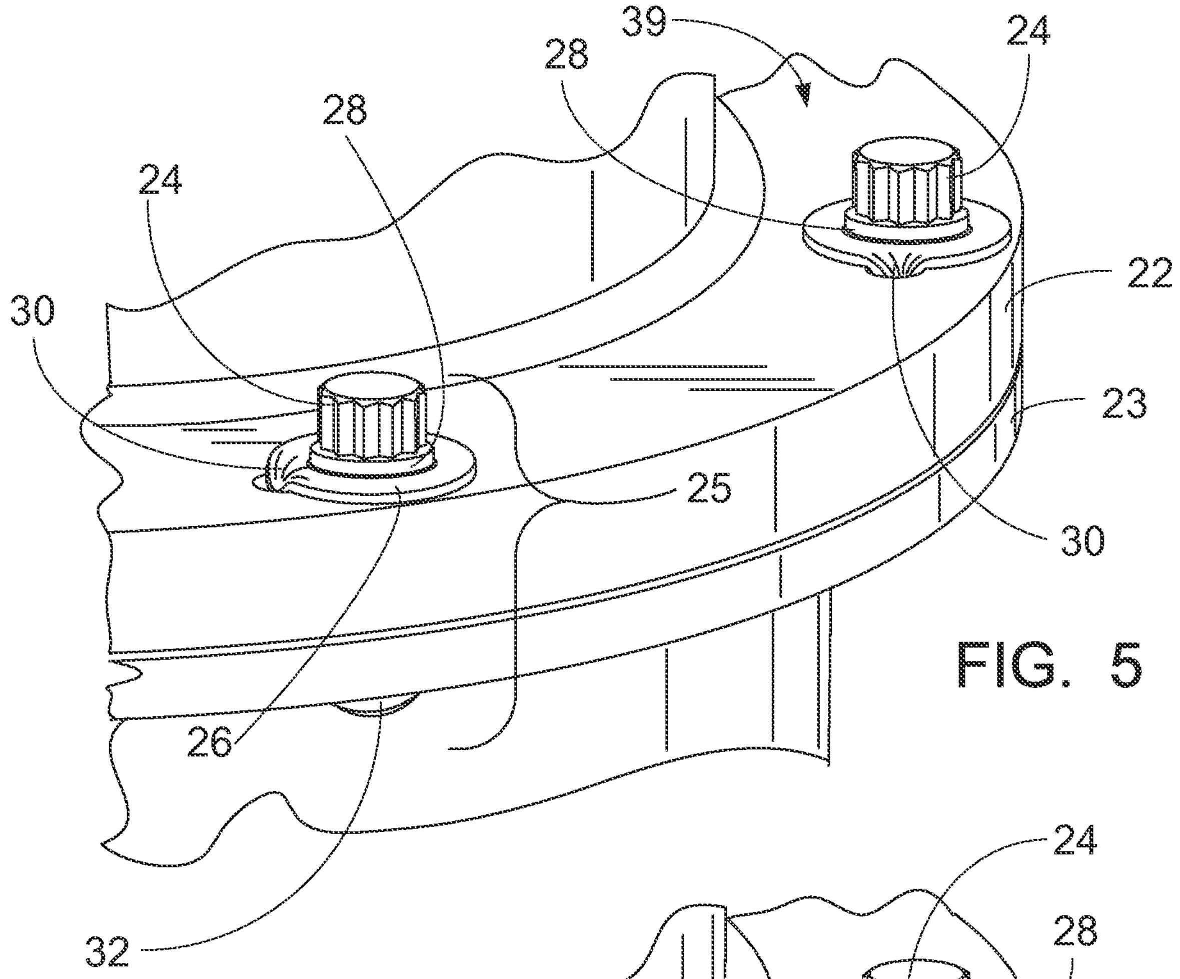
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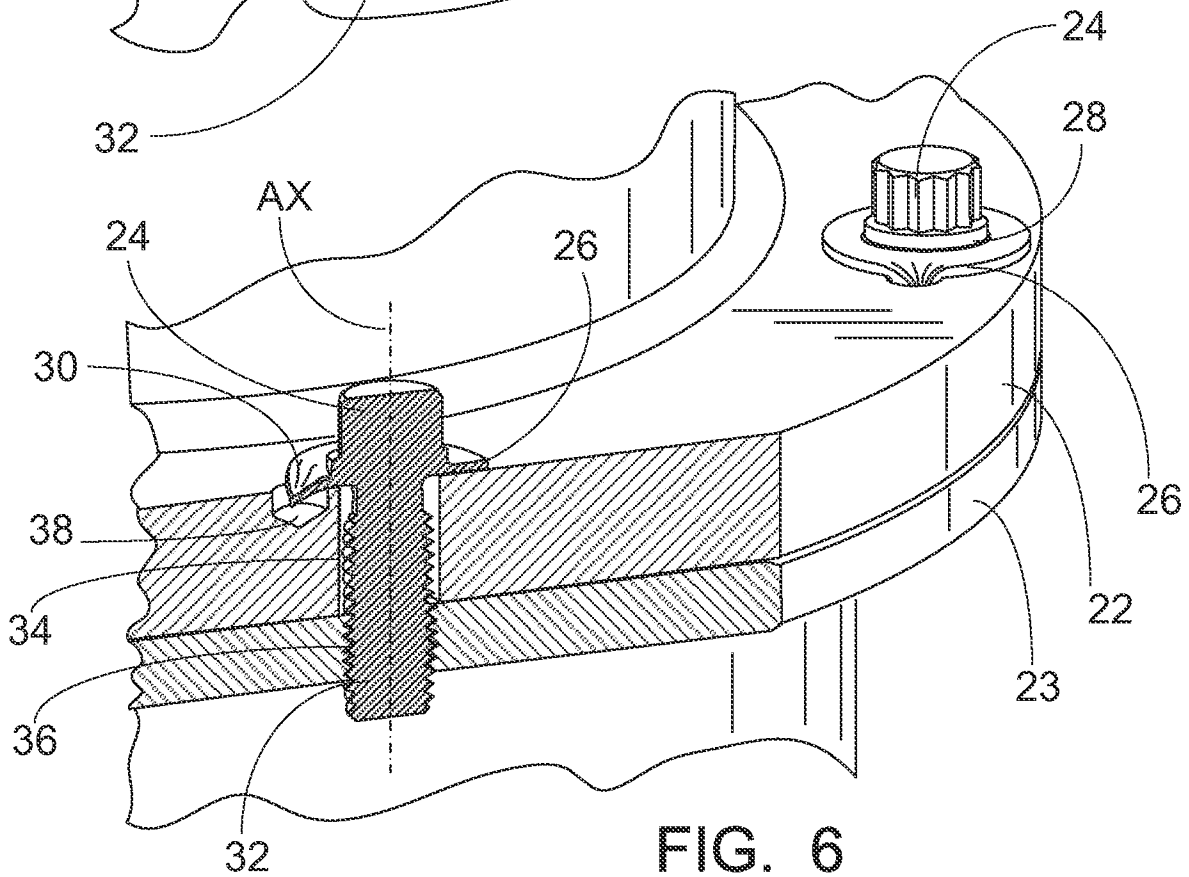
FIG. 5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AX
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22
23

