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(54) Title: LOWER END FITTING LOCKNUT FOR NUCLEAR FUEL ASSEMBLY

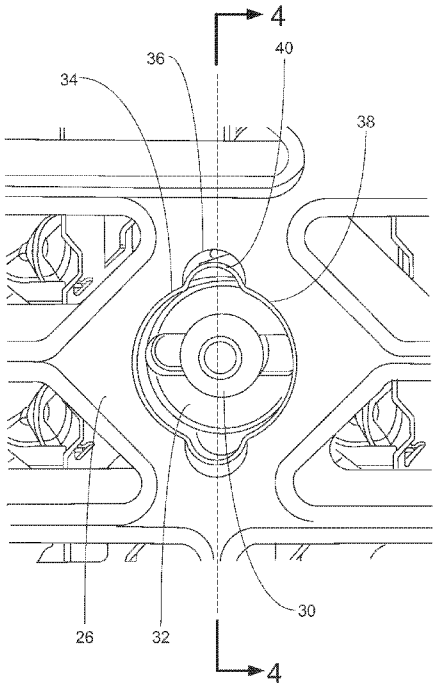


FIG.3

(57) Abstract: A fuel assembly includes a plurality of fuel rods comprising fissile material, a plurality of guide tubes interspersed amongst the fuel rods, an upper end fitting connected with upper ends of guide tubes, and a lower end fitting. End plugs are connected with the lower ends of the guide tubes. The end plugs have threaded male shafts extending from the lower ends of the guide tubes which pass through openings of the lower end fitting. Female lock nuts are threaded onto the threaded male shafts of the end plugs and lock with the lower end fitting to secure the lower end fitting to the lower ends of the guide tubes. The female lock nuts suitably have locking portions that are outwardly deformed into recesses of the lower end fitting to lock the lock nuts in place after tightening. Dashpot tubes may be disposed in the lower ends of the guide tubes and connected to the end plugs.

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LOWER END FITTING LOCKNUT FOR NUCLEAR FUEL ASSEMBLY

BACKGROUND

[0001] The following relates to the nuclear power reactor arts, nuclear fuel assembly manufacturing and deployment arts, and related arts.

[0002] In nuclear reactor designs of the integral pressurized water reactor (integral PWR) type, a nuclear reactor core is immersed in primary coolant water at or near the bottom of a pressure vessel. In a typical design, the primary coolant is maintained in a subcooled liquid phase in a cylindrical pressure vessel that is mounted generally upright (that is, with its cylinder axis oriented vertically). A hollow cylindrical central riser is disposed concentrically inside the pressure vessel. Primary coolant flows upward through the reactor core where it is heated and rises through the central riser, discharges from the top of the central riser and reverses direction to flow downward back toward the reactor core through a downcomer annulus defined between the pressure vessel and the central riser. In the integral PWR design, at least one steam generator is located inside the pressure vessel, typically in the downcomer annulus. Some illustrative integral PWR designs are described in Thome et al., "Integral Helical Coil Pressurized Water Nuclear Reactor", U.S. Pub. No. 2010/0316181 A1 published December 16, 2010 which is incorporated herein by reference in its entirety. Other light water nuclear reactor designs such as PWR designs with external steam generators, boiling water reactors (BWRs) or so forth, vary the arrangement of the steam generator and other components, but usually locate the radioactive core at or near the bottom of a cylindrical pressure vessel in order to reduce the likelihood of air exposure of the reactor core in a loss of coolant accident (LOCA).

[0003] The nuclear reactor core is built up from multiple fuel assemblies. Each fuel assembly includes a number of fuel rods. Spaced vertically along the length of the fuel assembly are grid assemblies which provide structural support to the fuel rods. At the top and bottom of the fuel assembly are an upper end fitting and a lower end fitting, respectively, providing structural support. The lower end fitting, sometimes called a

nozzle plate, may be supported by a lower core support plate, support pedestals, or the like.

[0004] The lower end fitting is the entrance for coolant flow into its fuel assembly. The fuel assembly also includes guide tubes interspersed amongst the fuel rods. Control rods comprising neutron absorbing material are inserted into and lifted out of the guide tubes of the fuel assembly to control core reactivity. The guide tubes in a conventional assembly are rigidly attached to the grid assemblies, and the upper and lower end fittings are secured to ends of the guide tubes using fasteners to form the structural framework of the fuel assembly.

[0005] A dashpot is optionally disposed at the lower end of the guide tube to slow the descent of the control rod during a scram. The dashpot may be formed as a narrowed-diameter lower portion of the guide tube, or as a small-diameter dashpot tube disposed coaxially inside the lower end of the guide tube. A fastening arrangement, typically including a threaded fastener, connects the lower end fitting to the guide tube. The fastening arrangement optionally also includes a locking element to prevent the threaded connection from working its way out over time. Some illustrative fastening arrangements of this type are described, for example, in Walton, U.S. Pat. No. 4,036,692 which is incorporated herein by reference in its entirety, and in John Jr. et al., U.S. Pat. No. 5,068,083 which is incorporated herein by reference in its entirety.

BRIEF SUMMARY

[0006] In accordance with one aspect, a fuel assembly includes a plurality of fuel rods comprising fissile material, a plurality of guide tubes interspersed amongst the fuel rods, an upper end fitting connected with upper ends of guide tubes, a lower end fitting, end plugs connected with the lower ends of the guide tubes and having threaded male shafts extending from the lower ends of the guide tubes and passing through openings of the lower end fitting, and female lock nuts threaded onto the threaded male shafts of the end plugs and locked with the lower end fitting to secure the lower end fitting to the lower ends of the guide tubes. The female lock nuts may have locking portions that are outwardly deformed into recesses of the lower end fitting to lock the lock nuts with the

lower end fitting after tightening. Dashpot tubes may be disposed in the lower ends of the guide tubes and connected to the end plugs. The female lock nuts do not engage the dashpot tubes.

[0007] In accordance with another aspect, a nuclear reactor is disclosed, comprising a pressure vessel containing a reactor core comprising an array of fuel assemblies as set forth in the immediately preceding paragraph.

[0008] In accordance with another aspect, an apparatus comprises: an end plug configured to connect with the lower end of a guide tube of a nuclear reactor fuel assembly, the end plug having a threaded male shaft that extends away from the lower end of the guide tube when the end plug is connected with the lower end of the guide tube, the threaded male shaft being sized to pass through an opening of a nuclear reactor fuel assembly lower end fitting; and a female lock nut configured to thread onto the threaded male shaft of the end plug, the female lock nut having a deformable side wall configured to be swaged into a recess of the nuclear reactor fuel assembly lower end fitting to lock the female nut with the nuclear reactor fuel assembly lower end fitting.

[0009] In accordance with another aspect, a method comprises: inserting a threaded male shaft of an end plug connected with the lower end of a guide tube of a nuclear reactor fuel assembly through an opening of a nuclear reactor fuel assembly lower end fitting; installing a female lock nut onto the inserted threaded male shaft of the end plug by rotating the female lock nut in a tightening direction to secure the nuclear reactor fuel assembly lower end fitting to the lower end of the guide tube; and deforming a locking portion of the female lock nut into a recess of the nuclear reactor fuel assembly lower end fitting to lock the female lock nut with the nuclear reactor fuel assembly lower end fitting. The method may further include, after the deforming, removing the female lock nut from the threaded male shaft by rotating the female lock nut in a loosening direction using rotational force sufficient to break the lock with the nuclear reactor fuel assembly lower end fitting provided by the deformed locking portion.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] 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.

[0011] FIGURE 1 diagrammatically shows a side view of a fuel assembly with a lower end fitting.

[0012] FIGURE 2A shows a perspective view of operations performed in connecting the lower end of a guide tube of fuel assembly frame to a lower end fitting.

[0013] FIGURE 2B shows an end view of the fuel assembly frame with the lower end fitting installed.

[0014] FIGURE 3 is an enlarged portion of FIGURE 2B.

[0015] FIGURE 4 is a cross-sectional view taken along the line 4-4 in FIGURE 3.

[0016] FIGURES 5 and 6 show end and perspective views, respectively, of a female nut used in the connection shown in FIGURE 3.

[0017] FIGURE 7 is a cross-sectional view taken through Section A-A indicated in FIGURE 5.

[0018] FIGURES 8 and 9 show perspective and end views, respectively, of a hand tool for installation/removal of the female nut of FIGURES 5-7.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0019] Existing end fitting fastening arrangements have certain disadvantages recognized herein. In some such arrangements, a threaded male shaft inserts into the bore of the guide tube, which is a blind operation. The installer has no feedback as to whether the shaft has fully engaged, and any error in this connection may not be discovered until after the fuel rods have been loaded into the fuel assembly frame formed by the rigid assembly of guide tubes and spacer grids. Fastening arrangements that include a locking element have an advantage in reliability, but at the cost of additional component cost and increased complexity of the fastening arrangement.

[0020] An improved connection disclosed herein employs an end plug for the guide tube which has a male threaded shaft that passes through the lower end fitting. A

female nut then engages the male threaded shaft to complete the connection. The installer can visually observe the position of the male threaded shaft passing through the opening of the lower end fitting, and the position of the female nut, and accordingly can visually verify complete engagement and proper connection. Moreover, the female nut can be a locknut with an integral deformable locking mechanism to enable the connection to be locked without welding and without the use of a separate locking element. In some embodiments, a designated combination tool provides both installation and swaged locking of the female nut.

