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(54) Titre : METHODE ET SYSTEME DE REMPLACEMENT DES SOUFFLETS D'UN REACTEUR NUCLEAIRE
(54) Title: NUCLEAR REACTOR BELLOWS REPLACEMENT SYSTEM AND METHOD

(57) Abrégé/Abstract:
A system and method of removing and replacing bellows on a nuclear reactor having a calandria and a fuel channel assembly includes severing the bellows of the fuel channel assembly at a ferrule adjacent a tube sheet of the reactor, removing the severed bellows, installing a replacement bellows at the remaining ferrule stub at or adjacent the tube sheet, and welding the replacement bellows to the ferrule stub at or adjacent the tube sheet.

ABSTRACT

A system and method of removing and replacing bellows on a nuclear reactor having a calandria and a fuel channel assembly includes severing the bellows of the fuel channel assembly at a ferrule adjacent a tube sheet of the reactor, removing the severed bellows, installing a replacement bellows at the remaining ferrule stub at or adjacent the tube sheet, and welding the replacement bellows to the ferrule stub at or adjacent the tube sheet.

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NUCLEAR REACTOR BELLOWS REPLACEMENT SYSTEM AND METHOD

RELATED APPLICATIONS

[0001] The present application claims priority to U.S. Provisional Application No. 61/433,377 of the same title, filed January 17, 2011, the entire contents of which are herein incorporated by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to methods and systems for retubing a nuclear reactor.

SUMMARY

[0003] A nuclear reactor has a limited life of operation. For example, second generation CANDU-type reactors ("CANada Deuterium Uranium") are designed to operate for approximately 25 to 30 years. After this time, the existing fuel channels can be removed and new fuel channels can be installed. Performing this "retubing" process can extend the life of a reactor. For example, retubing a CANDU-type reactor can extend the reactor's life by an additional 25 to 40 years. Without performing the retubing, a reactor that reaches the end of its useful life is typically decommissioned and replaced with a new reactor, which poses significant costs and time. Alternatively, replacement energy sources may be used to extend the life of a reactor. However, replacement energy sources are often more expensive than installing a new reactor, and can be difficult to acquire.

[0004] Nuclear reactor retubing processes include removal of a large number of reactor components, and include various other activities, such as shutting down the reactor, preparing the vault and installing material handling equipment and various platforms and equipment supports. The removal process can also include removing closure plugs and positioning hardware assemblies, disconnecting feeder assemblies, severing bellows, removing end fittings, releasing and removing calandria tube inserts, and severing and removing pressure tubes and calandria tubes. After the removal process is complete, an inspection and installation process is typically performed.

[0005] During the removal process, particular procedures can be used to improve the efficiency of the process. For example, a stand-alone retube tooling platform can be installed on each face of the reactor, which is used to support operators and tools during the retubing process. Also, when components are removed from the reactor, they must be transported and disposed of properly. In some embodiments, the components are volume reduced before being transported, such as by cutting the components into smaller pieces.

[0006] Furthermore, during the removal process, different components may be left on the reactor. For example, bellows that allow the fuel channel assemblies of the reactor to move axially can be removed and replaced with new bellows that are pre-installed on end fittings, or may instead be left intact for re-use in the event they have not been subject to unacceptable damage or deterioration. However, by removing the bellows, less inspection and preparation is needed in the process of installing new end fittings and fuel channel assemblies. Additionally, by removing the old bellows from the reactor, concern regarding potential damage to the old bellows due to other operations on the reactor face is eliminated, and the time and resources needed to repair and qualify the old bellows for continued operation is eliminated.

[0007] In many reactors (including CANDU-type reactors described above), the bellows of each fuel channel assembly must be severed in order to efficiently release, remove, and replace other components of the fuel channels, such as end fittings of the fuel channels. Based at least in part upon the relatively large number of such bellows in a typical reactor and the collective time consumed in severing each bellows, new and improved bellows severing tools and methods are welcome additions to the art.

[0008] Embodiments of the present invention provide fuel channel bellows severing tools and methods which can be used to streamline and at least partially automate much of the process in severing fuel channel bellows in nuclear reactors.

[0009] Some embodiments of the present invention provide a method of removing and replacing bellows on a nuclear reactor having a fuel channel assembly coupled to and extending through an aperture in a tube sheet, wherein the method comprises: severing the bellows from a tube of the fuel channel assembly at a ferrule adjacent the tube sheet; removing the severed bellows from the tube; and installing a replacement bellows by coupling the replacement bellows to the tube adjacent the tube sheet.

[0010] In some embodiments, a method of removing and replacing bellows in a nuclear reactor having a plurality of lattice tubes is provided, and comprises: installing a bellows replacement cutting tool on a mobile table; cutting the bellows off with a cutting tool; removing that portion of the bellows cut off with the cutting tool; measuring a remaining bellows stub left after removing that portion of the bellows cut off with the cutting tool; positioning a replacement bellows for installation; and affixing the replacement bellows onto the remaining bellows stub.

[0011] Some embodiments of the present invention provide a method of removing bellows from a nuclear reactor having a fuel channel assembly, the bellows including a first flange at a first end, a second flange at a second end and a plurality of convolutions between the first flange and the second flange, wherein the method comprises: removing a closure plug from an end of the fuel channel assembly; disconnecting a feeder assembly from the fuel channel assembly; removing an end fitting from the rest of the fuel channel assembly; severing the first flange of the bellows; severing a calandria tube; severing a pressure tube; removing the calandria tube through the bellows; removing the pressure tube through the bellows; after removing the calandria tube and the pressure tube, severing the second flange of the bellows; and after severing the second flange of the bellows, removing the bellows.

[0012] In some embodiments, a method of replacing bellows in a nuclear reactor having a plurality of lattice tubes is provided, and comprises: inserting a cutting tool into one of the lattice tubes; cutting through the bellows with the cutting tool; removing the bellows with a first ferrule and a portion of a second ferrule severed by the cutting tool; inserting a welding tool into that portion of the second ferrule remaining after the removing step; and welding replacement bellows to that portion of the second ferrule remaining after the removing step.

[0013] Some embodiments of the present invention provide a method of removing and replacing bellows in a nuclear reactor having a plurality of lattice tubes, wherein the method comprises: installing a shield plug installation tool on a mobile table; aligning the shield plug installation tool to one of the plurality of lattice tubes; installing a bellows replacement shield plug in the one of the plurality of lattice tubes with the shield plug installation tool; installing a bellows replacement cutting tool on the mobile table; cutting the bellows with the bellows replacement cutting tool, thereby leaving a bellows stub coupled to the one of the plurality of lattice tubes; measuring the bellows stub; positioning a replacement bellows for installation; installing welding equipment on the bellows replacement shield plug; securing the replacement bellows to the bellows stub; welding the replacement bellows to the bellows stub; and inspecting the weld.

[0014] In some embodiments, an apparatus is provided for removing bellows from a nuclear reactor including a plurality of lattice tubes, each of the plurality of lattice tubes being coupled to a respective bellows, wherein the apparatus comprises: a shaft having a longitudinal axis, the shaft insertable into any of the plurality of lattice tubes, and the shaft being rotatable about the longitudinal axis; a blade moveable between a stowed position and a deployed position to selectively engage and cut the bellows; a protrusion engageable with a bellows replacement shield plug, the apparatus operable to insert and remove the bellows replacement shield plug into any of the plurality of lattice tubes; and a bellows engagement mechanism operable to engage and remove the severed bellows from the respective one of the lattice tubes, wherein when the blade is in the deployed position and the shaft is inserted into the respective one of the plurality of lattice tubes, the deployed blade engages the bellows, and wherein upon rotation of the shaft about the longitudinal axis when the blade is in the deployed position and when the shaft is inserted into one of the plurality of lattice tubes, the blade severs the bellows at the ferrule of the bellows closest to the bellows replacement shield plug from the one of the plurality of lattice tubes.

[0015] Some embodiments of the present invention provide an apparatus for replacing bellows in a nuclear reactor having a plurality of lattice tubes each received within a respective aperture in a tube sheet, wherein the apparatus comprises: a first elongate member extending along a first axis; a weld head supported on the first elongate member; a second elongate member insertable into an aperture in the tube sheet to retain a position of the weld head with respect to the tube sheet; and a bellows supported on the first elongate member adjacent the weld head, wherein the weld head is operable to weld the bellows to a ferrule secured to the tube sheet.

[0016] Other aspects of the invention will become apparent by consideration of the detailed description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. 1 is a perspective view of a CANDU reactor.

[0018] FIG. 2 is a cut away view of a CANDU-type nuclear reactor fuel channel assembly.

[0019] FIG. 3 is a close up perspective view of a bellows, tube sheet, and end fitting of FIG. 2.

[0020] FIG. 4 is a longitudinal cross-sectional view of the inboard bellows ferrule with convolution stub of the bellows and tube connection shown in FIG. 3.

[0021] FIG. 5 illustrates a bellows replacement base tool assembly according to an embodiment of the present invention.

[0022] FIG. 6 illustrates a bellows replacement plug insertion tool according to an embodiment of the present invention.

[0023] FIG. 7 illustrates a bellows replacement shield plug according to an embodiment of the present invention, shown in a first perspective view.

[0024] FIG. 8 illustrates the bellows replacement shield plug of FIG. 7 in a second perspective view.

[0025] FIG. 9 illustrates the bellows replacement shield plug of FIGs. 7 and 8, shown installed in a lattice tube.

[0026] FIG. 10 illustrates a bellows replacement cutting tool according to an embodiment of the present invention, shown engaged in a fuel channel, received in a bellows replacement shield plug, and securing a bellows flange (convolutions of the bellows not shown for clarity).

[0027] FIG. 11 is a first perspective view of another embodiment of a bellows replacement cutting tool mounted on a bellows replacement base tool assembly.

[0028] FIG. 12 is a second perspective view of the bellows replacement cutting tool of FIG. 11.

[0029] FIG. 13 shows a weld head delivery tool with weld head according to an embodiment of the present invention, shown with a replacement bellows attached.

DETAILED DESCRIPTION

[0030] Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways.

[0031] FIG. 1 is a perspective of a reactor core of a CANDU-type reactor 6. The reactor core is typically contained within a vault that is sealed with an air lock for radiation control and shielding. A generally cylindrical vessel, known as a calandria 10, contains a heavy-water moderator. The calandria 10 has an annular shell 14 and a tube sheet 18 at a first end 22 and a second end 24. The tube sheets 18 include a plurality of apertures that each accept a fuel channel assembly 28. As shown in FIG. 1, a number of fuel channel assemblies 28 pass through the tube sheets 18 of calandria 10 from the first end 22 to the second end 24

[0032] As in the illustrated embodiment, in some embodiments the reactor core is provided with two walls at each end 22, 24 of the reactor core: an inner wall defined by the tube sheet 18 at each end 22, 24 of the reactor core, and an outer wall 64 (often referred to as a "end shield") located a distance outboard from the tube sheet 18 at each end 22, 24 of the reactor core. A lattice tube 65 spans the distance between the tube sheet 18 and the end shield 64 at each pair of apertures (i.e., in the tube sheet 18 and the end shield 64, respectively).