FIG. 6

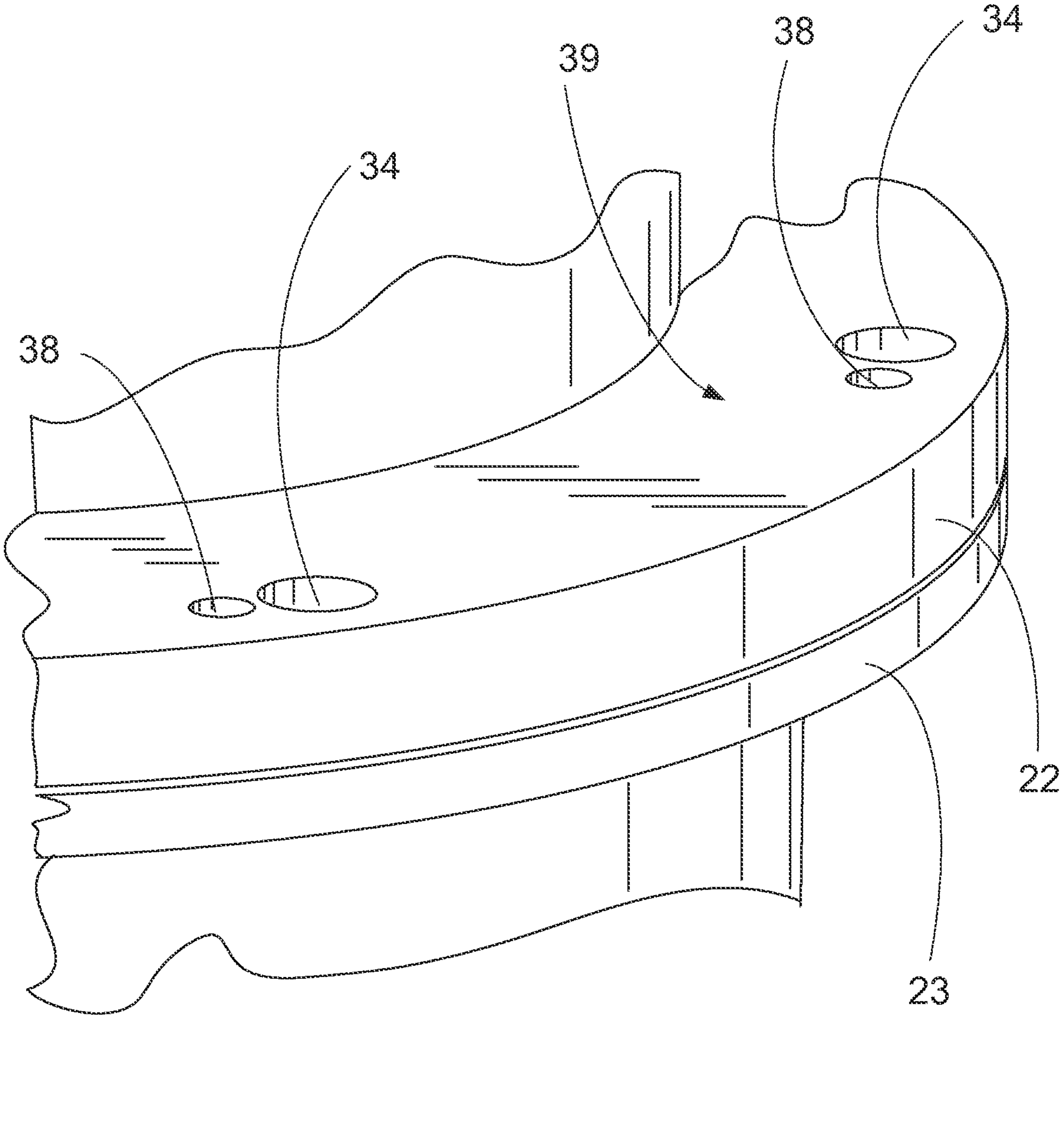

FIG. 7

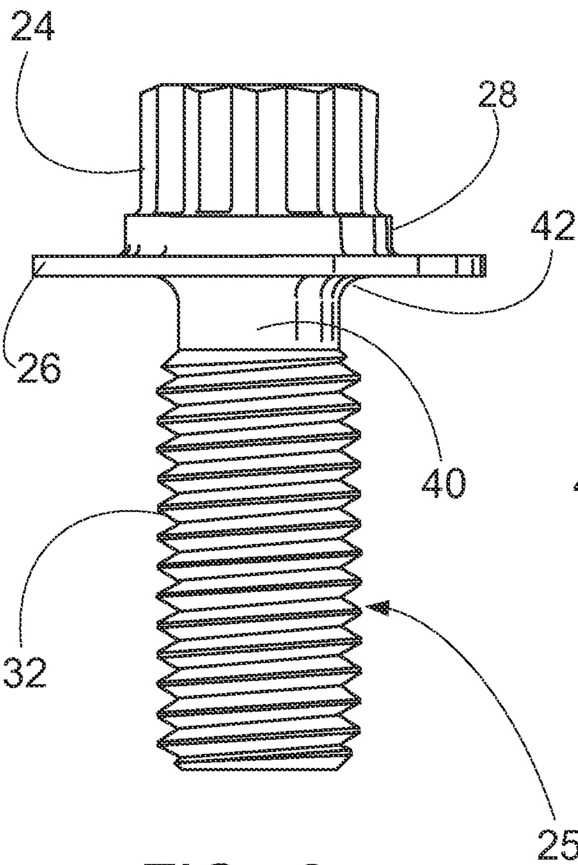