[0021] FIGURE 1 illustrates a typical nuclear fuel assembly generally designated by the numeral **10**. Fuel assembly **10** is typical of that used in a pressurized water reactor (PWR), and includes a plurality of fuel rods **12**, spacer grids **14**, guide tubes **16**, an upper end fitting **18**, and a lower end fitting **20**. The upper and lower end fittings **18**, **20** are sometimes also referred to as upper and lower end fittings. In the installed configuration the fuel rods **12** are generally vertically oriented, although some deviation from exact gravitational vertical is contemplated, for example in maritime nuclear reactors that may tilt with ocean currents or vessel maneuvers. Fuel rods **12** are maintained in an array spaced apart by the spacer grids **14**. The guide tubes **16** extend through the spacer grids **14** and are rigidly connected with the grids by welding or by a mechanical fastening arrangement to form a rigid fuel assembly frame. The guide tubes **16** are hollow tubes that, in addition to providing structural support for the fuel assembly, also serve as guides for control rods. Some guide tubes may also be used as conduits for instrumentation or sensors (elements not shown). The guide tubes **16** connect at their upper ends with the upper end fitting **18** using suitable fasteners (although welding is also contemplated for this connection). The lower ends of the guide tubes **16** connect with the lower end fitting **20** using a combination of an end plug with a male threaded shaft engaged by a female nut, as described herein.

[0022] Upper and lower end fittings **18**, **20** provide structural and load bearing support to the fuel assembly **10**. The end fittings **18**, **20** have openings, slots, grids, or the like to allow coolant to flow vertically through the fuel assembly **10**. The lower end fitting **20** may rest on a lower core support plate (not shown) of the reactor and directly above

coolant inlet openings in the lower core support plate that direct coolant upward to the fuel assembly. Alternatively, in some embodiments upward primary coolant flow is sufficient to lift the fuel assembly during reactor operation, in which case the upper end fitting **18** (or springs built into the fitting, not shown) may press against an upper plate or other "stop". The fuel assembly **10** shown in FIGURE 1 is merely an illustrative example, and the fuel assembly may have different numbers of fuel rods, non-square cross sections (e.g., a hexagonal cross section in some embodiments), different numbers and arrangements of guide tubes, and so forth.

[0023] With reference to FIGURES 2A, 2B, and 3, the lower end fitting **20** is a substantially planar square element with a plurality of flow channels **24** and guide tube bosses **26**. While the illustrative lower end fitting **20** is square, but more generally the lower end fitting is sized and shaped to match the cross section of the fuel assembly **10**. As best seen in FIGURE 2A, the lower end of each guide tube **16** is connected with an end plug **28** having a threaded male shaft **30**. (See leftmost guide tube **16** shown in FIGURE 2A in which the end plug **28** is not yet attached with the guide tube). When the end plug **20** is connected to the lower end of the guide tube **16**, the threaded male shaft **30** extends away from the lower end of the guide tube **16**. (See middle guide tube **16** shown in FIGURE 2A, which has the end plug installed so that the threaded male shaft **30** is seen extending away from the lower end). The guide tube bosses **26** include openings or through-holes passing through the generally planar square structure of the lower end fitting **20**, and the connection of the lower end fitting **20** to the lower ends of the guide tubes **16** entails inserting the threaded male shafts **30** through the openings of the bosses **26** (see rightmost guide tube **16** shown in FIGURE 2A) and installing female lock nuts **32** onto the threaded male shafts **30** (see FIGURES 2B and 3).

[0024] With reference to FIGURE 4, which shows Section A-A taken through the line A-A of FIGURE 3, the connection is further described. The threaded male shaft **30** of the end plug **28** connected with the guide tube **16** is received in the opening through the guide tube boss **26** of the lower end fitting **20**. The female lock nut **32** is installed on the threaded male shaft **30** of the guide tube **16** by turning it in a tightening direction. This draws the female lock nut **32** and the end plug **28** together. The boss **26** includes a

counterbore **34** that receives the female lock nut **32**, and the geometry of the boss **26** (e.g., the thickness of the boss **26** and the depth of the counterbore **34**, in the illustrative configuration) determines the extent of the final tightening of the female lock nut **32** onto the shaft **30**, and thus determines a penetration **P** of the tip of the threaded male shaft **30** outside of the female lock nut **32**. (It is contemplated in some embodiments for this penetration **P** to be zero or even negative, i.e. for the tip of the shaft to be flush with the surface of the nut or even to be slightly within the bore of the nut when fully tightened). From the extent of the observed penetration **P**, which is readily observed by the installer, it is visually verified that the female lock nut **32** is tightened over the threaded male shaft **30** by the proper amount.

[0025] As best seen in FIGURE 3, the counterbore **34** has a portion thereof having a non-circular profile comprised of diametrically opposed recesses **36** (e.g, radially outwardly extending recesses). The female lock nut **32** includes a deformable portion which in the illustrative embodiment is an outboard annular wall **38** that can be deformed, e.g. swaged, to form a deformed locking portion **40** that is deformed into the recesses **36** to lock the female lock nut **32** against rotation. Said another way, the female lock nut **32** is threaded onto the threaded male shaft **30** of the guide tube **16**. After the threading, a swaging operation is performed to deform the annular wall **38** to engage the recesses **36** of the boss **26** in order to lock the female lock nut **32** against (further) rotation. In this swaging operation, the deformable portion **38** of the female lock nut **32** is deformed to form the swage **40** (that is, the deformed portion **40** of the female lock nut **32**) that engages the recesses **36** of the boss **26** of the lower end fitting **20**. In this manner, the female lock nut **32** is secured in the tightened configuration and prevented from backing out during operation of the nuclear reactor and the accompanying vibrational, fluid flow, and differential thermal expansion stresses.

[0026] FIGURES 5 and 6 show end and perspective views, respectively, of the female lock nut **32** prior to the swaging operation. FIGURE 7 shows Section B-B along the line B-B indicated in FIGURE 5. These views show the threading **42** of the female lock nut **32**, as well as engagement features **44** by which a tool can engage and rotate the

female lock nut **32**. The illustrative engagement features **44** are two recesses, but other engagement features can be employed.

[0027] With returning reference to FIGURE 4, the guide tube **16** optionally includes a dashpot tube **50** disposed inside the lower end of the guide tube **16**. Alternatively, a dashpot can be formed integrally in the guide tube via a narrowed lower end of the guide tube. As yet another contemplated alternative, the dashpot can be omitted entirely. During a scram, the control rod is released from the control rod drive mechanism (CRDM) and falls toward the bottom of the guide tube **16**. Primary coolant in the dashpot tube **50** (or in a narrowed lower end of the guide tube that acts as a dashpot) is compressed by the descending control rod and acts to decelerate the control rod in a gradual fashion, and hence provides dampening of the falling control rod as it nears the bottom of the guide tube **16**. The dashpot tube **50** is not connected with the female lock nut **32** that secures the lower end of the guide tube **16** to the lower end fitting **20**). Rather, the dashpot tube **50** is connected to the end plug **28** of the lower end of the guide tube **16**. In the illustrative configuration of FIGURE 4, the end plug **28** includes a cylindrical nub or protrusion **52** of smaller diameter than the maximum outer diameter of the end plug **28**. The dashpot tube **50** is connected with this nub or protrusion **52** by a friction fit, or by welding, or by another bonding mechanism. This connection, and the installation of the end plug **28** into the lower end of the guide tube **16**, is suitably performed before the guide tube is connected with the lower end fitting **20**. The end plug **28** is attached to the lower end of the guide tube **16** by welding, or by a friction fit, or by another bonding mechanism. Typically the dashpot tube **50** will be attached to the end plug **28** first, followed by connection of the end plug **28** with the lower end of the guide tube **16**.

[0028] Turning to FIGURES 8 and 9, an illustrative hand tool **70** for installing the female lock nut **32** over the threaded male shaft **30** is illustrated. The tool **70** includes a body **72** having a nut engaging end **74**, and swaging handles **76** operatively coupled to the body **72** and configured to actuate a pair of swaging heads to deform (i.e., crimp or swage) the deformable portion **38** of the female lock nut **32** after the nut is threaded onto the threaded male shaft **30** of the end plug **28** of the guide tube **16**. The crimping

or swaging action can employ substantially any mechanical configuration. Since there is a tendency to squeeze the handles **76** during rotation of the hand tool **70** when threading the locknut onto the guide tube, in some embodiments the crimping or swaging action is effectuated by pulling the handles **76** outward.

[0029] As best seen in FIGURE 9, the nut engaging end **74** is generally cylindrical and includes diametrically opposed protrusions **80** configured to mate with the engagement recesses **44** of the female lock nut **32**. The cylindrical shape of the nut engaging end **74** is sized to be received coaxially within the outboard deformable annular sidewall **38** of the female lock nut **32**. Also provided at the locknut engaging end **74** are diametrically opposed crimping or swaging heads **82** that are movable between the position shown in FIGURE 9 where they are disposed within the circumference of the cylindrical locknut engaging end of the body **72**, to an expanded position where they protrude radially outwardly from the cylindrical shape of locknut engaging end **74** of the body **72**. The plier grips **76** are configured to move the swaging heads **82** to the expanded position when drawn apart, i.e. drawn outward, by the lower end fitting installer. Alternatively the swaging or crimping can be performed when the handles **76** are squeezed, or another mechanical actuation mechanism can be used to cause the swaging or crimping heads **82** to expand outward to perform the swaging or crimping. It is also contemplated for the rotational tightening and swaging operations to be performed robotically, in which case the grips **76** would be replaced by appropriate robotic actuators.