[0033] FIG. 2 is a cut away view of the fuel channel assembly 28. As illustrated in FIG. 2, each fuel channel assembly 28 includes a calandria tube ("CT") 32 surrounding other components of the fuel channel assembly 28. The CTs 32 each span the distance between the tube sheets 18. Also, the opposite ends of each CT 32 are received within and sealed to respective apertures in the tube sheets 18. In some embodiments, a CT rolled joint insert 34 is used to secure the CT 32 to the tube sheet 18 within the bores, although other tube-to-sheet joining structures and methods can instead be used. In this manner, the CTs 32 each form a first boundary between the heavy water moderator of the calandria 10 and the interior of the fuel channels assemblies 28.

[0034] A pressure tube ("PT") 36 forms an inner wall of the fuel channel assembly 28. The PT 36 provides a conduit for reactor coolant and fuel bundles or assemblies 40. The PT 36, for example, generally holds two or more fuel assemblies 40 and acts as a conduit for reactor coolant that passes through each fuel assembly 40. An annulus space 44 is defined by a gap between each PT 36 and its corresponding CT 32. The annulus space 44 is normally filled with a circulating gas, such as dry carbon dioxide, helium, nitrogen, air, or mixtures thereof. The annulus space 44 and gas are part of an annulus gas system typically having at least one of two primary functions. First, a gas boundary between the CT 32 and PT 36 provides thermal insulation between hot reactor coolant and fuel within the PTs 36 and the relatively cool CTs 32. Second, the annulus gas system provides indication of a leaking calandria tube 32 or pressure tube 36 via the presence of moisture, deuterium, or both detected in the annulus gas.

[0035] An annulus spacer or garter spring 48 is disposed between the CT 32 and PT 36. The annulus spacer 48 maintains the gap between the PT 36 and the corresponding CT 32, while allowing passage of the annulus gas through and around the annulus spacer 48. Maintaining the gap helps ensure safe and efficient, long-term operation of the reactor 6.

[0036] As also shown in FIG. 2, each end of each fuel channel assembly 28 is provided with an end fitting 50 located outside of the corresponding tube sheet 18. At the terminal end of each end fitting 50 is a closure plug 52. Each end fitting 50 also includes a feeder assembly 54. The feeder assemblies 54 feed reactor coolant into or remove reactor coolant from the PTs 36. In particular, for a single fuel channel assembly 28, the feeder assembly 54 on one end of the fuel channel assembly 28 acts as an inlet feeder, and the feeder assembly 54 on the opposite end of the fuel channel assembly 28 acts as an outlet feeder. As shown in FIG. 2, the feeder assemblies 54 can be attached to the end fittings 50 using a coupling assembly 56 including a number of screws, washers, seals, and/or other types of connectors.

[0037] The lattice tube 65 (described above) encases the connection between the end fitting 50 and the PT 36 containing the fuel assemblies 40. Shielding ball bearings 66 and cooling water surround the exterior the lattice tubes 65, which provides additional radiation shielding.

[0038] With continued reference to FIGS. 2 and 3, coolant from the inlet feeder assembly 54 flows along a perimeter channel of the end fitting 50 until it reaches a shield plug 58. The shield plug 58 is contained within the PT 36 and the lattice tube 65, and includes a number of openings that allow the coolant provided by the inlet feeder assembly to enter the end of the PT 36. Another shield plug 58 is located within the PT 36 and the lattice tube 65 at the other end of the fuel channel assembly 28, and includes similar openings that allow coolant passing through the PT 36 to exit the PT 36 and flow to the outlet feeder assembly 54 through a perimeter channel of another end fitting 50 at the opposite face of the reactor 6. As shown in FIG. 1, feeder tubes 59 are connected to the feeder assemblies 54 that carry coolant to or away from the reactor 6.

[0039] Returning to FIGS. 2 and 3, a positioning hardware assembly 60 and bellows 62 are also coupled to each end fitting 50. The bellows 62 allows the fuel channel assemblies 28 to move axially – a capability that can be important where fuel channel assemblies 28 experience changes in length over time, which is common in many reactors. The positioning hardware assemblies 60 can be used to set an end of a fuel channel assembly 28 in either a locked or an unlocked position. In the locked position, the end of the fuel channel assembly 28 is fixed in an axial position. In the unlocked position, the end of the fuel channel assembly 28 is allowed to move axially. A tool can be used with the positioning hardware assemblies 60 to switch the position of a particular fuel channel assembly 28.

[0040] The positioning hardware assemblies 60 are also coupled to the end shield 64. The positioning hardware assemblies 60 each include a rod having an end that is received in a bore of the respective end shield 64. In some embodiments, the rod end and the bore in the end shield 64 are threaded.

[0041] It should be understood that although a CANDU-type reactor is illustrated in FIGS. 1-3, the methods and systems described below for retubing a reactor also apply to other types of reactors containing similar components as illustrated in FIGS. 1-3.

[0042] The various tools utilized in the present invention can be installed and/or used adjacent the calandria 10 of the nuclear reactor on a mobile table. The table can carry and support the tooling from lattice site to lattice site (i.e., those positions on each side of the reactor 6 defined by the locations of the fuel channel assemblies 28 described above) across the face of the calandria 10. In some embodiments, the table is laterally movable in an x direction (e.g., upon rails, on a cart, and the like) at a common elevation across the face of the calandria 10, whereas in other embodiments, the table is also vertically movable in a y direction and/or is movable toward and away from the reactor face in a z direction. By way of example, in some embodiments, the table is movable in x and z directions, and is mounted upon a retube tooling platform ("RTP") assembled in front of the calandria face and vertically movable (in the y direction) to different lattice sites. In some embodiments, the RTP is an adjustable platform upon which much of the fuel channel component removal operations are performed. Also in some embodiments, the RTP is a stand-alone machine that does not rely on existing plant structures for positioning or movement, and is adapted to adjustably support one or more tables.

[0043] The tools and methods of severing and replacing fuel channel bellows as described and illustrated herein can be utilized under normal nuclear reactor retubing conditions, or alternatively as a contingency operation performed if a bellows 62 is not fit for service. In any case, there can be a much higher probability of needing the tools and methods disclosed herein when attempting to recover and reuse existing bellows, compared to replacing all bellows during reactor retubing. Retubing projects may require bellows replacements as a result of damage that either existed prior to a retubing campaign, or that was inflicted during the campaign.

[0044] As shown in greater detail in FIG. 3, the bellows 62 includes a bellows flange 70 at a first end, a ferrule 72 at a second end and a plurality of convolutions 74 between the bellows flange 70 and the ferrule 72. In some embodiments, the bellows 62 can initially be severed at or proximate the bellows flange 70 to separate the bellows 62 from the end fitting 50 and/or the PT 36 to thereby permit removal of the end fitting 50 and/or the PT 36 from the bellows 62. In such cases, a portion of the bellows flange 70 can remain connected to the convolutions 74 and the ferrule 72. The severed bellows 62 can then be inspected to determine if the severed bellows 62 can be re-used or must be replaced. If the severed bellows 62 can be re-used, the severed bellows 62 can be repaired (if needed), machined, and otherwise prepared for re-attachment.

Some possible machining processes include deburring and face-grinding, whereas preparation processes can include cleaning and inspection of the bellows 62.

[0045] In some embodiments, the bellows 62 are removed without inspection, such as if a decision has already been made to replace all of the bellows 62 in a retubing campaign. If the severed bellows 62 will be replaced (in such cases, or in cases in which inspection has shown that the bellows 62 have sustained unacceptable damage or deterioration), the bellows 62 are additionally severed at the ferrule 72 to permit removal of the severed bellows 62. As shown in greater detail in FIGS. 3 and 4, in some embodiments the ferrule 72 includes an annular groove 76. The ferrule 72 can be cut at the groove 76 to facilitate cutting and removal of the severed bellows 62. Alternatively, the ferrule 72 can be cut inboard or outboard of the groove 76 (if such a groove exists in the ferrule 72) as desired. However, cutting at the groove 76 can speed the severing process while at the same time providing a substantial ferrule stub 72' on which to attach a new bellows 62 in later operations. After the ferrule 72 has been cut, a ferrule stub 72' can remain connected to the tube sheet 64 and/or the lattice tube 65 (part of the ferrule stub 72' being visible in FIG. 9).

[0046] With continued reference to FIGS. 3 and 4, in some embodiments the ferrule 72 includes a journal ring 78 positioned and held between first and second retaining rings 80, 82 on the inside surface of the ferrule 72. The journal ring 78 engages a sleeve 84 which is part of the end fitting 50, and permits the end fitting 50 to move with respect to the ferrule 72. The journal ring 78 and the first and second retaining rings 80, 82 are optionally removed and replaced during the retubing operation. Also, in other embodiments, the journal ring 78 (and therefore the retaining rings 80, 82) are not used, or are replaced with a feature on the inside surface of the ferrule performing the same or similar functions as the journal ring 78 and retaining rings 80, 82.

[0047] The bellows replacement system and method according to some embodiments of the present invention is comprised of two main activities. The first main activity is severing the bellows 62 at the ferrule 72. The second main activity is welding a replacement bellows to the ferrule stub 72' at or proximate the tube sheet 64.

[0048] In some embodiments of the bellows replacement system and method according to the present invention, all mounted tools used in the system and method are releasably fastened to a base tool assembly, such as the base tool assembly 86 shown in FIG. 5. The base tool assembly 86 can allow for accurate positioning of all tools mounted thereon, and itself can be mounted to a mobile table (described in greater detail above) that is adjustable in x, y, and/or z directions, and that can also adjusted for pitch and yaw changes with respect to a lattice site. As also described above, the mobile table can be supported upon an RTP which moves the mobile table and anything thereon to different lattice sites across the reactor face.

[0049] Once aligned with a particular lattice site with any necessary adjustments of a mobile table and/or RTP, if used, the base tool assembly 86 of FIG. 5 can provide accurate repeatable positioning of other tools (used for bellows replacement) at the lattice site. The illustrated base tool assembly 86 includes hand wheels 88, 90 to adjust the position of the base tool assembly 86 on the mobile table, and brakes 92, 94 to affix the base tool assembly 86 to the mobile table.

[0050] FIG. 6 illustrates an example of a plug insertion tool 96 that can be mounted on the base tool assembly 86 of FIG. 5. The illustrated plug insertion tool 96 includes a hand crank 98, a housing 100, and a nose 102. The crank 98 can be actuated by a user (either locally, or remotely using an appropriate motor drive connected thereto) to move the nose 102 along the direction of arrow A. In some embodiments, the housing 100 remains stationary while a threaded shaft (not shown) telescopes a protrusion 104 of the nose 102 in the direction of arrow A. The nose 102 of the illustrated plug insertion tool 96 also includes a pin having first and second ends 106, 108, the purpose of which will be apparent below. The first end 106 of the pin projects from a first side of the protrusion 104 and the second end 108 of the pin projects from a second side of the protrusion 104, although separate pins or similar protrusions can be attached or defined on the nose 102 to arrive at a similar structure.