FIG. 8

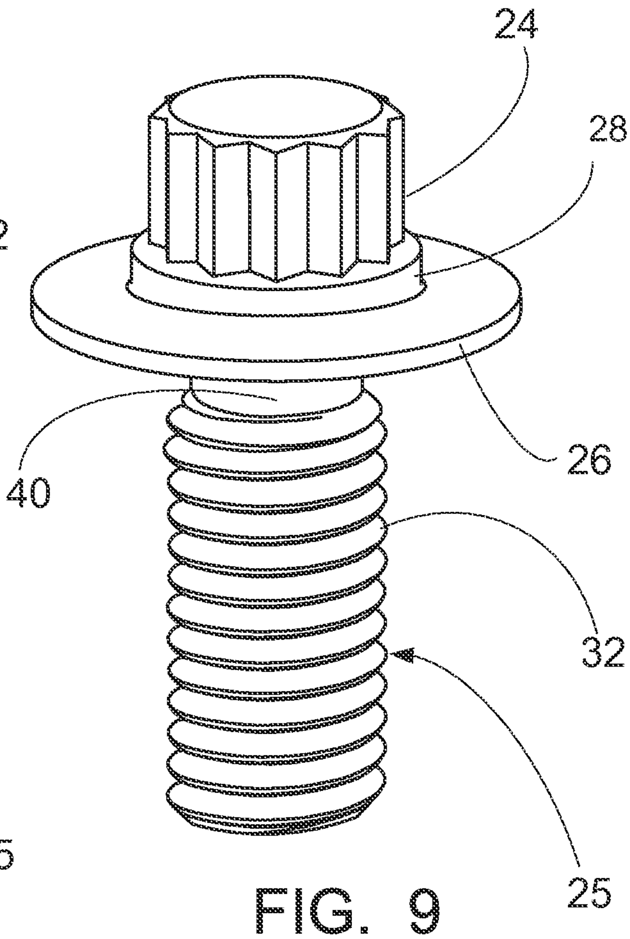

FIG. 9

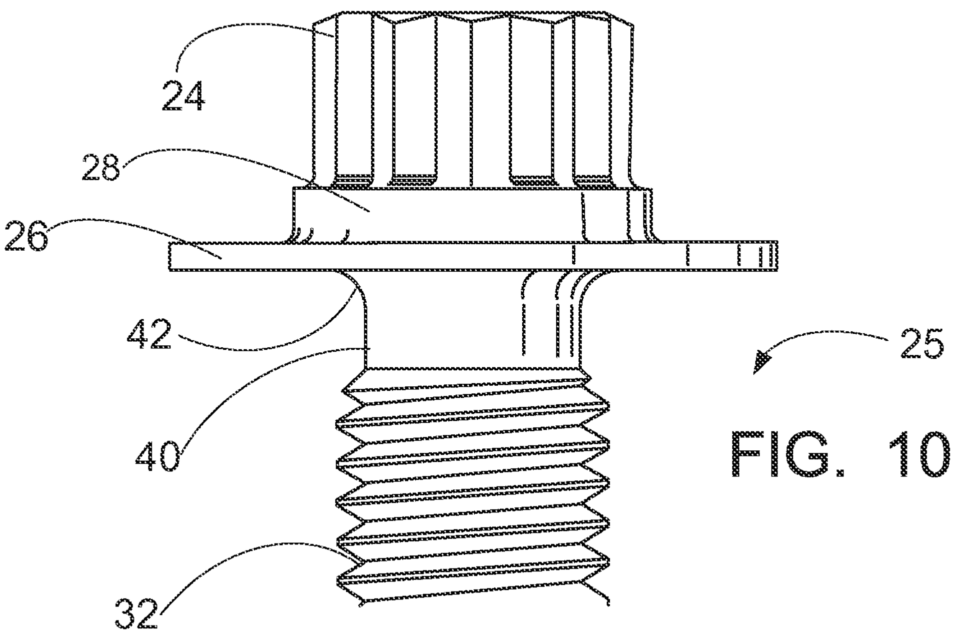

FIG. 10