[0030] With reference to FIGURES 10-12, another illustrative tool **100** for installing the female lock nut **32** over the threaded male shaft **30** is illustrated, which is suitably used in place of the hand tool **70** of FIGURES 8-9. The tool **100** is configured for mounting on a ratchet wrench (not shown). FIGURE 10 shows an exploded perspective view of the tool **100**, while FIGURE 11 shows an assembled view of the tool **100** configured for applying torque to the lock nut **32** and FIGURE 12 shows an assembled view of the tool **100** configured to perform a "punch" operation that swages the outboard annular sidewall **38** outward at two deformation locations located 180° apart around the lock nut **32**. The tool **100** includes a cylindrical sleeve **102** that coaxially surrounds a cylindrical nut engaging element **104** that in turn coaxially surrounds a punch element **106**. The

three elements are locked against relative rotation by a holding pin **108** that engages slots **110**, **112** in the nut engaging element **104** and the punch element **106**, respectively. (Slots **110**, **112** are visible only in the exploded view of FIGURE 10). The slots **110**, **112** provide defined allowable axial travel for the nut engaging element **104** and the punch element **106**, respectively, respective to the sleeve **102**. A holding screw **114** can be tightened to lock the nut engaging element **104** in either the extended position (i.e., the torqueing configuration shown in FIGURE 11) or in a retracted position (i.e. the punch configuration shown in FIGURE 12). In the extended or torqueing position, diametrically opposed protrusions **120** are configured to mate with the engagement recesses **44** of the female lock nut **32**. These protrusions **120** are functionally equivalent to the protrusions **80** of the hand tool of FIGURES 8-9. In the retracted or punch position, the protrusions **120** are retracted into the sleeve **102**. The punch element **106** includes wedges **122** that are functionally equivalent to the swaging heads **82** of the hand tool of FIGURES 8-9, i.e. they swage portions of the outboard annular sidewall **38** outward to lock the lock nut **32**, although they operate somewhat differently.

[0031] With particular reference to FIGURE 11, in the extended position, i.e. the torqueing configuration, the diametrically opposed protrusions **120** extend out from the sleeve **102** to mate with the engagement recesses **44** of the female lock nut **32**. A square recess **126** at the top of the punch element **106** (visible only in FIGURE 12) mates with a conventional square fitting (optionally with spring-loaded ball detent) of a ratchet wrench (elements not shown), so that the ratchet wrench can apply torque to the female lock nut **32** via the protrusions **120** in order to rotate the lock nut **32** onto the threaded male shaft **30** of the end plug **28** of the guide tube **16**. Note that in FIGURE 11 the wedges **122** of the punch element **106** protrude from between the nut-engaging protrusions **120** of the nut-engaging element **104**. However, because the nut-engaging element **104** is free to travel axially within the limits defined by the slot **112**, these wedges **122** will be readily pushed into the sleeve **102** when the protrusions **120** are brought to bear against the lock nut **32**. On the other hand, the holding screw **114** serves to ensure that the nut engaging element **104** does not get pushed back into the

sleeve **102**. (Note, the holding screw **114** can engage the nut engaging element **104** frictionally, or can insert into a bored recess in the nut engaging element **104**). As is conventional, the ratchet wrench is typically configured to ratchet in only one direction (possibly selectable), i.e. in the nut-tightening direction. The ratchet wrench may optionally also include a torque setting such that it will only tighten the lock nut **32** to a specified torque.

[0032] With particular reference to FIGURE 12, after the lock nut **32** is tightened onto the threaded male shaft **30** of the end plug **28**, the tool **100** is switched to the retracted position, i.e. torqueing configuration, shown in FIGURE 12. In this configuration the nut engaging element **104** is retracted such that the protrusions **120** are withdrawn into the sleeve **102**. The holding screw **114** is suitably loosened to enable the nut engaging element **104** to be slid back, as allowed by slot **110**, and then the holding screw **114** is tightened again to hold the nut engaging element **104** in the torqueing configuration. The wedges **122** are then brought to bear against the lock nut **32**. Doing so causes the punch element **106** to slide axially backward as permitted by the slot **112** in the punch element **106**. A mallet, hammer, or other tool is then brought down onto the top of the punch element **106** (i.e., onto the surface into which the recess **126** is formed) to force the wedges **122** downward so as to swage the outboard annular sidewall **38** of the lock nut **32** outward at the diametrically opposed locations of the wedges **122**. The downward punch travel is defined by the slot **112** as the travel distance $\mathbf{d}_{\mathbf{punch}}$, which is preferably selected to ensure a slight remaining upward protrusion of the top of the punch element **106** above the top of the nut engaging element **104** when the punch is fully applied.

[0033] While operation of the tool **100** is described herein with reference to manual operation, it will be appreciated that the tool **100** is alternatively readily operated by a robotic apparatus, for example employing a robotic ratcheting mechanism and a pneumatic or hydraulic mechanism to deliver the punch force. The robotic approach may employ a different coupling than the conventional square recess **126** shown in FIGURE 12.

[0034] In a typical lower end fitting installation procedure, the lower ends of the guide tubes **16** are first pre-assembled by attaching the dashpot tube **50** to the end plug **28** and then inserting the end plug **28** (with the dashpot tube **50** attached) into the lower end of the guide tube **16** and forming a connection, for example by welding or using a friction fit. The threaded male shafts **30** of the end plugs **28** of the guide tube **16** are then inserted into the openings of the bosses **26 of** the lower end fitting **20** (best seen in FIGURE 2A) and the female lock nuts **32** are installed. In a suitable approach, the lock nuts **32** are partially threaded onto the threaded male shafts **30** by hand. The hand tool **70**, or alternatively the tool **100**, is then used to tighten down each female lock nut **32** in turn. Once the female lock nut **32** is suitably tightened (as verified by visual assessment of the protrusion **P** of the shaft end as shown in FIGURE 4), the plier grips **76** of the hand tool are squeezed together to force the swaging heads **82** radially outwardly to deform the outboard annular side wall **38** into the recesses **36** of the counterbore **34** of the boss **26** of the lower end fitting **20**, so as to form the locking portions or swages **40**. Alternatively, if using the tool **100** the most efficient approach is typically to tighten all the lock nuts **32** first using the tool **100** in the torqueing configuration (FIGURE 11), and then to switch the tool **100** to the punch configuration (FIGURE 12) and swage the lock nuts **32** to form the locking portions or swages **40**.

[0035] Typically, the lower end fitting **20** is not removed from the lower ends of the guide tubes **16** of the fuel assembly frame. The fuel rods are designed to be loaded (and, if necessary, unloaded) from the top after removing the upper end fitting **18**. However, under certain circumstances it may become necessary to remove the lower end fitting **20**. Such a circumstance could arise prior to loading the fuel rods, if some error occurs during construction of the fuel assembly frame. In this case, the hand tool **70** or the tool **100** can be used to remove the female lock nuts **32** from the threaded male shafts **30**. A nut is removed by rotating the female lock nut **32** in the loosening direction using rotational force sufficient to break the locks provided by the deformed locking portions **40** of the female lock nuts **32**. (In the case of the tool **100**, the direction of ratcheting is switched to the loosening direction).

[0036] Another possible circumstance calling for removal of the lower end fitting **20** could arise if a fuel rod breaks after loading. In this circumstance, a possible remedial procedure to be performed robotically and in a submerged state (in view of high radiation levels emitted by the loaded fuel assembly) is to move the fuel assembly into a spent fuel pool and perform fuel unloading by removing the upper end fitting **18** as per usual procedure. This leaves the fuel assembly frame (i.e., the guide tubes **16** rigidly secured together by spacer grids and still including the installed lower end fitting **20**) which is empty of fuel except for the lower portion of the broken fuel rod. That broken lower fuel rod portion typically cannot be removed from the opening provided by removal of the upper end fitting **18**. Rather, removal of this remaining broken lower end is via the lower end. To accomplish this, robotic apparatus is employed to remove the lower end fitting **20**. The robotic apparatus suitably includes a nut removal tool such as the tool **100** operated by the robotic apparatus. The robotic nut removal tool is used to remove the female lock nuts **32** from the threaded male shafts **30**. Again, a nut is removed by rotating the female lock nut **32** in the loosening direction using rotational force sufficient to break the locks provided by the deformed locking portions **40** of the female lock nuts **32**. After removal of the female lock nuts **32**, the lower end fitting **20** can be pulled away from the lower ends of the guide tubes **16**, providing access to the lower portion of the broken fuel rod. (It should be noted that an alternative is to cask the entire fuel assembly frame including the lower portion of the broken fuel rod and the lower end fitting, without removing the lower end fitting. However, in some situations this may require a larger cask than is desirable).

[0037] Although shown and described with reference to the illustrative embodiment, it is to be understood that numerous variants are contemplated. For example, while the illustrative lock nut **32** includes two swaged portions **40** located at opposing sides of the female lock nut **32**, the number of swaged portions can be as few as one, or can be two, three, four, or more. In general, employing N swaged portions with N-fold rotational symmetry around the lock nut has advantages in terms of enabling the application of balanced forces around the lock nut during the swaging operation. In the illustrative example the two swaged portions **40** are located 180° apart around the lock nut and

hence have two-fold rotational symmetry around the lock nut **32**. Three swaged portions at 120° intervals around the lock nut, or four swaged portions at 90° intervals around the lock nut, or so forth would also allow for advantageously balanced outward swaging forces. Moreover, the entire annular side wall **34** can be swaged, for example by deforming the annular sidewall **34** into an oval shape having two crimps at opposing sides along the major axis of the oval. Other approaches can be used by which the lock nut can lock with the lower end fitting. As another illustrative example, the annular side wall **34** can be replaced by one or more discrete deformable tabs that are deformed outward to provide the deformed locking portions.