[0051] The plug insertion tool 96 is used to install and secure a bellows replacement shield plug (BRSP) 110 into the lattice tube 65 of a fuel channel assembly 28 in preparation of performing a bellows cutting operation, such as to sever the ferrule 72 of the bellows 62 as described above. The plug insertion tool 96 can also be used as an alignment structure for the cutting tool used in the bellows cutting process, and well as for removing the BRSP 110. As an alternative to the plug insertion tool 96 of FIG. 6, a manually-operated bellows replacement shield plug insertion tool can be used to handle the BRSP 100. However, due to the relatively heavy weight of the BSRP 100, it is anticipated that a manually-operated bellows replacement shield plug insertion tool could be used with the aid of a trolley or hoist(s).

[0052] A BRSP 110 according to an embodiment of the present invention is shown in FIGS. 7 and 8. The BRSP 110 provides shielding from radiation that would otherwise stream from the calandria 10 through the lattice tube 65, and can also provide (i) an axial reference for tools performing bellows cutting; (ii) an axial reference for tools performing welding of replacement bellows; and/or (iii) radial anchoring for the either or both types of tools. In some embodiments, the BRSP provides shielding from radiation and one or more separate components provide axial reference and radial anchoring for tools. The BRSP 110 of the illustrated embodiment includes a first end 112, a second end 114, and a reduced-diameter shaft 116 extending between the first end 112 and the second end 114. The reduced diameter shaft 116 can provide significant weight savings for the BRSP, although in other embodiments the BSRP has no reduced diameter portion or is otherwise shaped as necessary to fit within the lattice tube 65.

[0053] With continued reference to the illustrated embodiment, the first end 112 of the BSRP includes a recess 118 and a pair of opposing slots 120 on opposite side of the recess 118. The recess 118 is sized to receive and mate with the protrusion 104 of the plug insertion tool 96, and the slots 120 are sized to receive the first and second ends 106, 108 of the pin of the plug insertion tool 96 in a bayonet connection (i.e., axially inserted into the slots, followed by a circumferential rotation of the pin to secure the BRSP 110 to the nose 102 of the plug insertion tool 96. Accordingly, to mount the BRSP 110 to the plug insertion tool 96, a user inserts the protrusion 104 of the plug insertion too 96 into the recess 118 of the BRSP until the user is able to twist the BRSP about its own longitudinal axis to clinch the bayonet connection defined by the pin of the plug insertion tool 96 within the slots 120 of the BRSP 110. When connected to the plug insertion tool 96, the BRSP 110 can be inserted into (or removed from) the lattice tube 65 by operation of the hand crank 98 and/or adjustment of the base tool assembly 86 as described above.

[0054] With reference back to FIGs. 7 and 8, the second end 114 of the illustrated BRSP 110 includes a recess 122 and a plurality of radial projections 124. The radial projections 124 can engage an interior of the lattice tube 65 to inhibit radial movement of the BRSP 96 within the lattice tube 65, and in some embodiments can also center the BRSP 96 within the lattice tube 65.

[0055] An alternative embodiment of a BRSP 110' is illustrated in FIG. 9, and is dimensioned to extend into a lattice tube 65 and to abut a calandria side bearing when fully inserted in some embodiments. The BRSP 110' of FIG. 9 includes a first end 112', a second end 114' and a shaft 116' extending between the first end 112' and the second end 114'. The first end 112' includes a recess 118' and a pair of opposing slots 120' which substantially correspond to the recess 118 and slots 120 of the BRSP 110 of FIGs. 7 and 8. The second end 114' of the BRSP 110' of FIG. 9 includes a recess 122' and a plurality of radial projections 124', which substantially correspond to the recess 122 and the plurality of radial projections 124 of the BRSP 110 of FIGs. 7 and 8.

[0056] In some embodiments, an alignment tool can be secured to the plug insertion tool of FIG. 6. The alignment tool can provide information on alignment of the plug insertion tool with respect to the fuel channel (e.g., with respect to the lattice tube 65) in x, y, pitch and yaw orientations.

[0057] A bellows cutting tool 126 according to an embodiment of the present invention is shown in FIG. 10, and can be mounted to the base tool assembly 86 of FIG. 5. The bellows cutting tool 126 includes a head end 128 and a drive end 130. The head end 128 of the illustrated bellows cutting tool 126 can include a parting tool 132 that is insertable into the bellows 62 (the convolutions 74 and bellows flange 70 of which are not shown in FIG. 10 for clarity), the ferrule 72 of the bellows 62, and optionally into the tube sheet 64 and calandria tube 65. One or more depth limiting rods 137 (illustrated in FIGS. 11 and 12) on the head end 128 of the bellows cutting tool 126 can limit the insertion depth of the head end 128 by abutment against surfaces adjacent the lattice site, such as upon the external surface of the lattice tube sheet 64. The head end 128 of the bellows cutting tool 126 can also include a clamp 134 that selectively clamps the bellows 62 by rotation of a hand crank 133 connected thereto. The drive end 130 of the tool includes a drive 136, such as a servo motor, that rotates the parting tool 132 to cut the ferrule 72. Alternatively, the bellows 65 can be severed by a milling cutter, shears, a laser cutter, one or more blades, a boring bar or other similar severing mechanism.

[0058] In operation, the cutting tool 126 can be used to first secure the bellows 62 with the clamp 134 (e.g., by securing the clamp 134 about the bellows flange 70). With the bellows 62 clamped in this manner, the drive 136 can be started to cause one or more retractable blades (not shown) at the head end 128 of the cutting tool 126 to begin rotating with the head end 128 about the longitudinal axis of the cutting tool 126. The blade(s) can then be extended radially outward into cutting engagement with the ferrule 72 by a suitable drive motor or (as shown in FIG. 10, and better shown in an alternative cutting tool embodiment of FIGs. 11 and 12) a hand crank 135 mechanically connected to the retractable blade(s). After the blade(s) have severed the ferrule 72, the blade(s) can be retracted, the drive 136 can be stopped, and the severed bellows 62 still attached to the cutting tool 126 via the clamp 134 can be withdrawn from the fuel channel.

[0059] FIGS. 11 and 12 illustrate an alternative embodiment of a bellows cutting tool 126' that is mounted to a base tool assembly 86' similar to the base tool assembly 86 of FIG. 5. The bellows cutting tool 126' includes a head end 128' and a drive end 130'. The head end 128' of the bellows cutting tool 126' can include a parting tool 132' that can be inserted into the bellows 62 and the ferrule 72 of the bellows 62, and optionally into the tube sheet 64 and calandria tube 65. Like the embodiment of FIG. 10, the head end 128' of the bellows cutting tool 126' can also include a clamp 134' that selectively clamps the bellows 62. The drive end 130' of the tool includes a drive 136', such as a servo motor, that rotates the parting tool 132' to cut the ferrule 72. The cutting tool 126' can be used to secure the bellows 62 with the clamp 134', cut through the ferrule 72 by rotation of the parting tool 132' in response to the operation of the drive 136', and then safely remove the bellows 62 from the target site with the clamp 134' in a manner similar to that discussed above in connection with the embodiment of FIG. 10.

[0060] A weld head delivery tool 140 according to an embodiment of the present invention is shown in FIG. 13. The weld head delivery tool 140 can be mounted to a fixture on the base tool assembly 86 for being retained in a desired position in front of the subject lattice site, or can be retained in such a position in any other suitable manner. The weld hand delivery tool 140 can include a weld head 142, a rod 144 that supports the weld head 142, and a projection 146 connected to the rod 144. The projection 146 is sized to extend into the bore 118 of the bellows replacement shield plug 110. Replacement bellows 62 are mounted on the weld head delivery tool 140. The weld head delivery tool 140 further includes first and second support shafts 148, 150 spaced from and substantially parallel to the rod 144. The first shaft 148 includes a first projection 152 and the second shaft 150 includes a second projection 154. The first and second projections 152, 154 can extend into apertures in the tube sheet 64 for proper orientation and alignment of the weld head 142 with respect to the bellows ferrule 72 in preparation for welding the new bellows 62 in place.

[0061] The weld head delivery tool 140 can provide centering and support for the weld head 142 and the replacement bellows 62 through the engagement between the projection 146 and the bore 118 and the engagement between the first and second projections 152, 154 and the apertures in the tube sheet 64. In some embodiments, the weld head delivery tool 140 holds the replacement bellows 62 tightly against the cut ferrule stub 72', thereby eliminating any potential axial gap of the weld joint.

[0062] Tools for the bellows replacement process disclosed herein can be locally operated from a work table as described above, and tool operation can be largely automated in some embodiments. Also, radiation exposure during the process can be minimal, as personnel are only in the vault for a limited amount of time for each fuel channel. During the time personnel are in the vault, there are also no exposed radioactive components.

[0063] Thus, embodiments of the present invention provide, among other things, methods and systems for retubing a nuclear reactor. It should be understood, however, that the methods and systems described above can be performed in various orders and configurations, and that some steps can be performed in parallel to other steps. Some steps can also be combined or distributed among more steps. Also, the details of the methods and systems can be modified according to the specific configuration of the fuel channel, and/or the reactor being retubed.

[0064] Also, it should be noted that the embodiments described above and illustrated in the accompanying figures are presented by way of example only and are not intended as a limitation upon the concepts and principles of the present invention. As such, it will be appreciated by one having ordinary skill in the art that various changes in the elements and their configuration and arrangement are possible without departing from the spirit and scope of the present invention as set forth in the appended claims.

CLAIMS

What is claimed is:

1. A method of removing and replacing bellows on a nuclear reactor having a fuel channel assembly coupled to and extending through an aperture in a tube sheet, the method comprising:

severing the bellows from a tube of the fuel channel assembly at a ferrule adjacent the tube sheet;

removing the severed bellows from the tube; and

installing a replacement bellows by coupling the replacement bellows to the tube adjacent the tube sheet.

2. The method of claim 1, further comprising installing a bellows replacement shield plug through the aperture in the tube sheet to shield radiation emitting from the calandria.

3. The method of claim 1, further comprising

removing an end fitting from the fuel channel assembly;

removing a calandria tube of the reactor through the aperture in the tube sheet; and

removing a pressure tube of the reactor through the aperture in the tube sheet.

4. The method of claim 3, wherein severing the bellows occurs after removing the end fitting, after removing the calandria tube and after removing the pressure tube.

5. The method of claim 1, further comprising removing a positioning hardware assembly limiting axial movement of an end fitting of the fuel channel assembly prior to severing the bellows.

6. The method of claim 1, wherein severing the bellows includes severing the bellows and the ferrule adjacent the tube sheet.

7. The method of claim 6, wherein:

severing the bellows and the ferrule occurs at a circumferential groove of the ferrule; and the circumferential groove has a smaller thickness than a remainder of the ferrule.

8. The method of claim 1, further comprising machining a remaining portion of the ferrule left after severing the bellows and prior to installing the replacement bellows.

9. The method of claim 1, further comprising measuring a remaining portion of the ferrule left after severing the bellows and prior to installing the replacement bellows.