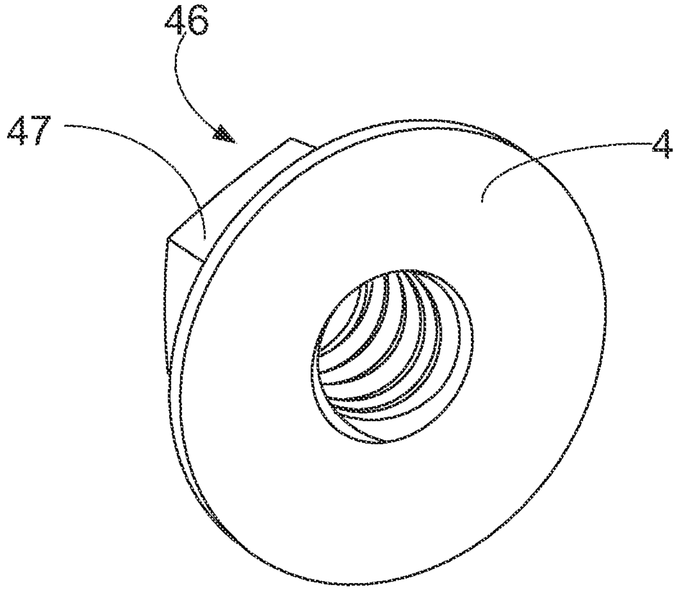

FIG. 11

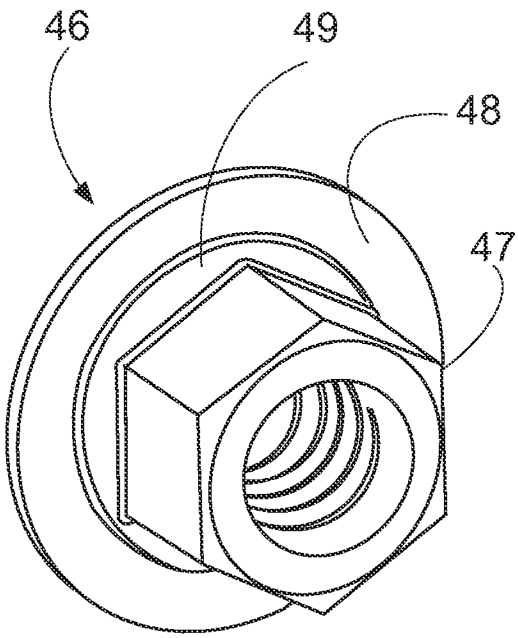

FIG. 12