[0038] As some illustrative further contemplated variations, the illustrative crimping handles or grips **76** can be replaced by another actuator, such as a rotational actuator disposed in the central cylinder of the hand tool that linearly drives a member between the crimping or swaging heads to force them outward, e.g. similarly to the linear operation of the punch element **106** of the tool **100**. Still further, while the illustrative hand tool **70** providing both rotational (for threading) and swaging actions is convenient, it is contemplated to employ separate hand or robotic tools: one tool for threading the lock nut onto the threaded end of the guide tube, and a second tool for performing the crimping or swaging. Also, as previously noted, the hand tool **70** or manual wrench operation of the tool **100** can be replaced by an equivalent robotic mechanism (and indeed, robotic tooling must be used for any removal operation performed after the fuel rods are loaded). Still further, it is contemplated to adapt the disclosed connection for use in the upper end fitting. In this case, the female locknut preferably engages a threaded outer diameter of the upper end of the guide tube, as an end plug is not an option (since the control rod passes through the upper end of the guide tube).

[0039] 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 fuel assembly including:

a plurality of fuel rods comprising fissile material;

a plurality of guide tubes interspersed amongst the fuel rods,

an upper end fitting connected with upper ends of guide tubes,

a lower end fitting,

end plugs connected with the lower ends of the guide tubes and having threaded male shafts extending from the lower ends of the guide tubes and passing through openings of the lower end fitting, and

female lock nuts threaded onto the threaded male shafts of the end plugs and locked with the lower end fitting to secure the lower end fitting to the lower ends of the guide tubes.

2. The apparatus of claim 1, further comprising:

dashpot tubes disposed in the lower ends of the guide tubes and connected to the end plugs, the female lock nuts not engaging the dashpot tubes.

3. The apparatus of claim 1, wherein the female lock nuts have swaged locking portions engaging recesses of the lower end fitting.

4. The apparatus of claim 1, wherein the female lock nuts have locking portions outwardly deformed into recesses of the lower end fitting.

5. The apparatus of claim 4, wherein the locking portions comprise portions of outboard annular walls of the female lock nuts that are outwardly deformed into recesses of the lower end fitting.

6. The apparatus of claim 5, wherein the locking portions comprise two locking portions of outboard annular walls of the female lock nuts that are outwardly deformed into recesses of the lower end fitting.

7. The apparatus of claim 4, wherein the locking portions comprise N locking portions arranged with N-fold symmetry around the female lock nut that are outwardly deformed into recesses of the lower end fitting.

8. The apparatus of claim 1, wherein the end plugs are welded to the lower ends of the guide tubes.

9. The apparatus of claim 1, further comprising:

a tool configured to rotate a female lock nut to thread it onto a threaded male shaft of an end plug connected with the lower end of a guide tube and to swage the female lock nut to form swaged locking portions of the lock nut that engage recesses of the lower end fitting to lock the lock nut with the lower end fitting.

10. The apparatus of claim 1, further comprising:

a pressure vessel containing a reactor core comprising an array of said fuel assemblies.

11. An apparatus comprising:

an end plug configured to connect with the lower end of a guide tube of a nuclear reactor fuel assembly, the end plug having a threaded male shaft that extends away from the lower end of the guide tube when the end plug is connected with the

lower end of the guide tube, the threaded male shaft being sized to pass through an opening of a nuclear reactor fuel assembly lower end fitting; and

a female lock nut configured to thread onto the threaded male shaft of the end plug, the female lock nut having a deformable side wall configured to be swaged into a recess of the nuclear reactor fuel assembly lower end fitting to lock the female lock nut with the nuclear reactor fuel assembly lower end fitting.

12. The apparatus of claim 11, further comprising:

a tool configured to rotate a female lock nut to thread it onto the threaded male shaft of an end plug connected with the lower end of a guide tube and to swage the female lock nut to form the swaged locking portions engaging recesses of the nuclear reactor fuel assembly lower end fitting .

13. The apparatus of claim 12, wherein the tool is configured to connect with a torque wrench.

14. The apparatus of claim 11, wherein the deformable side wall of the female lock nut comprises an annular deformable sidewall that is outwardly deformable into one or more recesses of the nuclear reactor fuel assembly lower end fitting to lock the female lock nut with the nuclear reactor fuel assembly lower end fitting.

15. The apparatus of claim 11, wherein the deformable side wall is configured to be swaged into N recesses of the nuclear reactor fuel assembly lower end fitting having N-fold rotational symmetry around the female lock nut to lock the female lock nut with the nuclear reactor fuel assembly lower end fitting.

16. A method comprising:

inserting a threaded male shaft of an end plug connected with the lower end of a guide tube of a nuclear reactor fuel assembly through an opening of a nuclear reactor fuel assembly lower end fitting;

installing a female lock nut onto the inserted threaded male shaft of the end plug by rotating the female lock nut in a tightening direction to secure the nuclear reactor fuel assembly lower end fitting to the lower end of the guide tube; and

deforming a locking portion of the female lock nut into a recess of the nuclear reactor fuel assembly lower end fitting to lock the female lock nut with the nuclear reactor fuel assembly lower end fitting.

17. The method of claim 16, further comprising:
connecting the end plug to the lower end of the guide tube.

18. The method of claim 17, wherein the connecting comprises:
welding the end plug to the lower end of the guide tube.

19. The method of claim 17, further comprising:
connecting a dashpot tube to the end plug; and
inserting the dashpot tube into the end plug.

20. The method of claim 16, further comprising:

after the deforming, removing the female lock nut from the threaded male shaft by rotating the female lock nut in a loosening direction using rotational force sufficient to break the lock with the nuclear reactor fuel assembly lower end fitting provided by the deformed locking portion.

21. The method of claim 16, further comprising:

installing the nuclear reactor fuel assembly lower end fitting on the lower end of a fuel assembly frame including a plurality of guide tubes by performing the inserting, installing, and deforming for each guide tube of the fuel assembly frame; and

loading fuel rods comprising fissile material into the fuel assembly frame with the installed nuclear reactor fuel assembly lower end fitting.

22. The method of claim 21, further comprising:

after the installing and loading, unloading the fuel rods except for a broken fuel rod from the fuel assembly frame;

removing the nuclear reactor fuel assembly lower end fitting from the lower end of the fuel assembly frame by removing the female lock nuts from the threaded male shafts by rotating the female lock nuts in a loosening direction using rotational force sufficient to break the locks provided by the deformed locking portions of the female lock nuts; and

with the nuclear reactor fuel assembly lower end fitting removed, extracting a lower portion of the broken fuel rod from the fuel assembly frame via the lower end of the fuel assembly frame.