10. A method of removing and replacing bellows in a nuclear reactor having a plurality of lattice tubes, the method comprising:

installing a bellows replacement cutting tool on a mobile table;

cutting the bellows off with a cutting tool;

removing that portion of the bellows cut off with the cutting tool;

measuring a remaining bellows stub left after removing that portion of the bellows cut off with the cutting tool;

positioning a replacement bellows for installation; and

affixing the replacement bellows onto the remaining bellows stub.

11. The method of claim 10, further comprising performing the following steps prior to installing the bellows replacement tool on the mobile table:

aligning a shield plug installation tool with one of the plurality of lattice tubes; and

installing a bellows replacement shield plug in the one of the plurality of lattice tubes.

12. The method of claim 11, further comprising performing the following steps after measuring the remaining bellows stub:

installing welding equipment on the bellows replacement shield plug;

welding the replacement bellows to the remaining bellows stub; and

inspecting the weld.

13. The method of claim 10, further comprising securing the replacement bellows to the remaining bellows stub prior to affixing the replacement bellows onto the remaining bellows stub.

14. A method of removing bellows from a nuclear reactor having a fuel channel assembly, the bellows including a first flange at a first end, a second flange at a second end and a plurality of convolutions between the first flange and the second flange, the method comprising:

removing a closure plug from an end of the fuel channel assembly;

disconnecting a feeder assembly from the fuel channel assembly;

removing an end fitting from the rest of the fuel channel assembly;

severing the first flange of the bellows;

severing a calandria tube;

severing a pressure tube;

removing the calandria tube through the bellows;

removing the pressure tube through the bellows;

after removing the calandria tube and the pressure tube, severing the second flange of the bellows; and

after severing the second flange of the bellows, removing the bellows.

15. The method of claim 14, wherein severing the first flange of the bellows occurs prior to removing the calandria tube and the pressure tube.

16. The method of claim 14, wherein severing the second flange of the bellows includes severing a circumferential groove of the second flange of the bellows, and wherein the circumferential groove of the second flange is thinner than a remainder of the second flange.

17. The method of claim 14, further comprising aligning a bellows cutting tool prior to severing the second flange of the bellows.

18. A method of replacing bellows in a nuclear reactor having a plurality of lattice tubes, the method comprising:

inserting a cutting tool into one of the lattice tubes;

cutting through the bellows with the cutting tool;

removing the bellows with a first ferrule and a portion of a second ferrule severed by the cutting tool;

inserting a welding tool into that portion of the second ferrule remaining after the removing step; and

welding replacement bellows to that portion of the second ferrule remaining after the removing step.

19. The method of claim 18, further comprising inserting a bellows shield plug into the one of the lattice tubes and shielding radiation with the bellows shield plug.

20. The method of claim 18, further comprising measuring that portion of the second ferrule remaining after the removing step prior to welding replacement bellows.

21. The method of claim 18, further comprising machining that portion of the second ferrule remaining after the removing step prior to welding replacement bellows.

22. The method of claim 18, further comprising removing the welding tool from the one of the lattice tubes, and testing the weld between the replacement bellows and that portion of the second ferrule remaining after the removing step for leaks.

23. A method of removing and replacing bellows in a nuclear reactor having a plurality of lattice tubes, the method comprising:

installing a shield plug installation tool on a mobile table;

aligning the shield plug installation tool to one of the plurality of lattice tubes;

installing a bellows replacement shield plug in the one of the plurality of lattice tubes with the shield plug installation tool;

installing a bellows replacement cutting tool on the mobile table;

cutting the bellows with the bellows replacement cutting tool, thereby leaving a bellows stub coupled to the one of the plurality of lattice tubes;

measuring the bellows stub;

positioning a replacement bellows for installation;

installing welding equipment on the bellows replacement shield plug;

securing the replacement bellows to the bellows stub;

welding the replacement bellows to the bellows stub; and

inspecting the weld.

24. An apparatus for removing bellows from a nuclear reactor including a plurality of lattice tubes, each of the plurality of lattice tubes being coupled to a respective bellows, the apparatus comprising:

a shaft having a longitudinal axis, the shaft insertable into any of the plurality of lattice tubes, and the shaft being rotatable about the longitudinal axis;

a blade moveable between a stowed position and a deployed position to selectively engage and cut the bellows;

a protrusion engageable with a bellows replacement shield plug, the apparatus operable to insert and remove the bellows replacement shield plug into any of the plurality of lattice tubes; and

a bellows engagement mechanism operable to engage and remove the severed bellows from the respective one of the lattice tubes,

wherein when the blade is in the deployed position and the shaft is inserted into the respective one of the plurality of lattice tubes, the deployed blade engages the bellows, and

wherein upon rotation of the shaft about the longitudinal axis when the blade is in the deployed position and when the shaft is inserted into one of the plurality of lattice tubes, the blade severs the bellows at the ferrule of the bellows closest to the bellows replacement shield plug from the one of the plurality of lattice tubes.

25. The apparatus of claim 24, wherein the bellows engagement mechanism is a clamp.

26. The apparatus of claim 24, wherein the apparatus is mountable to a mobile table.

27. The apparatus of claim 24, wherein the apparatus is controlled by an operator at a location remove from the plurality of lattice tubes.

28. An apparatus for replacing bellows in a nuclear reactor having a plurality of lattice tubes each received within a respective aperture in a tube sheet, the apparatus comprising:

a first elongate member extending along a first axis;

a weld head supported on the first elongate member;

a second elongate member insertable into an aperture in the tube sheet to retain a position of the weld head with respect to the tube sheet; and

a bellows supported on the first elongate member adjacent the weld head, wherein the weld head is operable to weld the bellows to a ferrule secured to the tube sheet.

29. The apparatus of claim 28, wherein the apparatus is mountable to a mobile work table adjustable in position with respect to the ferrule.