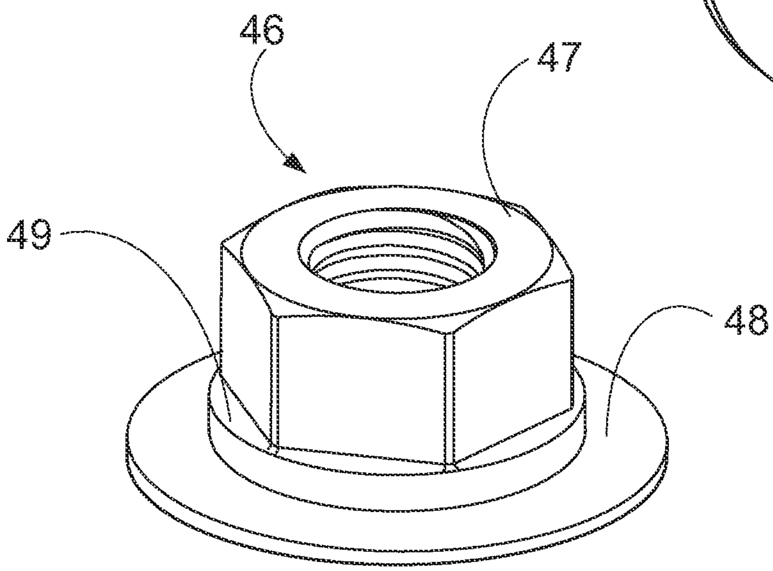

FIG. 13

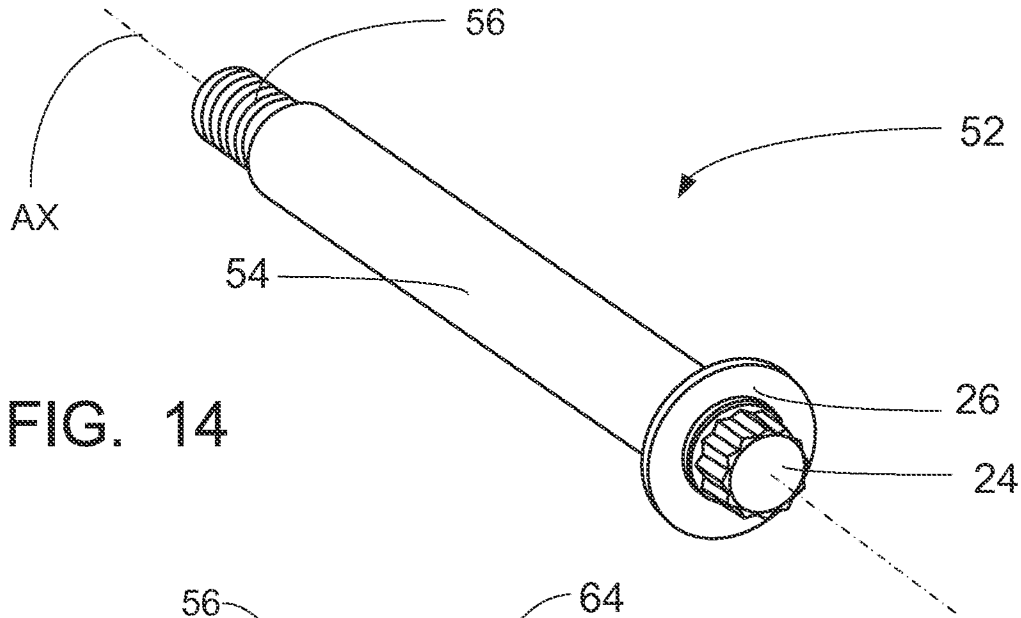

FIG. 14