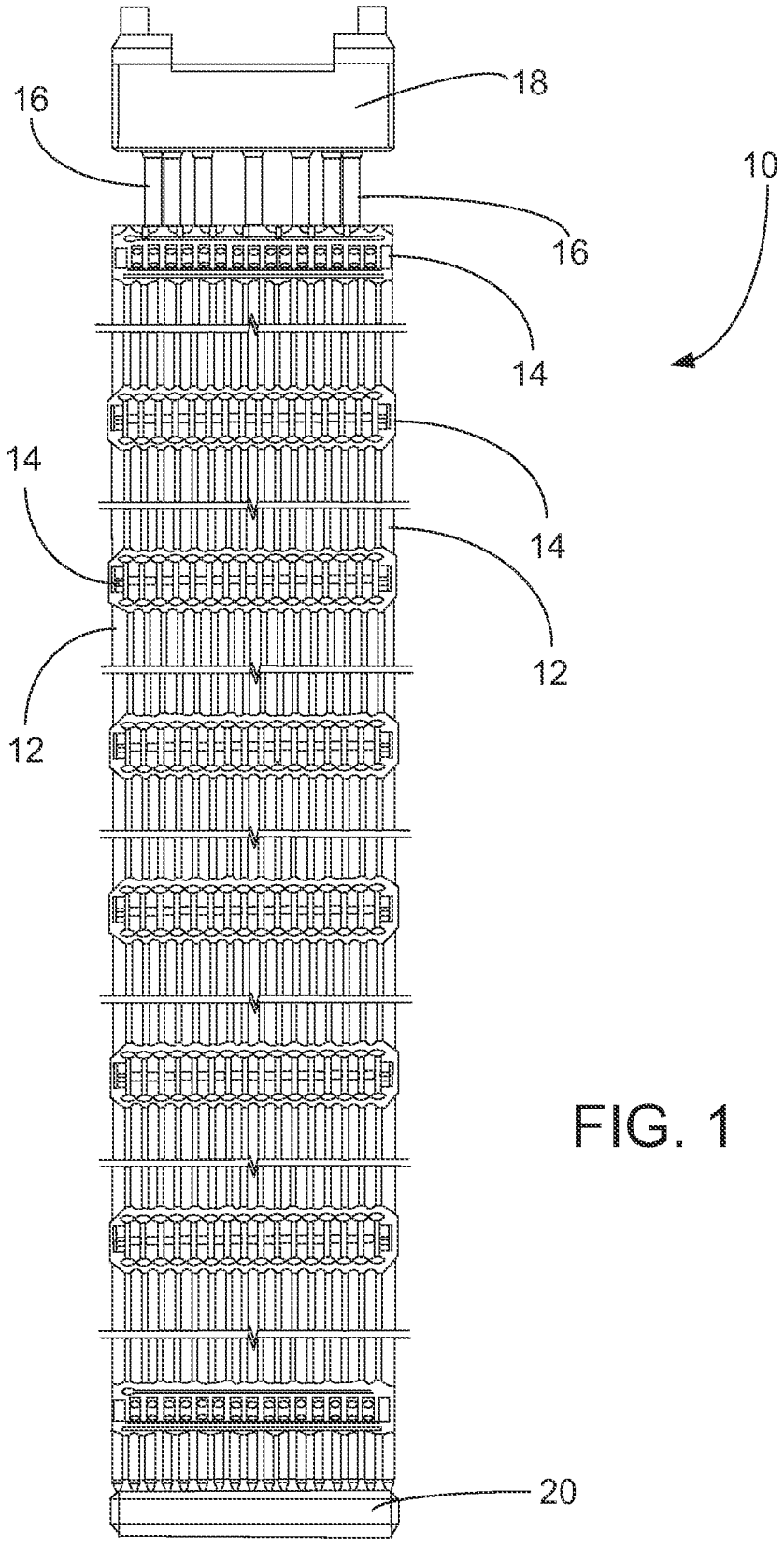


FIG. 1

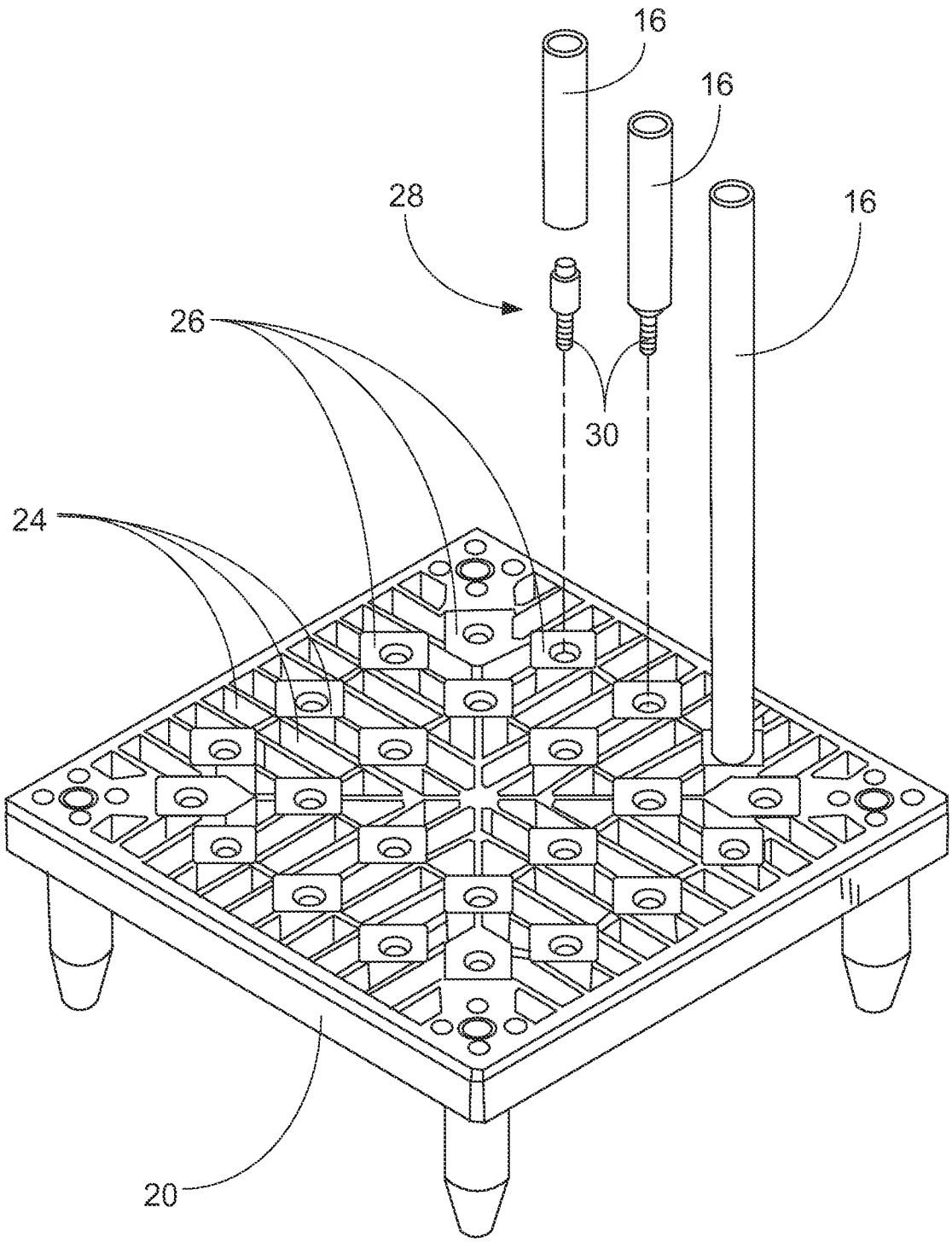


FIG. 2A

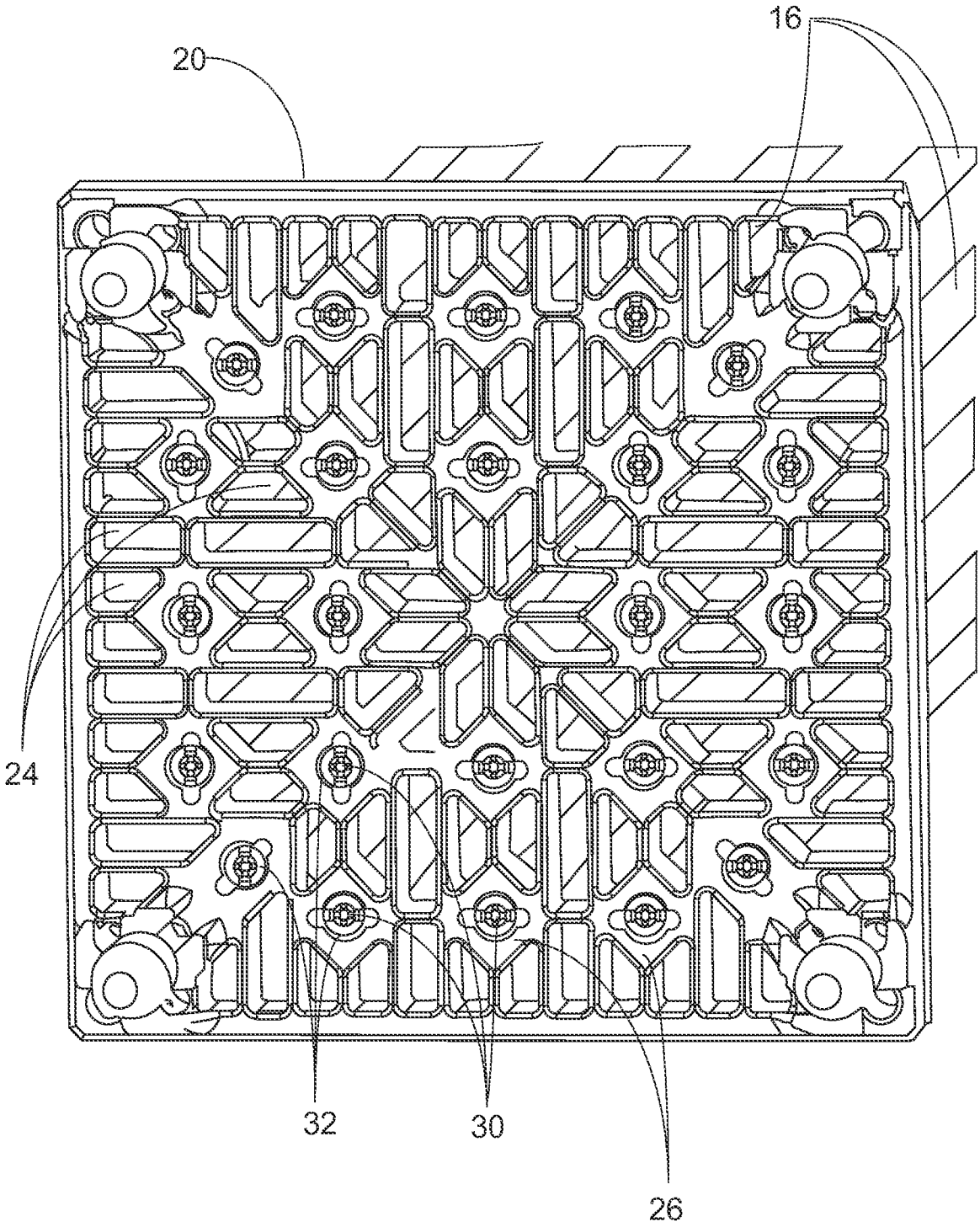


FIG. 2B