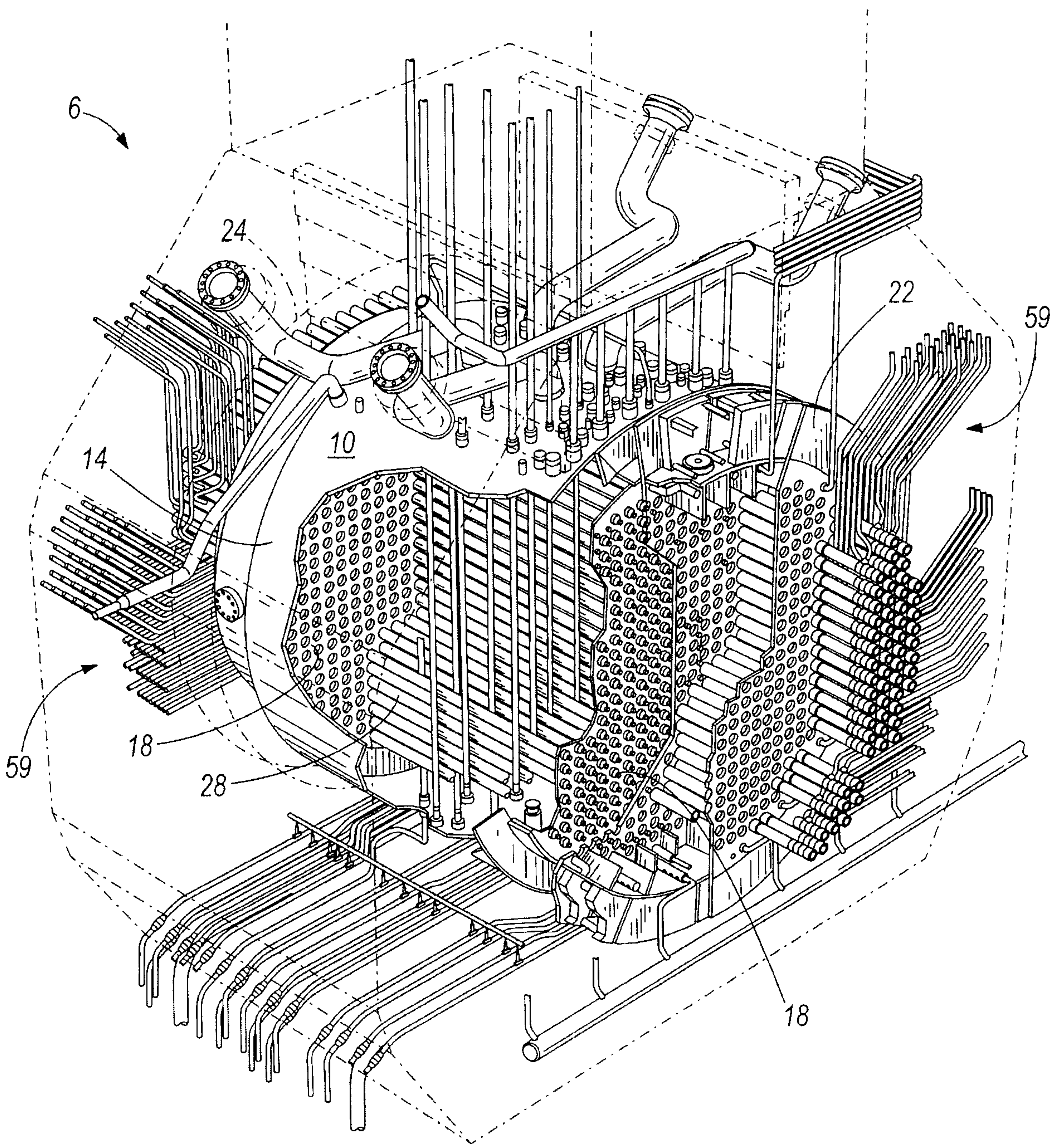

FIG. 1

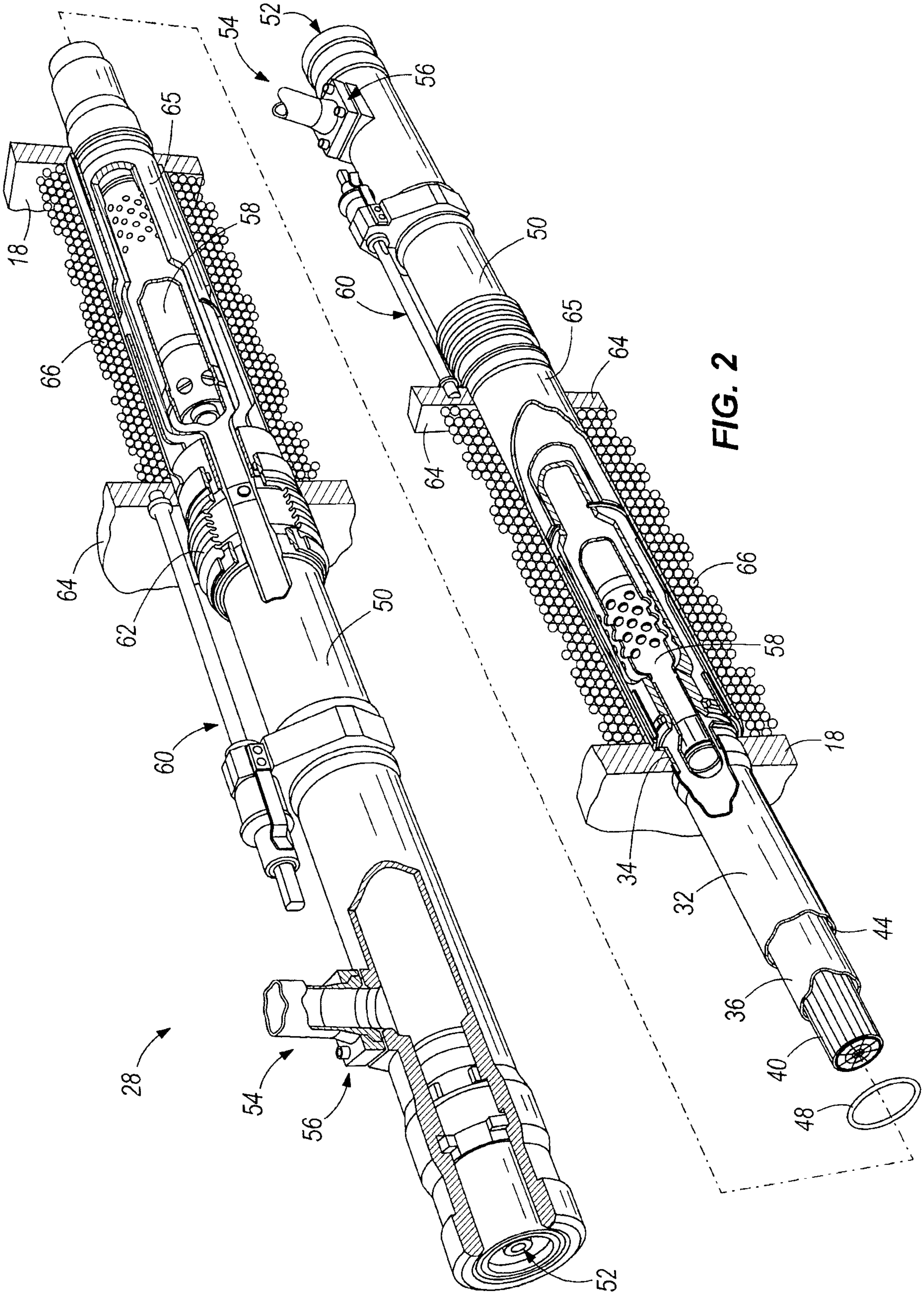

FIG. 2

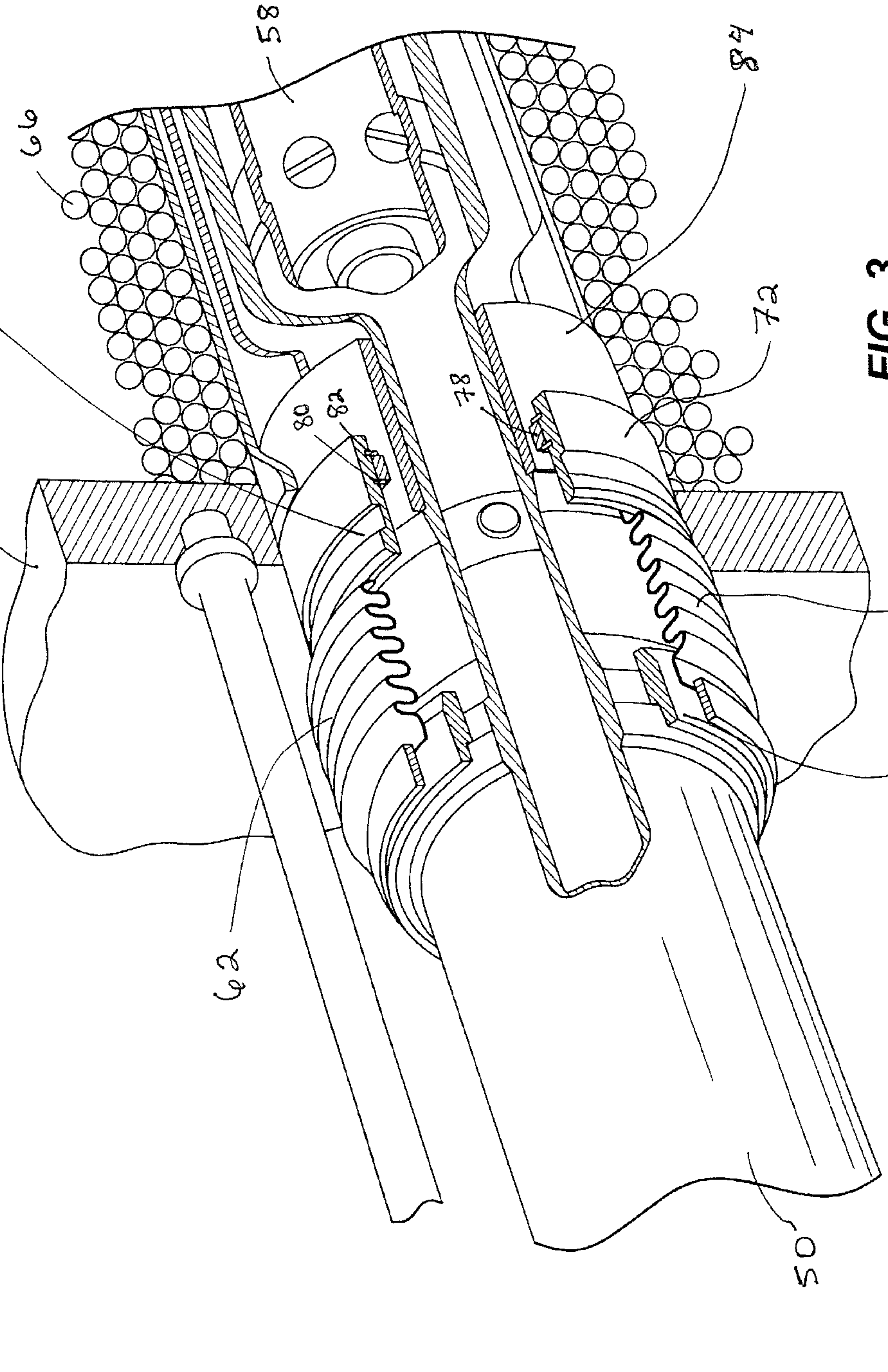

FIG. 3