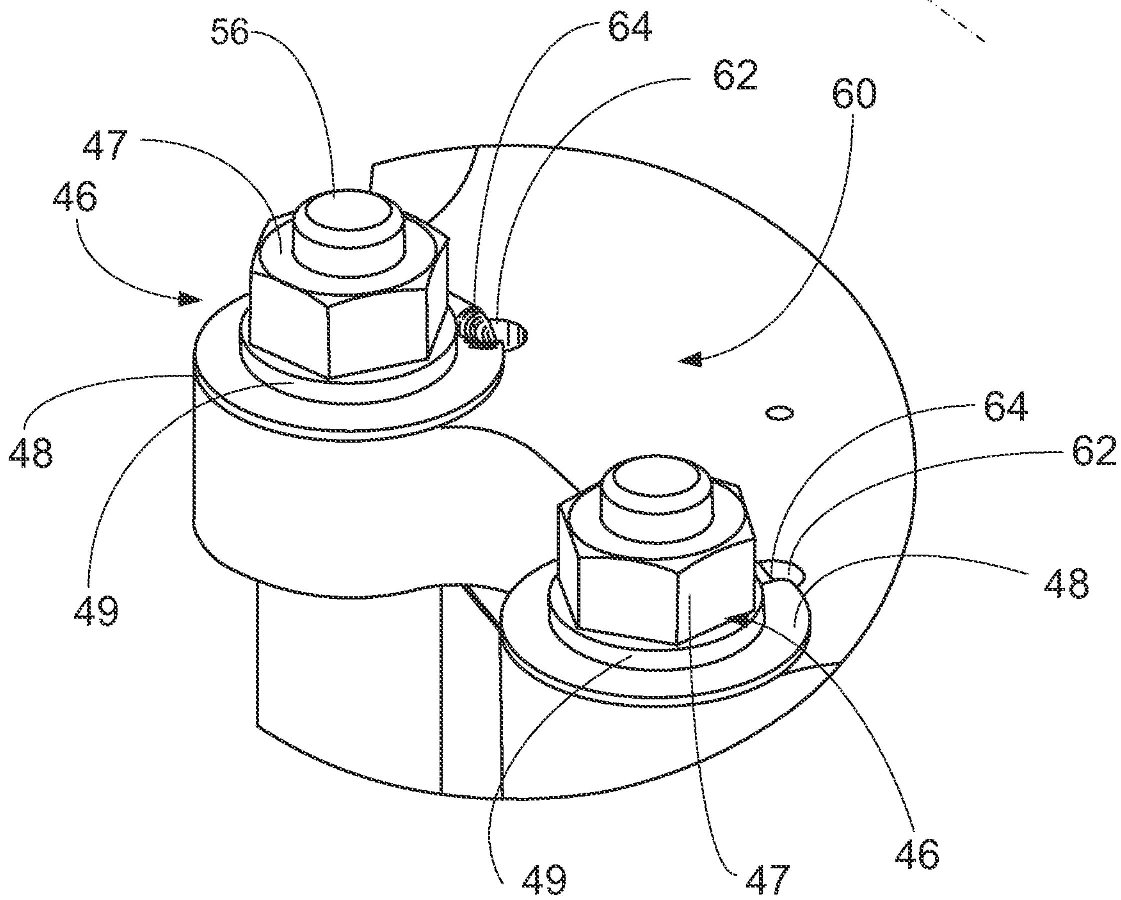

FIG. 15

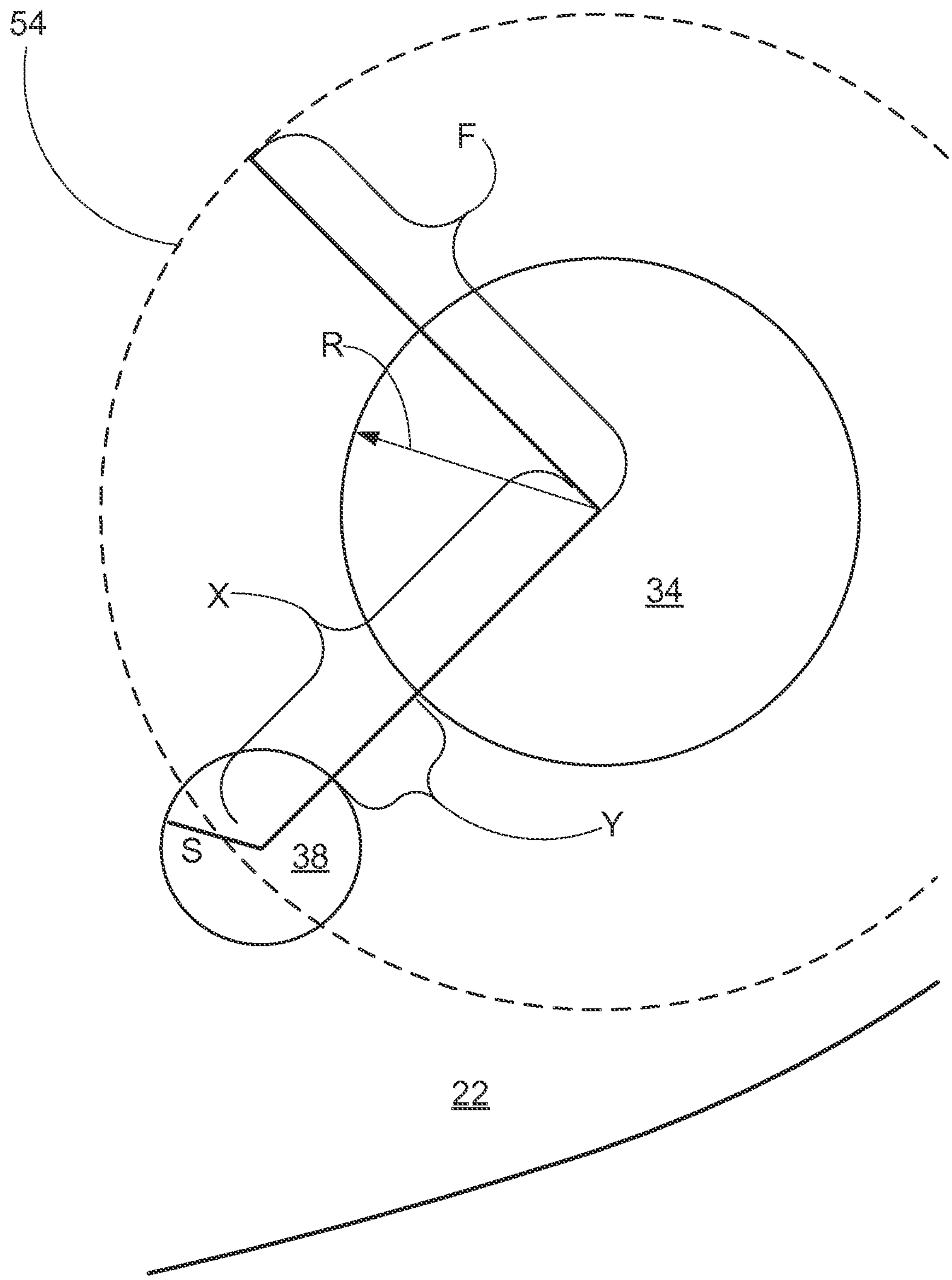

FIG. 16