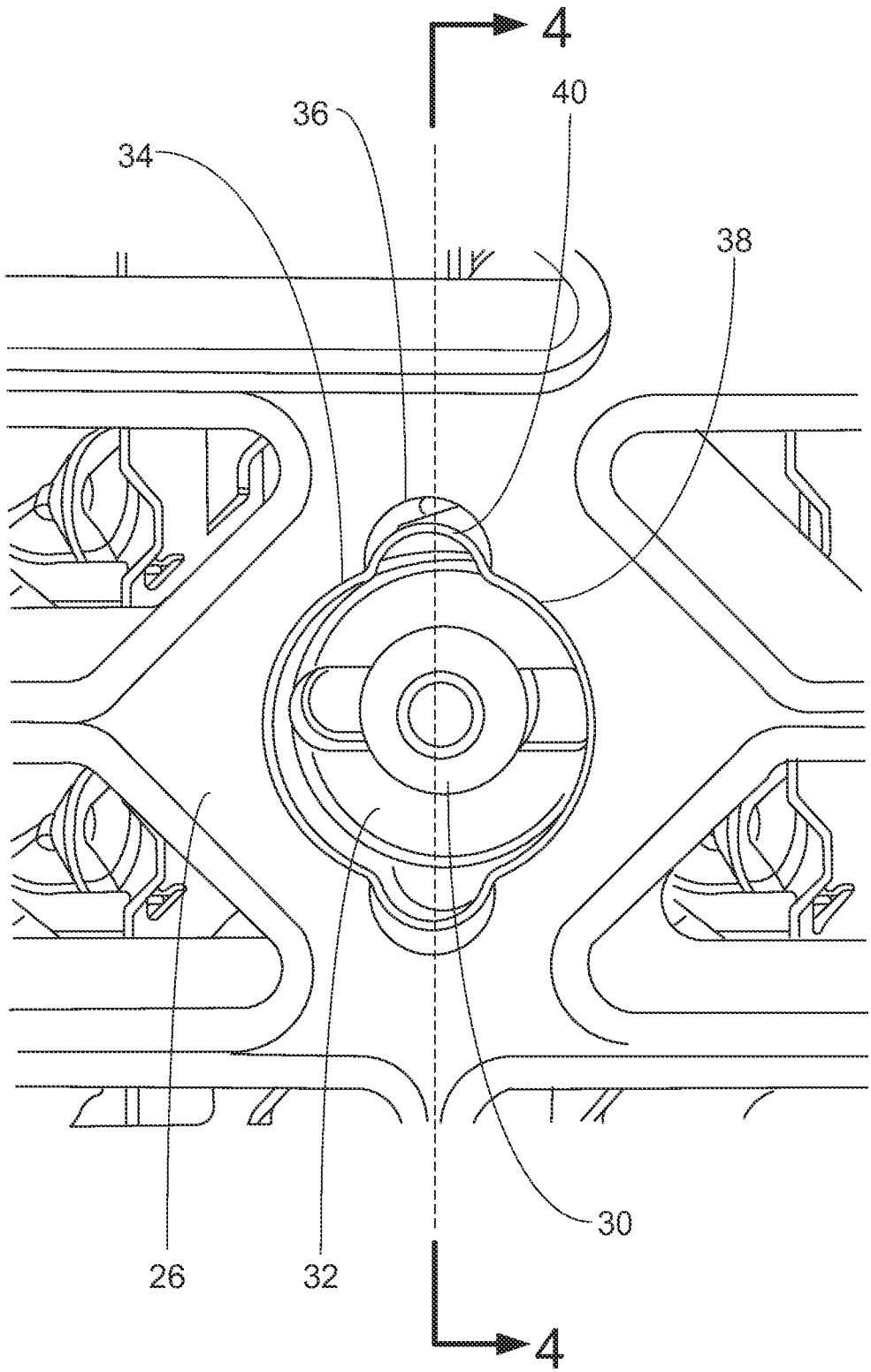


FIG.3

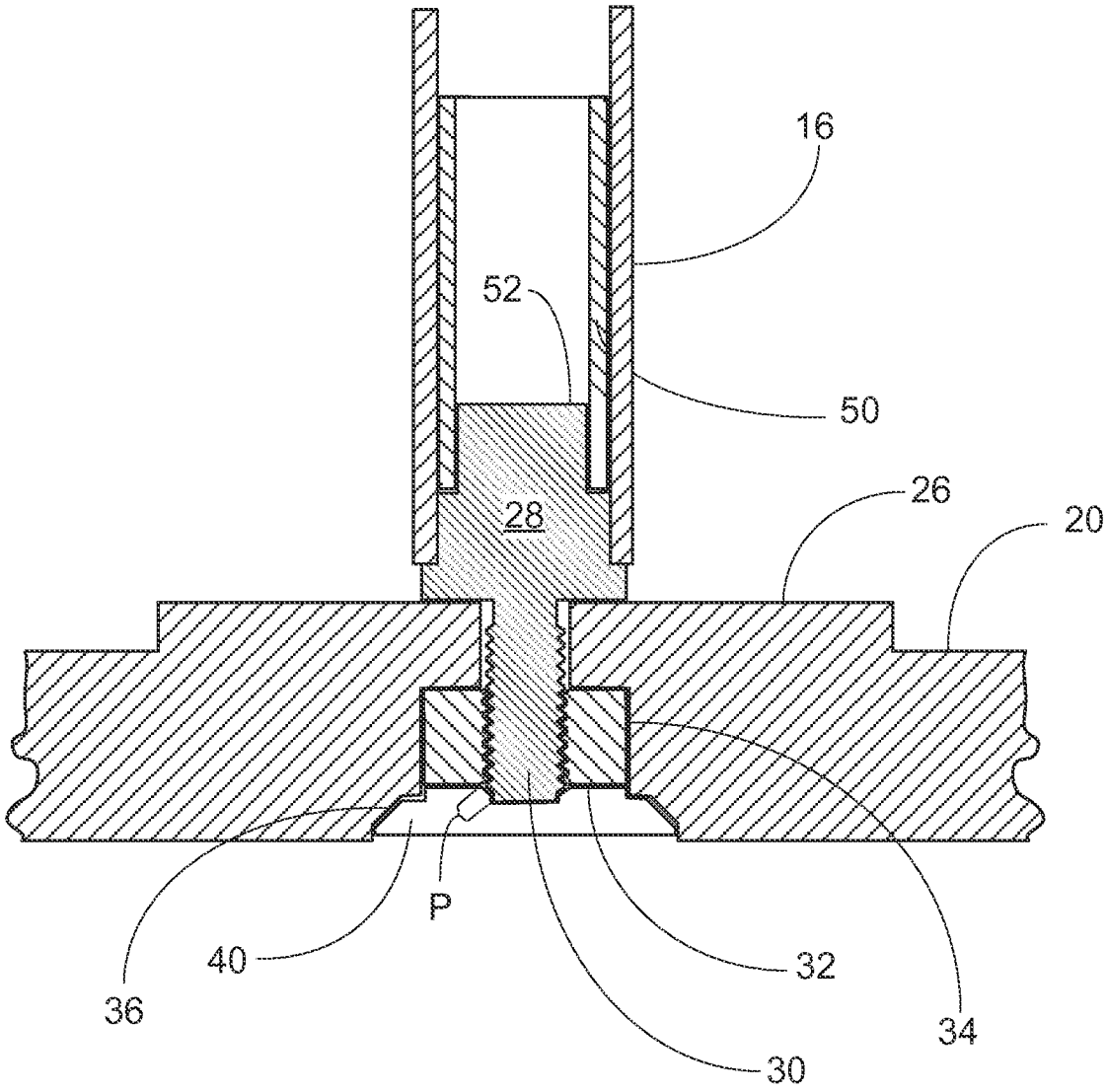


FIG. 4

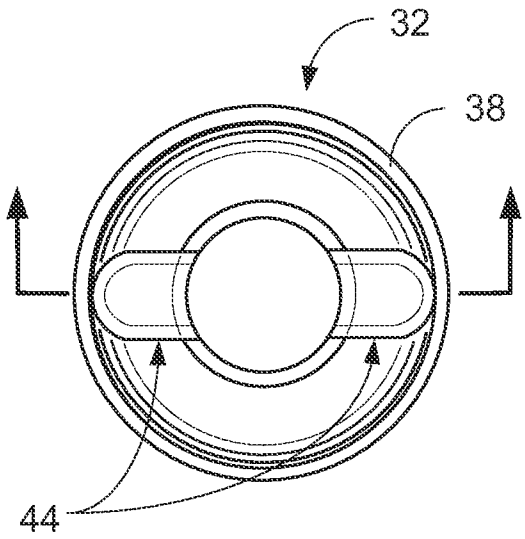


FIG. 5

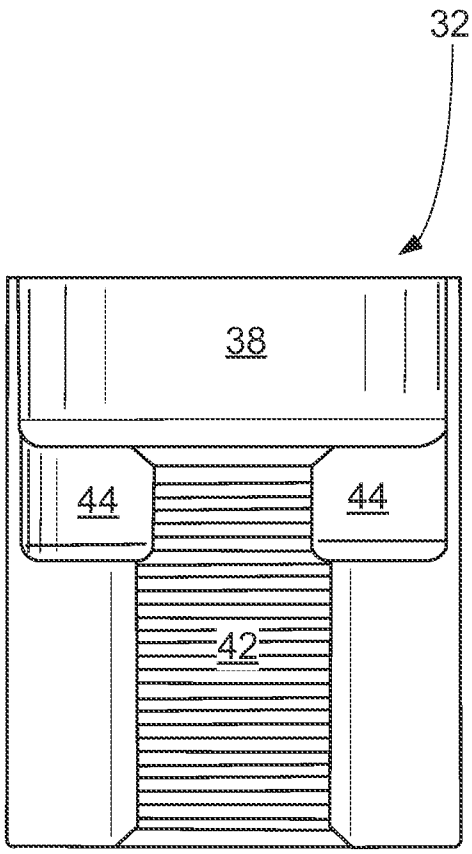