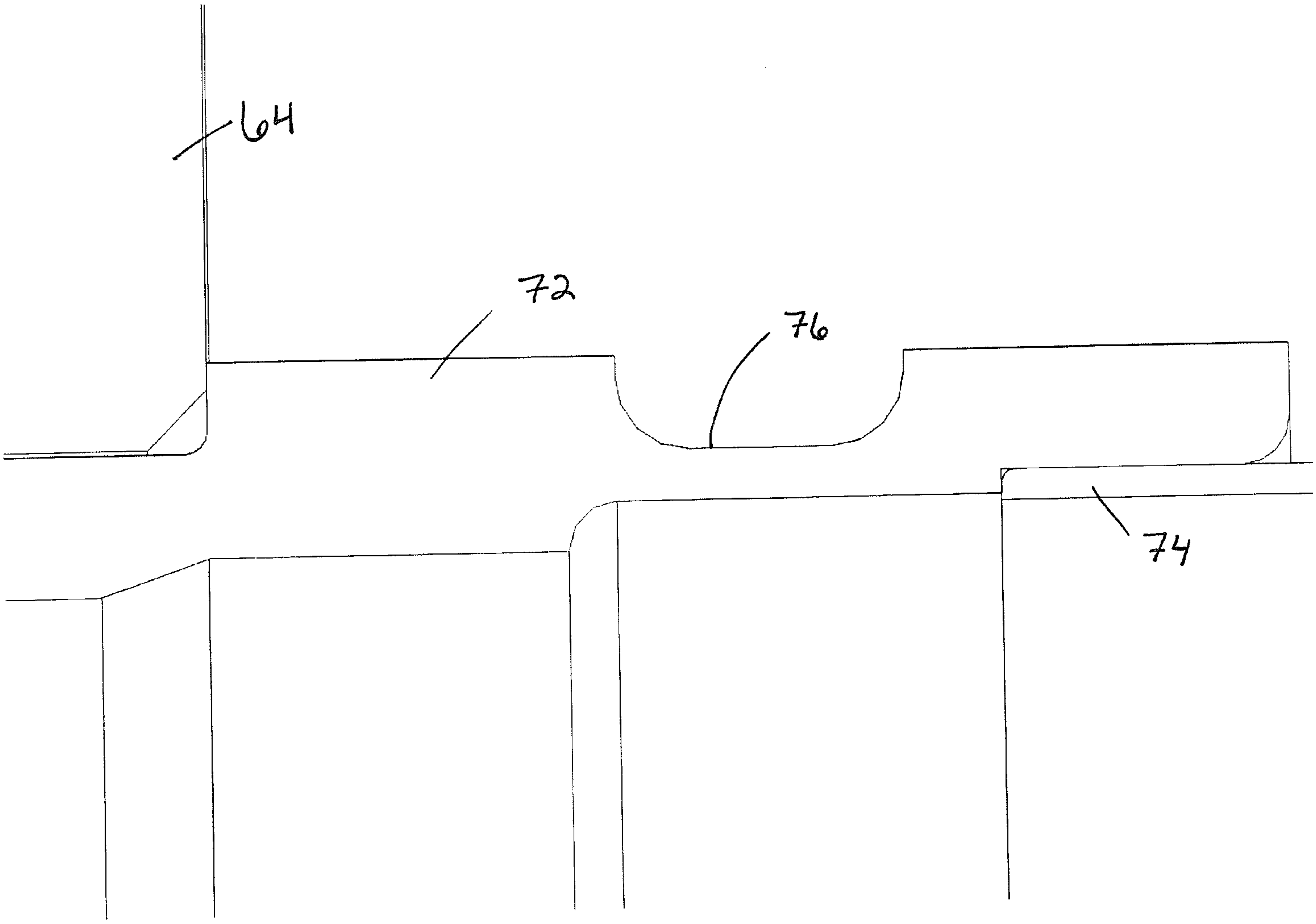

Fig. 4

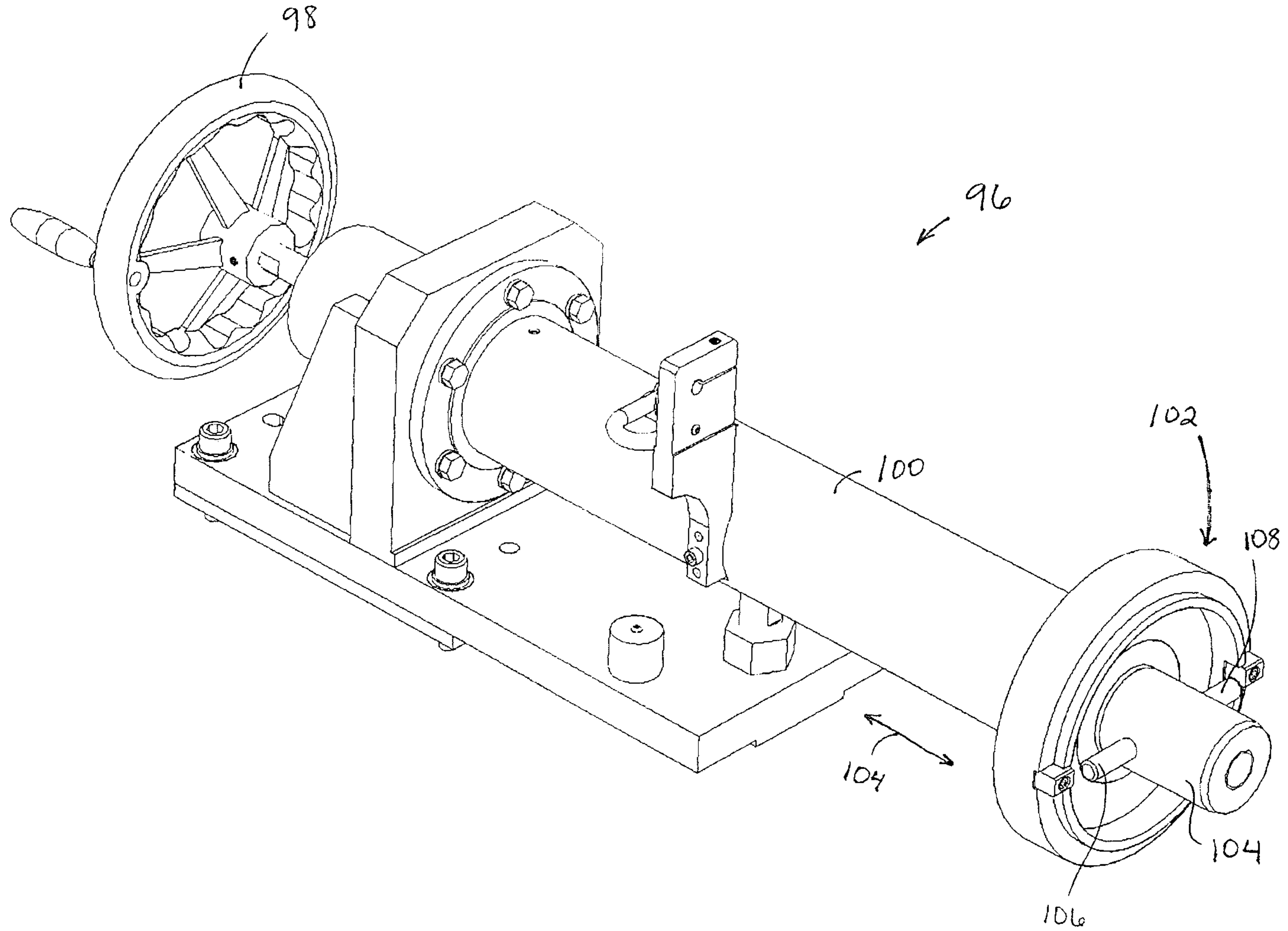

Fig. 6

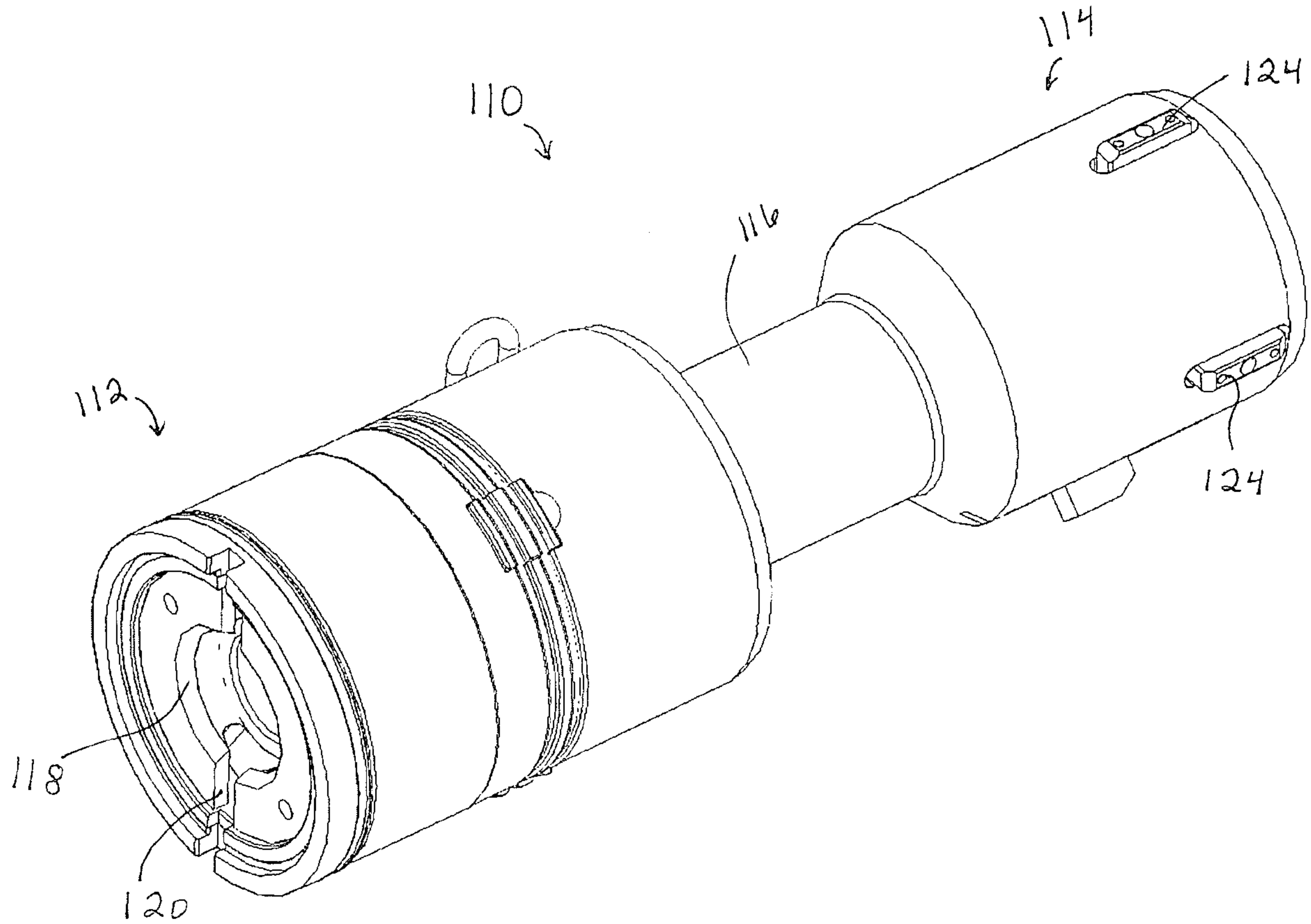

Fig. 7

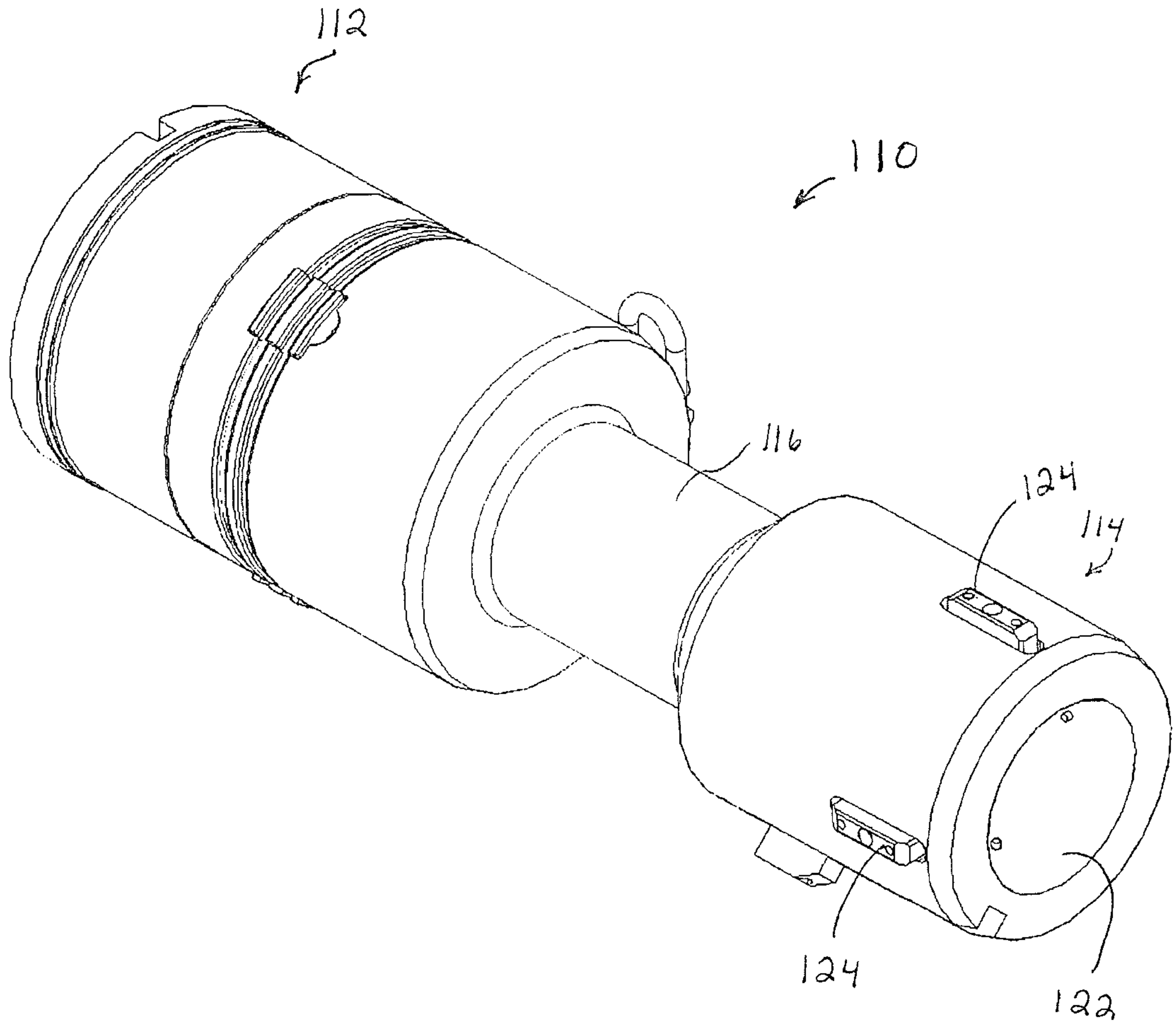

Fig. 8

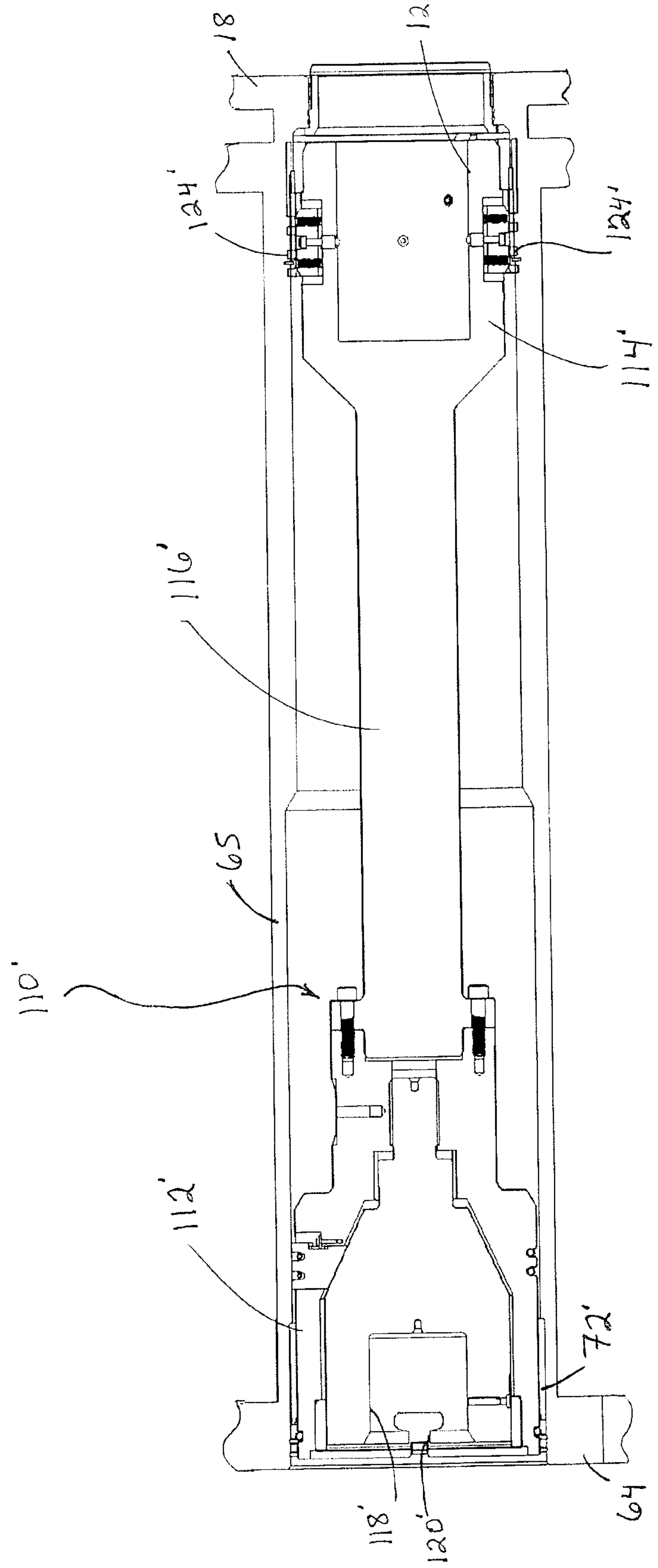

Fig. 9

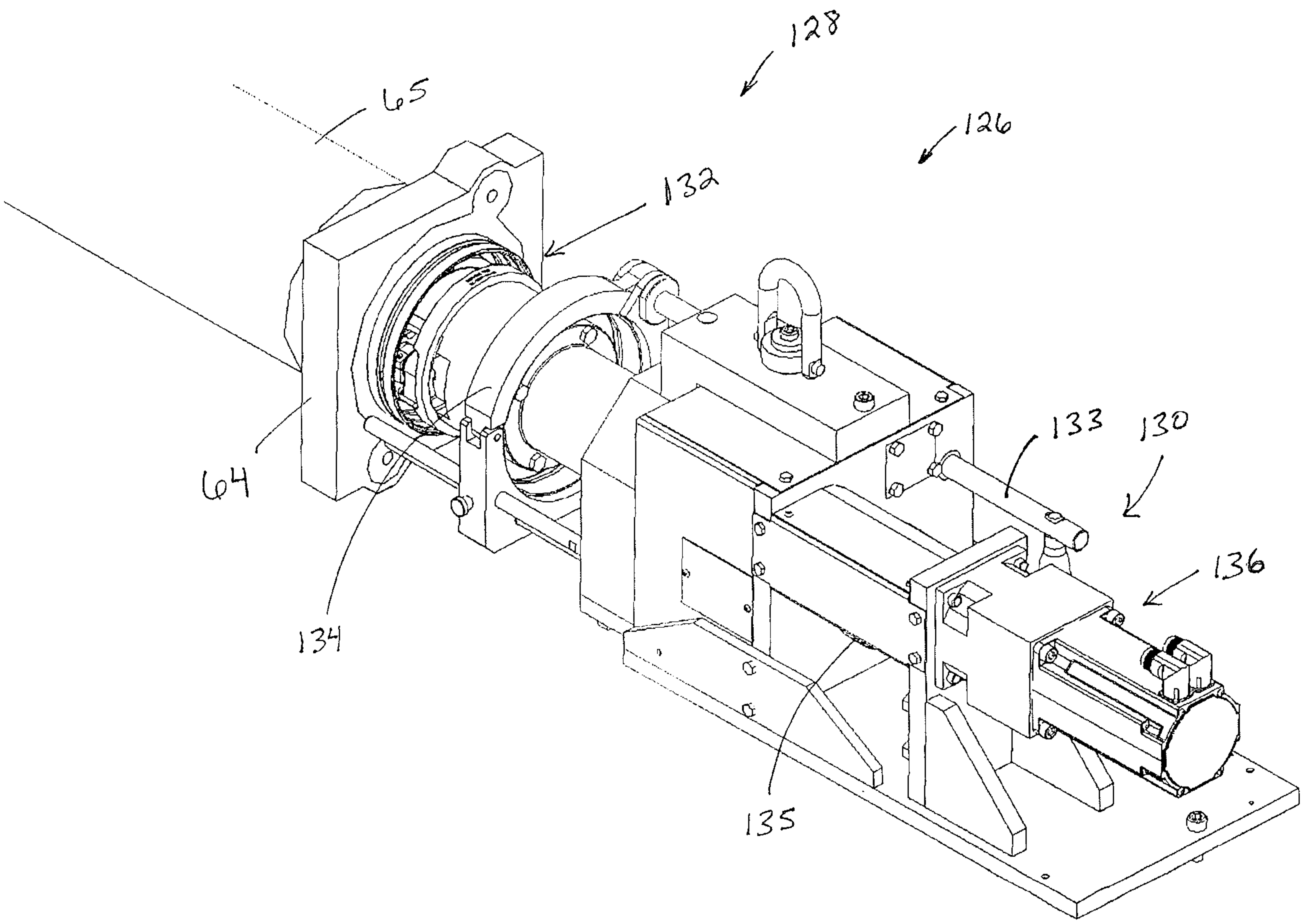

Fig. 10

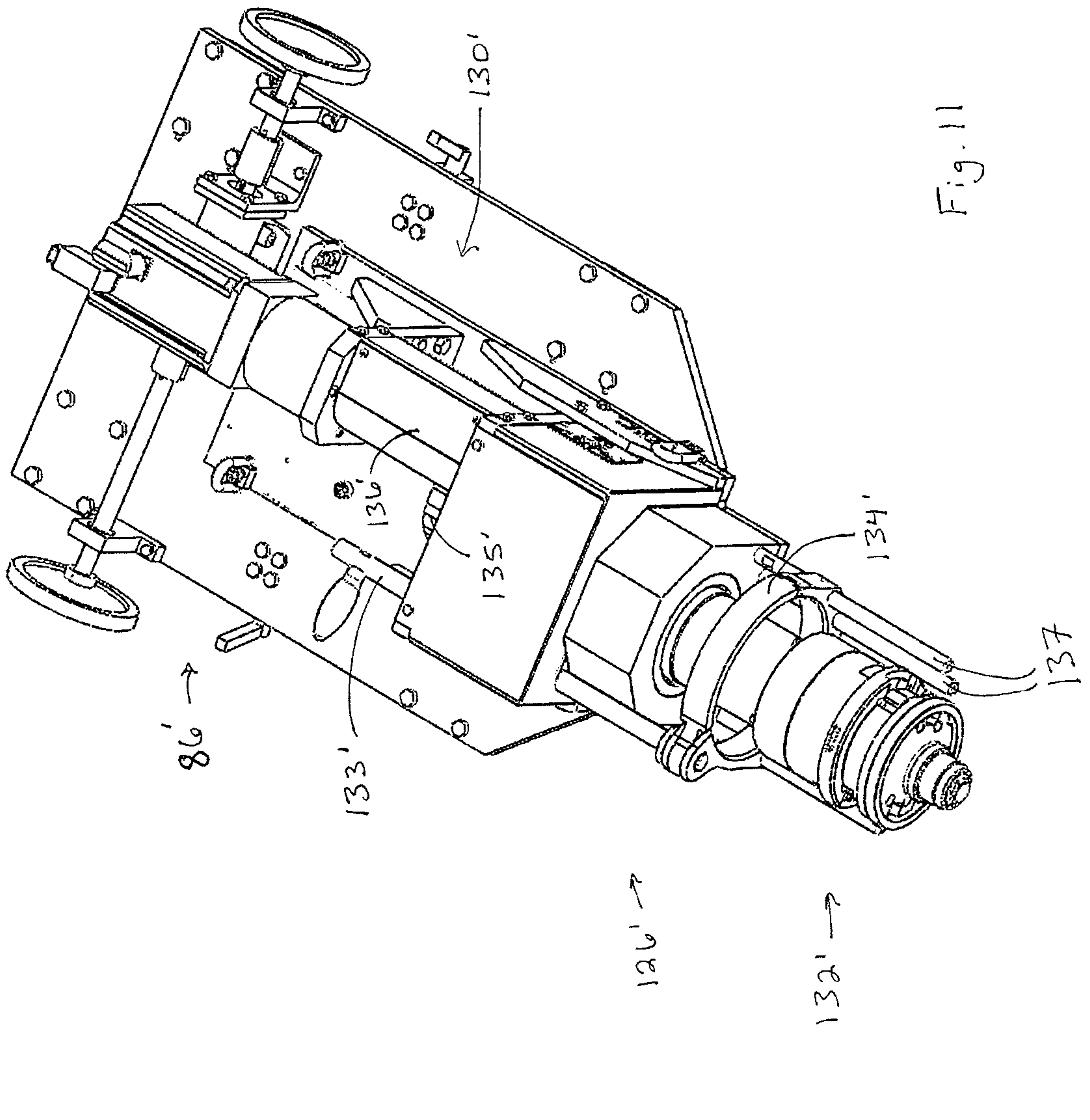