FIG. 7

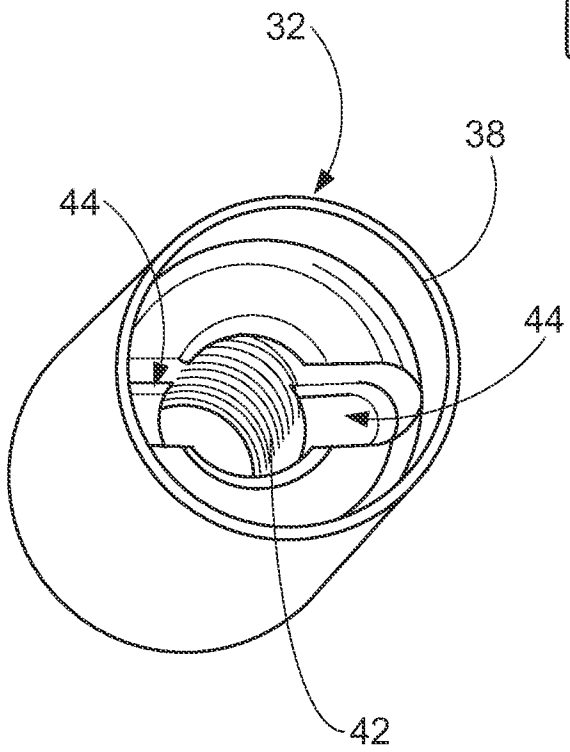


FIG. 6

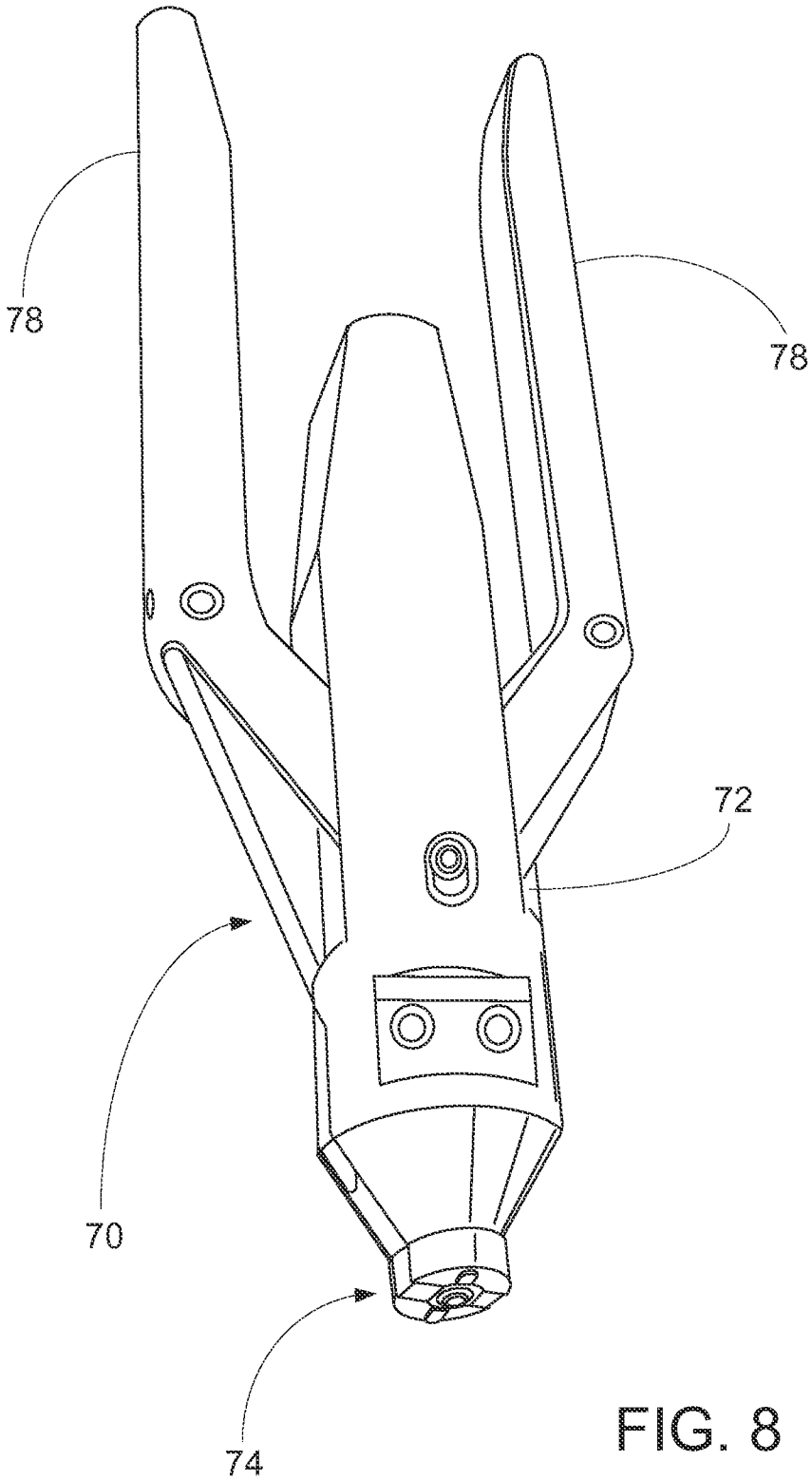


FIG. 8

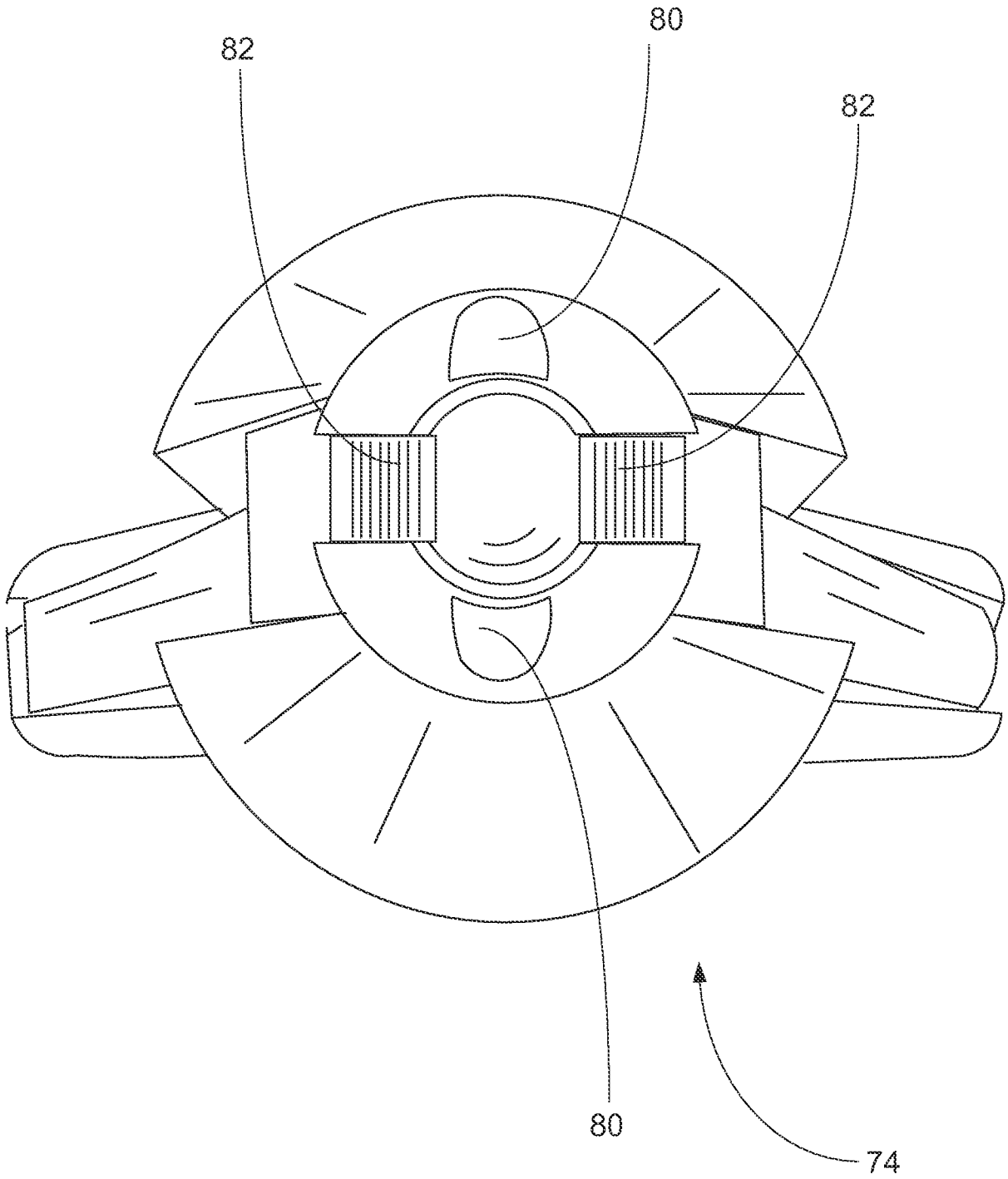