Fig. 11

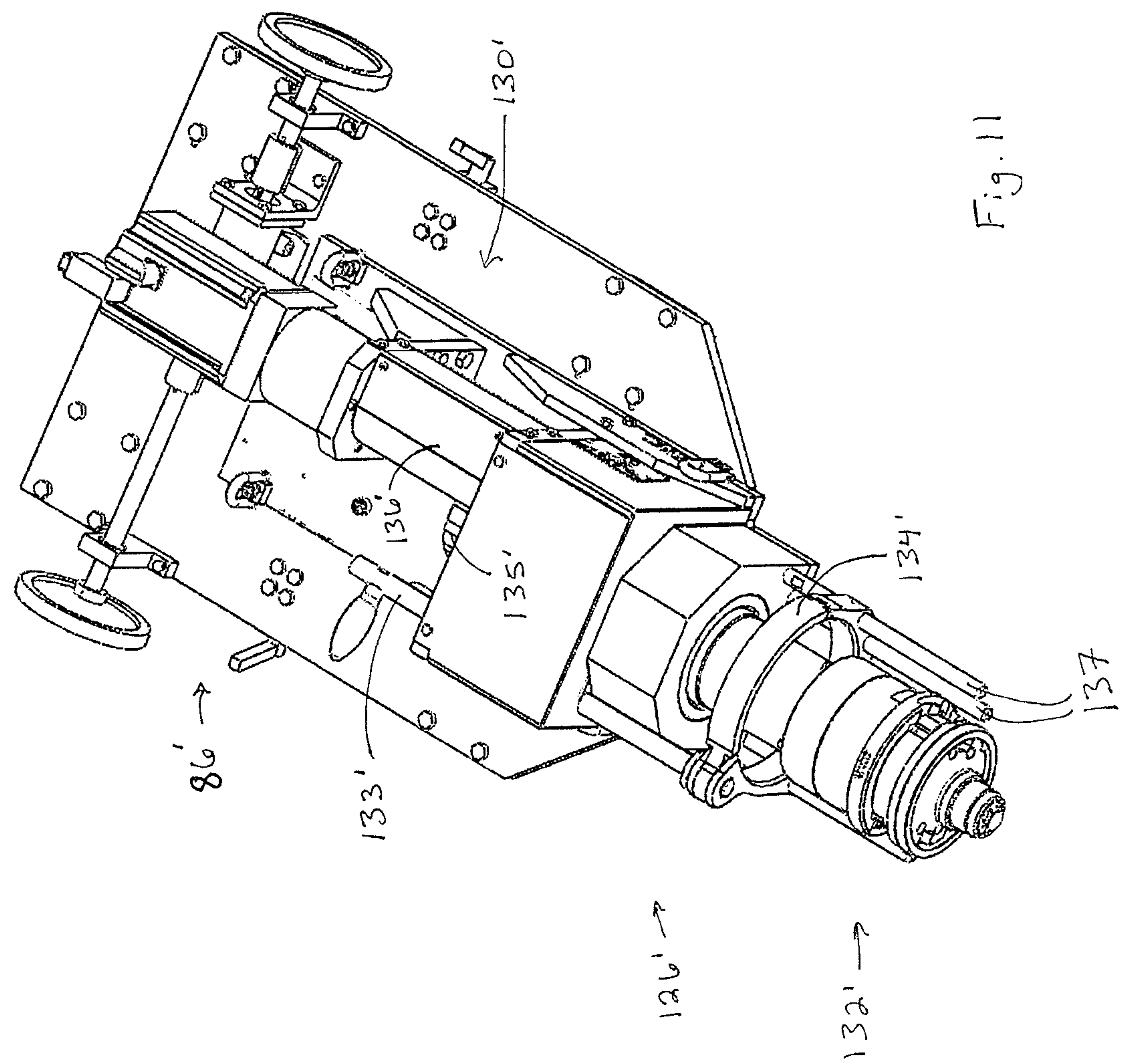

Fig. 11

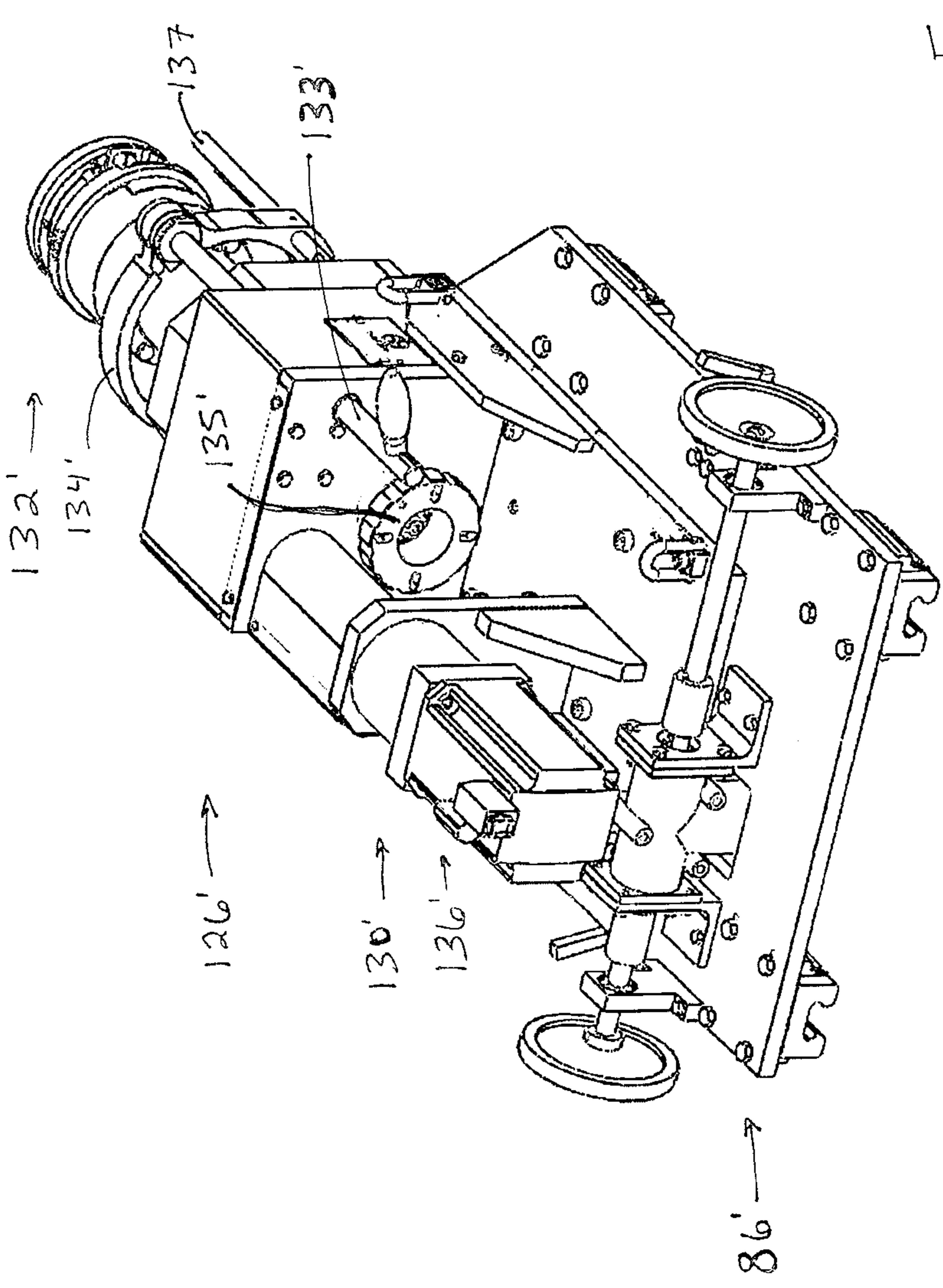

Fig. 12

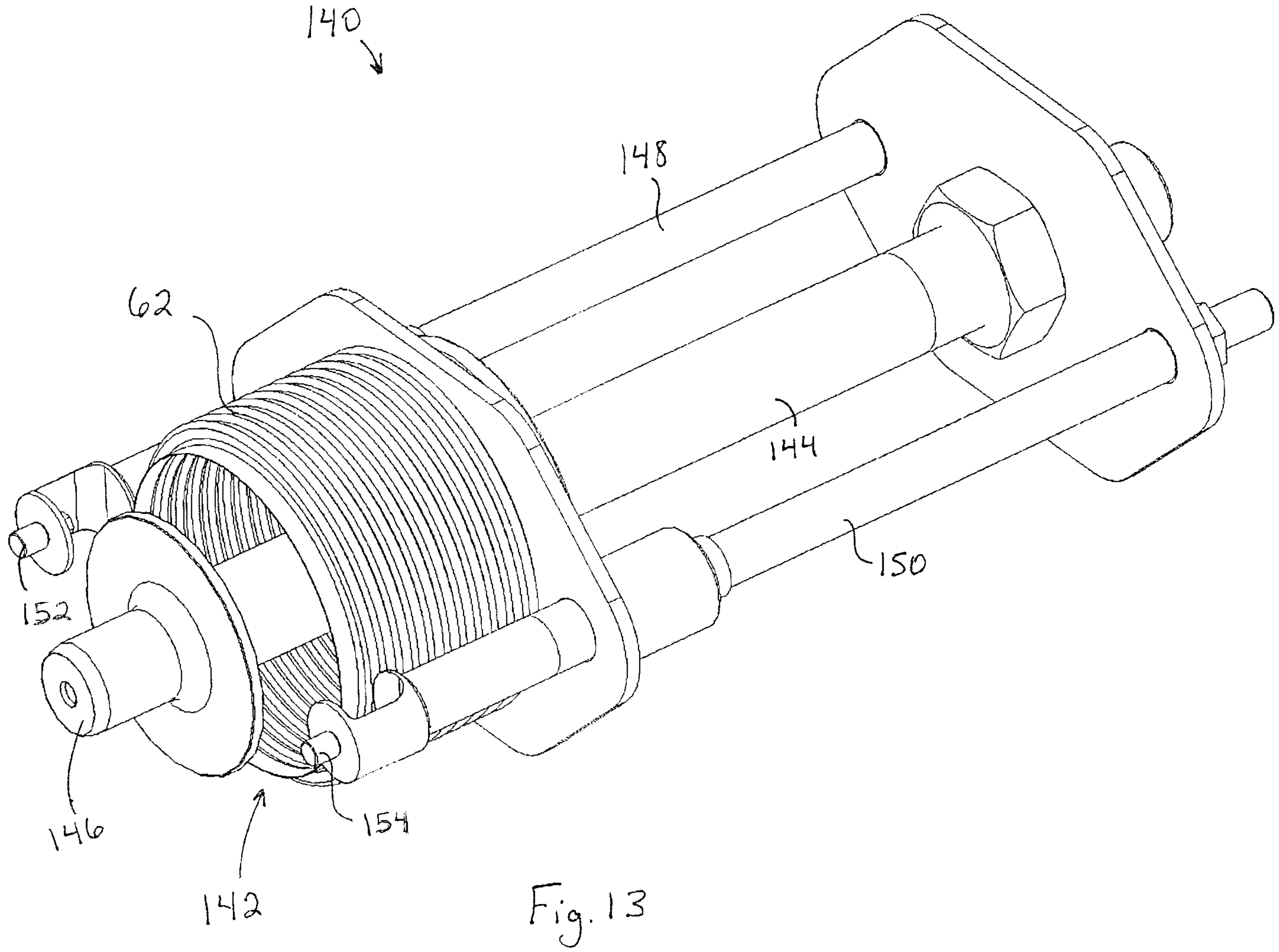

Fig. 13