FIG. 9

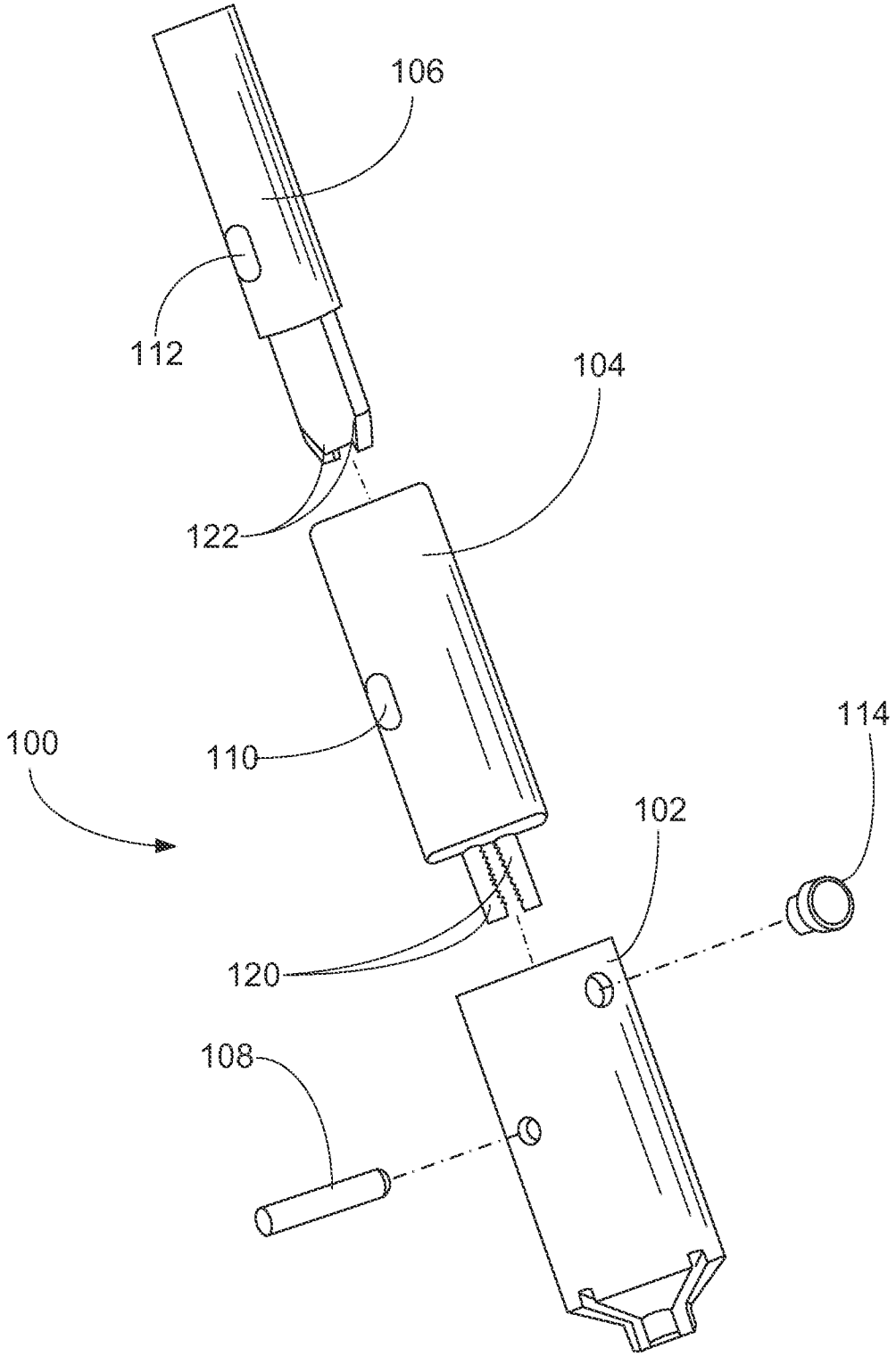


FIG. 10

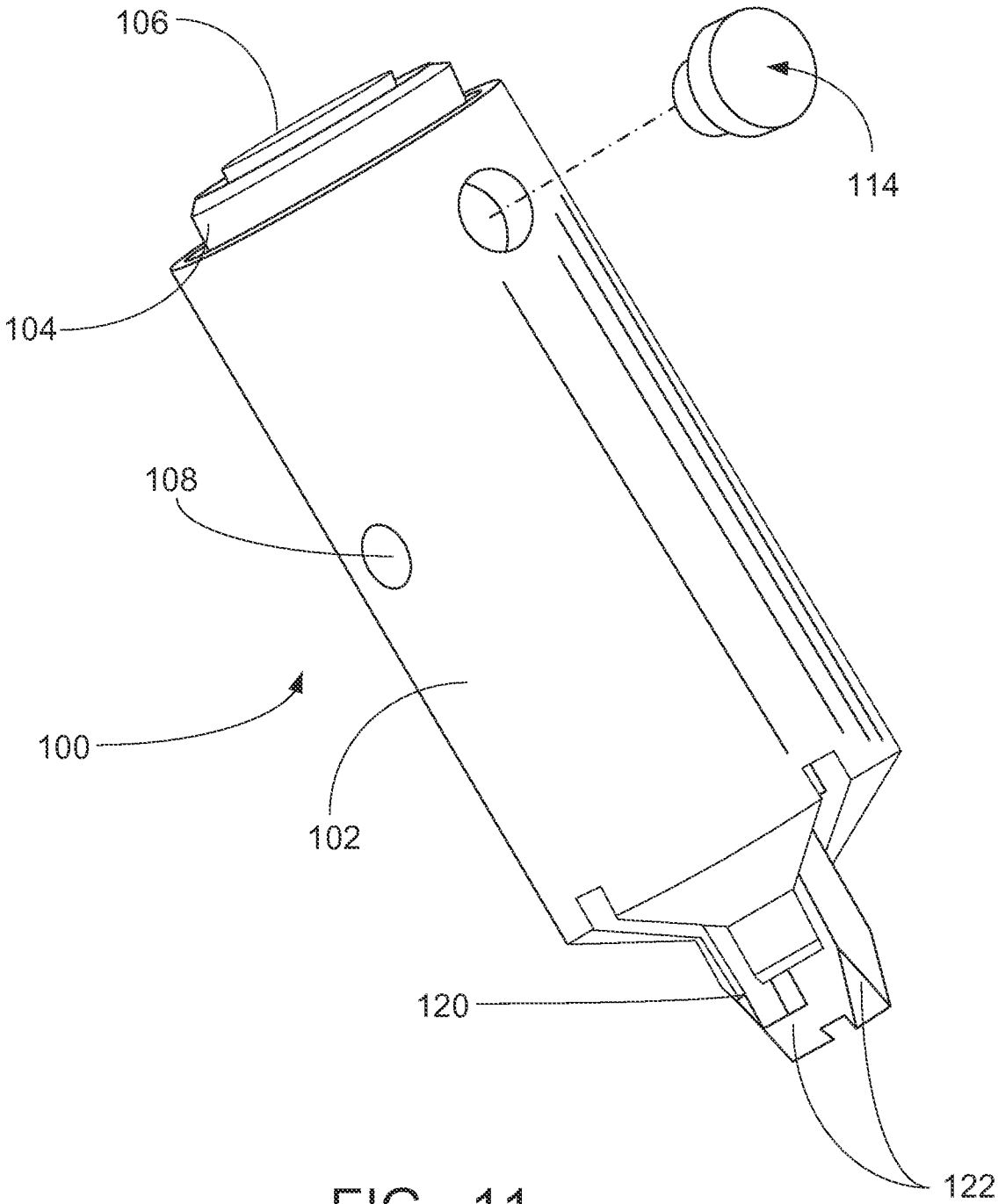


FIG. 11

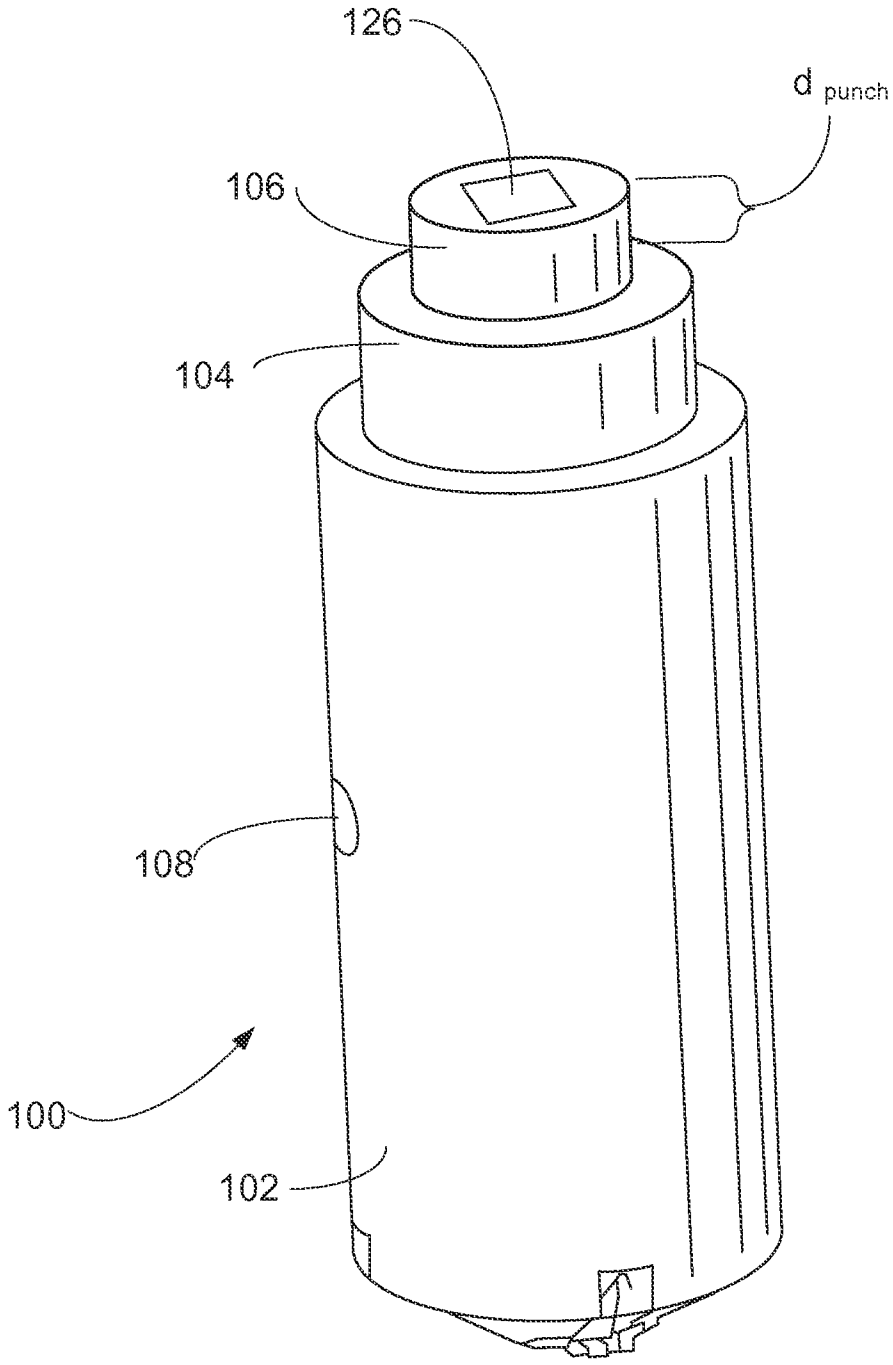


FIG. 12